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Effects of Priming and ing and Coating on Seed Germination Field Establishment, Yield, and Yield-Related Traits of Sorghum (Sorghum Bicolor (L.) Moench) in Northwestern Ethiopia

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BAHIR DAR UNIVERSITY

COLLEGE OF AGRICULTURE AND ENVIRONMENTAL SCIENCES

GRADUATE PROGRAM IN SEED SCIENCE AND TECHNOLOGY

EFFECTS OF PRIMING AND COATING ON SEED GERMINATION, FIELD ESTABLISHMENT, YIELD AND YIELD RELATED TRAITS OF SORGHUM (*Sorghum bicolor*(*L.*) *Moench*) IN NORTHWESTERN ETHIOPIA

M.Sc. Thesis

By

Sintayehu Asmare Fekadu

March 2026

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Submitted in Partial Fulfillment of the Requirements for the Degree of Master of Science (M.Sc.) in Seed Science and Technology

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Bahir Dar, Ethiopia

THESIS APPROVAL SHEET

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As a member of the Board of Examiners of the Master of Science (M.Sc) thesis, open defense examination. We have read and evaluated this thesis prepared by Mr. Sintayehu Asmare Fekadu, entitled "Effects of Priming and Coating on Seed Germination, Field Establishment, Yield and Yield Related Traits of Sorghum (*Sorghum bicolor*(*L.*) *Moench*) in Northwestern 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

Ahadu Menzer (PhD) Name of External Examiner	------------ Signature	13/03/2026 Date
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DECLARATION

DECLARATION

This is to certify that this thesis entitled "Effects of Priming and Coating on Seed Germination, Field Establishment, Yield and Yield Related Traits of Sorghum (*Sorghum Bicolor*(*L.*) *Moench*) in Northwestern Ethiopia" submitted in partial fulfillment of the requirements for the award of the degree of Master of Science in Seed Science and Technology to the Graduate Program of College of Agriculture and Environmental Sciences, Bahir Dar University by Mr. Sintayehu Asmare Fekadu (ID. No. BDU1500177) is an original and authentic work carried out by him under my guidance.

The matter embodied in this project work has not been submitted earlier for the award of any degree or diploma to the best of my knowledge and belief.

Name of the Student

Sintayehu Asmare Fekadu **Signature** ______ **Date** 12/3/2026

Name of the Advisor

Wossen Tarekegn (Ph. D) **Signature** ______ **Date** 13/3/2026

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DEDICATION

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Rest in peace, Aboy. You are forever remembered.

LIST OF ABREVIATIONS AND ACRONYMS

ANOVA	Analysis Of Variance
CIMMYT	Centro Internacional de Mejoramiento de Maíz y Trigo
CRD	Complete Randomized Design
CSA	Central Statistical Agency
DAP	Di Ammonium Phosphate
DAS	Days After Sowing
EGS	Early Generating Seed
GARC	Gondar Agricultural Research Center
GB	Gross Benefit
ISTA	International Seed Testing Association
LSD	Least Significant Difference
MARC	Melkassa Agricultural Research Center
m.a.s.l	Meter Above Sea Level
MLE	Moringa Leaf Extract
MoARD	Ministry of Agriculture and Rural Development
MRR	Marginal Rate of Return
NB	Net Benefit
RCBD	Randomized Complete Block Design
SVI	Seedling Vigor Index
TVC	Total Variable Cost

Effects of Priming and Coating on Seed Germination, Field Establishment, Yield and Yield Related Traits of Sorghum (*Sorghum bicolor*(***L.***) ***Moench***) **in Northwestern Ethiopia**

By: Sintayehu Asmare

Advisor: Wossen Tarekegn (PhD)

ABSTRACT

Sorghum is the fourth most widely produced cereal in Ethiopia. Despite its coverage and importance, the productivity remains low due to several constraints, notably the use of poor-quality seed, limited availability of improved seed, and low adoption of pre-sowing seed treatment technologies, which results poor field establishment, low stand uniformity, and ultimately low yield, particularly in the lowland areas of Gondar. To address these challenges, an experiment was conducted at Gondar City in the GARC seed laboratory, and the field experiment at Metema and West Armachiho districts in the 2023 main cropping season to evaluate the effects of priming and coating on seed germination and yield of sorghum. The treatments consisted of a factorial combination of four priming materials (control, Tap water, MLE, and cow urine) and four coating materials (Control, Thiram, Apron Star, and Dynamic). The laboratory and field experiments were laid out in a CRD and RCBD design with four and three replications, respectively. Data were analyzed using R software version 4.4.2. Combined ANOVA revealed significant ($p < 0.05$) interaction effects of priming and coating on germination %, speed of germination, shoot and root length, VI_1 and VI_2, head length, width and weight, dry biomass, Stover yield, grain yield, and HI. In contrast, seedling dry weight, days to emergence, heading and maturity, plant height, and TSW were significantly ($p < 0.05$) affected only by the main effects of priming and coating. The highest germination (94.25%) and grain yield (4,364.92 kg ha^{-1}) were obtained from seeds primed with MLE and coated with Apron Star, followed by MLE-primed seeds coated with Thiram. The PBA also indicated that seeds primed with MLE and coated with Apron Star had the highest NB (146,999.7 Birr ha^{-1}) with an acceptable level of MRR (116,792.1%) as compared to other treatments. Therefore, treatment combinations of seeds primed by MLE with coated by Apron Star, as well as seeds primed by MLE with coated by Thiram, are recommended for sorghum growers in lowland areas of Gondar and other similar agro-ecologies. However, these results are from a single year; extending the study across multiple seasons would help account for seasonal variability and strengthen the final recommendation.

Keywords: Field emergence, Germination, Partial budget analysis, Vigor, Yield

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Chapter 1: INTRODUCTION

1.1. Background and Justification

Sorghum (*Sorghum bicolor* (L.) Moench) is a C4 annual grass that belongs to the family Poaceae and is a diploid species (2n = 20) with a genome size of 735 mega base pairs with wide genetic diversity, enabling it to adapt to diverse agro-ecological conditions (Dillon *et al., 2005)*. It is characterized by a deep and fibrous root system, thick waxy leaves, and efficient water-use mechanisms, which confer strong resistance and broad adaptability to a variety of biotic and abiotic stresses. A wide range of end uses, high returns, greater resilience to harsh environmental conditions than many other cereal crops, and an excellent performance in marginal lands with limited water and extreme temperatures are contributing to the widespread popularity of this crop in the world. These best qualities of sorghum have drawn interest as a possible "star" crop to address the issue of global food security (HUANG, 2018; Zhang *et al*., 2019; Hao *et al*., 2021).

Sorghum is well adapted to a wide range of agro-ecological conditions. It performs best in warm climates with temperatures ranging between 25–35°C. The minimum temperature required for germination is about 10–12°C, while optimal germination occurs at around 30°C (Nezafat *et al.*, 2025). Sorghum can grow in areas receiving annual rainfall of above 350 mm, though improved varieties can perform well under higher rainfall with proper drainage (Yahaya *et al*., 2023). The crop exhibits considerable tolerance to a wide range of soil conditions, from heavy vertisol to light sandy soils, provided drainage is adequate. Optimal performance occurs in well-drained loamy soils with pH ranging from 5.5 to 8.5. However, salinity and water logging remain significant limitations to productivity (Khalifa and Eltahir, 2023).

Sorghum is a staple food crop for more than half a billion people in developing countries and contributes a significant portion of the daily energy intake in Sub-Saharan Africa (Nyoni *et al.*, 2020). Nutritionally, sorghum grain contains approximately 10–15% protein, considerable dietary fiber, polyunsaturated fatty acids, B-vitamins, and essential minerals such as potassium, phosphorus, magnesium, and zinc. In addition, it contains various phenolic compounds and tannins that contribute antioxidant activity and potential health-protective benefits. (Khalid *et al.*, 2022). In addition, it is used as feed and fodder (stover, green biomass, and silage) and as a raw material for producing starch, alcohol, bioethanol, biomethane, and other bio-based products. Its stems and by-products are also utilized for fuel, fiber, and construction materials (Endalamaw Chalachew and Asfaw Adugna, 2025). In Ethiopia, it can be used alone or combined with other crops to prepare a variety of local foods such as *injera, porridge, nefro,* and local drinks like *Tella and Arkie*. Sorghum is mostly used in the preparation of *injera*, either alone or in combination with Teff. Sorghum serves as a substitute for making *injera* when the price of *teff* is high among urban dwellers (Demeke Mekonnen and Di Marcantonio, 2013).

Sorghum is the fifth most important cereal crop in the world, following maize, rice, wheat, and barley. The world's annual sorghum production and consumption reached over 60 million tons and are continuously increasing. The USA, Nigeria, Mexico, Brazil, Ethiopia, India, Sudan, and China are the main producers of sorghum in the world (FAOSTAT, 2024). It is the real native grain and the second most significant cereal in Africa by tonnage. Approximately one-third of the global sorghum crop (20 million tons) is produced on the continent each year. Nigeria, Sudan, and Ethiopia are the leading producers of sorghum on the continent (FW Africa, 2023; FAOSTAT, 2024).

As the official report of the Central Statistical Agency of Ethiopia after the 2021 Meher season was not available online by late 2025, estimates from the USDA International Production Assessment Division suggest that sorghum production in Ethiopia during the 2023/24 season was about 4.01 million tonnes from around 1.48 million hectares. It is a major staple food crop, ranking fourth after maize, Teff, and wheat in total production, third after wheat and maize in productivity per hectare, and fourth after Teff, maize, and wheat in the area cultivated. It is grown in almost all regions between 400 and 2500 m.a.s.l., covering a total land area of 1.6 million hectares (CSA, 2021). In the Amhara region, it is the third most important food crop after Teff and wheat. It accounted for 17% of the area covered under cereal cultivation and 16.5% of the total cereal production in private peasant holdings (CSA, 2021). The West Gondar zone is the second major high-potential agro ecology for sorghum production in the Amhara region, both in the area coverage and production (CSA, 2021).

Despite the significant importance and the large-scale production of sorghum, its productivity has been far below its potential in Ethiopia. This is due to an interacting abiotic, biotic and socio-economic constraints (Mundia *et al.*, 2019; Dinku Anega, 2024). The cultivation system of the crop is dependent on a rain-fed production system with traditional farming practices, which results in poor crop performance and low yields (Beyene Amelework *et al*., 2016). The most important factors that reduce the yield of sorghum are poor seed quality, poor adoption of improved agronomic technologies, soil fertility depletion, abiotic stresses like drought, and biotic stresses (Geremew Gebeyehu *et al*., 2004; Beyene Amelework *et al.*, 2016). Studies in East Africa indicate that low-quality seeds resulting from poor seed sources, informal seed systems, sub-optimal on-farm seed production, and inadequate post-harvest handling are the major constraint that leads to low field emergence, weak seedlings, and poor stand establishment, ultimately resulting in reduced grain yield (Ochieng *et al*., 2011). Recent quantitative analyses further show that seed weight and germination rate are among the strongest predictors of grain yield in sorghum, underscoring the central role of seed physiological quality in determining productivity under field conditions (Ahn *et al*., 2025).

In marginal rain-fed production systems, poor stand establishment is the main barrier to sorghum production. This is due to the use of poor-quality seeds, lack of appropriate improved technologies, and insufficient soil moisture, which have a large influence on the speed of germination and seedling emergence, resulting in the failure of the crop to emerge quickly and uniformly. Therefore, improving the seed quality is an important determinant of successful crop establishment under adverse growing conditions (Yazdani and Ghanbari-Malidarreh, 2011; Wondimu Teshome *et al*., 2014).

To address these challenges, several ways and techniques were adopted to enhance the germination potential and vigour of the seed to achieve a uniform crop stand and finally, more yield. Amongst a couple of those techniques, pre-sowing seed treatments such as seed priming (Qadir *et al*., 2011), the unique one, and coating (Nawaz, 2022) play a significant role in improving seed performance.

Seed priming is a pre-sowing technique used to improve germination and plant growth by activating pre-germination metabolic processes before radicle emergence, thereby enhancing seed vigor, germination rate, and drought tolerance(Kumar *et al*., 2015). It enhances germination rate, seedling emergence, stand establishment, and yield, and various priming techniques are now widely applied to improve crop performance under different environmental conditions (Singh *et al*., 2015).

Primed seeds generally exhibit higher final germination, greater vigor index, longer root and shoot growth, and increased seedling dry weight compared with unprimed seeds, leading to better field establishment and higher grain yield across environments. Studies have shown that seed priming can improve low seed vigor and reduce non-uniform emergence in sorghum. Hydro, osmo, and botanical priming have been reported to enhance emergence, germination, seedling growth, vigor, and yield parameters compared with unprimed seeds (Al-baldawi and Hamza, 2017; Wondimu Teshome *et al*., 2018; Andayani *et al*., 2023).

Seed coating is a common technique used to improve the quality of seeds by creating the ideal microenvironment for quick germination and improved growth. Coating the seeds with diverse materials like pesticides, nutrient coating, and pelleting is very important to produce uniform seed germination and development of a uniform crop stand, which finally displays enhanced productivity coupled with good seed quality attributes (Mandal et al., 2015). Seed coatings have been shown to increase sorghum grain yield and control seed-borne diseases. It increases the yield by 13–30% (Asfaw Azanaw *et al.*, 2020). Seed coatings maintained higher germination, vigor, and field emergence during storage than the uncoated seeds (Rao *et al*., 2017; Hilli *et al.*, 2021).

Far less attention has focused on pre-sowing seed enhancement technologies, particularly under farmer-relevant conditions in Ethiopian drylands. Existing work demonstrates that improving agronomic management can mitigate climate-change-induced yield losses, but does not address how to systematically improve initial stand establishment through better seed physiological quality (Adem Mohammed and Abebe Misganaw, 2022). In parallel, evidence that seed quality traits strongly drive yield has not yet been translated into practical, locally validated seed treatments for smallholders in northwestern Ethiopia (Ahn *et al*., 2025). As a result, evaluating seed priming and coating techniques for sorghum in northwestern Ethiopia is essential to address existing gaps by linking germination performance with field emergence, stand establishment, and yield under local agro-ecological conditions. The study aims to develop location-specific recommendations for effective seed enhancement methods that improve seed vigor, early growth, plant population stability, and grain yield, thereby supporting sustainable and climate-resilient sorghum production.

1.2. Statement of the Problem

In the lowland areas of Ethiopia, particularly in the high-potential lowlands of Gondar, sorghum is the dominant cereal crop grown for human consumption. The crop performs better and poses lower production risk than other crops under both high and low rainfall conditions due to its strong adaptation to moisture stress. Consequently, it occupies a large share of cultivated land among both small-scale farmers and commercial investors. According to the West Gondar Zone Agricultural Office (2021) annual report, sorghum covered about 43% of the cultivated land during the 2021 main cropping season; however, its productivity was below 2.2 t ha^{-1}, which is lower than the national average (2.69 t ha^{-1}) (CSA, 2021).

This low productivity is due to low application of improved agronomic practices, lack of improved technologies, unavailability of quality seeds and erratic rainfall during sowing, which results in poor crop stand, and finally, low yield. To solve these challenges, the application of pre-sowing seed treatment technologies that can enhance early and uniform field emergence and stand establishment, which enables the crop to capture more soil moisture, nutrients, and solar radiation to reach the yield potential, quality, and ultimately maximize profit in sorghum production, is very important. Research findings suggested that seed priming and coating are a useful way for better germination, seedling growth, establishment, and yield, either alone or in combination (Yazdani and Ghanbari-malidarreh, 2011; Wondimu Teshome *et al*., 2014; Kumar *et al*., 2015; Abebe Worku *et al*., 2017; Nawaz, 2022).

Despite these advancements, most studies have been conducted only under laboratory conditions or in field conditions, as well as only on priming or coating methods. Specifically, there is a shortage of empirical evidence on the application of priming and coating required to improve seed quality, yield, and yield components of sorghum under the agro-ecological conditions of the lowland area of Gondar, North Western Ethiopia. Therefore, to address this gap, well-studied results on the identification of locally available priming materials and best coating chemicals are required to enhance seed physiological quality, better field emergence, and optimum yield of sorghum in the study area.

1.3. Objectives of the Study

1.3.1. General objective

- To investigate seed germination and field performance of sorghum in response to priming and coating to contribute to optimum production and productivity

1.3.2. Specific objectives

- ✓ To evaluate the interaction effects of priming and coating materials on the seed germination and field performance of sorghum;
- ✓ To determine the profitability of treatments for sorghum production in the study area; and
- ✓ To identify the appropriate priming and coating materials for maximum yield and seed quality of sorghum

Chapter 2: LITERATURE REVIEW

2.1. Taxonomy and Botany of Sorghum

The term sorghum usually refers to cultivated sorghum (*Sorghum bicolor* (L.) Moench subsp. bicolor), a grass belonging to the tribe Andropogoneae, subtribe Sorghinae, and family Poaceae. It is a C4 plant with improved photosynthetic capacity and greater resistance to abiotic stress that has evolved to thrive in a variety of global conditions. It is produced for its grain (grain sorghum), its sweet sap (sweet sorghum), or as a feed (forage sorghum) (Reddy *et al*.,2009). Cultivated sorghums (*S. bicolor ssp. bicolor*) are classified into five basic botanical races (Bicolor, Caudatum, Durra, Guinea, and Kafir) and ten intermediate ones (combinations of the five basic races), based on panicle and spikelet morphology (Harlan and Wet, 1972).

2.2. Origin and Geographical Distribution of Sorghum

Sorghum (*Sorghum bicolor* (L.) Moench) is believed to have originated and first domesticated 3000-5000 years ago in the northeastern part of Africa, in an area extending from the Ethiopian Sudanese border to Chad, where most of its genetic diversity can still be found (Henzell and Jordan, 2009) and has since been expanded all over the dry areas of the world. Sorghum has been expanded in its area in the hot and temperate regions from 40-45 degrees North Latitude to 40-45 degrees South Latitude. Nowadays, sorghum can be found in many arid areas of numerous African countries, in Central and Southern America, in Southern Asia, and in Mediterranean countries (Billot *et al*., 2013). Areas of greater concentration of sorghum production in Ethiopia are north-central, the eastern mid-altitude, northwestern, and western areas of the country (Wortmann *et al.*, 2009).

2.3. Sorghum Importance and Production

Sorghum is an important source of food for people who reside in the semi-arid tropics and subtropics of Asia and Africa (Duodu *et al.*, 2003). It is also an important feed grain and fodder crop in the Americas and Australia. Sorghum is largely a subsistence food crop in Africa, especially in sub-Saharan Africa. It is the major food security crop, supporting more than 300 million people. It is grown in semi-arid, drought-prone, and marginal areas where other crops are unable to thrive. It is used as food (grain), feed (grain and biomass), fuel (ethanol production), fiber (paper), fermentation (methane production), malt, and fertilizer by the utilization of organic by-products across a range of environments and production systems (Mutegi *et al*., 2010; Tari *et al*., 2013). Sorghum grain is as nutritious as other cereal grains. It is gluten-free and a rich source of antioxidants that confer multiple health benefits. 120 grams of whole grain sorghum flour contains about 6.6g fiber, 8.4g protein, 76.6 g carbohydrate, and 3.3 g fat (McGinnis and Painter, 2020). Its leaves and stalks are utilized for animal feed, and the stalks are used to build houses, fences, fuel wood, mulch, and shade for nurseries (Nebyou Masebo and Muluneh Menamo, 2016). In Ethiopia, it can be used alone or combined with other crops to prepare a variety of local foods such as *injera, porridge, nefro,* and local drinks like *Tella and Arkie*. It is also consumed when it is boiled and roasted. It is the second most important crop for *injera* quality, next to teff, either alone or in combination with other cereals. Sorghum serves as a substitute for making *injera* when the price of *Teff* is increased (Demeke Mekonnen and Di Marcantonio, 2013).

Sorghum is widely distributed throughout Ethiopia and it is the most important cereal in the lowland areas; ranking fourth (4,517,350.2 tones) after Maize (10,557,093.6 tones), Wheat (5,780,130.6 tones), and Teff (5,509,961.5 tones) in total production, third (2.69 tones) after maize (4.18 tones) and wheat (3.05 tones) in productivity per hectare, and fourth after Teff (2,928,206.26 Ha), maize (2,526,212.36 Ha), and wheat (1,897,405.05 Ha) in the area cultivated. It is grown in almost all regions between 400 and 2500 m.a.s.l., covering a total land area of 1,679,277.06 hectares (CSA, 2021). It accounts for 13.22% of production and 12.94% area coverage of total cereal production in the country. Oromia (40.25%) and Amhara (34.5%) regions are the major producers of sorghum in the country (CSA, 2021).

2.4. Sorghum Production Constraints in Ethiopia

Drought, low soil fertility, insects like stem borers and shoot flies, quelea birds, and parasitic weeds like Striga are the major production constraints affecting sorghum yield in eastern Africa, including Ethiopia (Wortmann *et al*., 2009). Insect pests and parasitic weeds like *Striga hermonthica* are the most severe constraints for sorghum production. Drought and Striga weed are the most severe production constraints in the northern and northeastern parts of the country (Rebeka G./Tsadik *et al.*, 2014). The major sorghum pests are stalk borer, armyworm, bollworm, grasshoppers, sorghum chaffer, shoot fly, and storage weevils.

Poor soil fertility is a significant problem, which is associated with high soil erosion, deforestation, burning of vegetation, and continuous cultivation of the land with no fallowing or nutrient replenishment due to high population density (Beyene Amelework *et al*., 2016). This low soil fertility status is highly observed in semi-arid areas, which have low organic carbon (< 1.0%) and nitrogen (< 0.2%) due to a lack of organic materials for decomposition, nitrogen losses due to denitrification, leaching, and volatilization at existing high temperatures, and soil erosion (de Queiroz *et al*., 2018).

In developing countries, farmers with limited financial resources often apply little or no mineral fertilizer in their small-scale farming systems, relying on the availability of native soil nutrients and nutrient recycling from organic residues (Vitousek *et al.*, 2009). These low nutrient inputs, associated with erratic rainfall distributions and pest attacks, contribute to the generally low productivity of sorghum. Poor agronomic practice and low usage of improved seed are the major factors that reduce the yield of sorghum. Hence, the high potential return on sorghum depends on the good-quality seed. Because only high-field sprouting provides the necessary prerequisite for good returns, the high-quality seed can germinate in the local climate (Lobato *et al*., 2008).

2.5. Environmental Requirements of Sorghum

Sorghum is well adapted to tropical and subtropical climates, but the greater part of the area of the crop falls in drought-prone, semi-arid tropical regions of the world. In these harsh environmental conditions, sorghum is predominantly grown for human consumption and animal feed. Sorghum is a warm-season annual, better adapted to withstand high temperatures than other cereal crops (Hall, 2000). Sorghum is often grown in regions that get between 350 and 700 mm of precipitation annually (Mejia and Lewis, 1999). As a predominantly rain-fed crop, its yield depends largely on its drought resistance. The ideal soil moisture during germination ranges between 25% and 50% of field capacity, and the sorghum plant can survive flooding events as it is more tolerant of wet soils.

The ideal average temperature requirement is between 24 ^oC and 27 ^oC for better yields, and its growth is highly affected by low temperatures (Carter *et al.*, 1989). Sorghum grows well in a wide range of soils except in waterlogged places. It grows best on well-drained, fertile soils with a moderate amount of organic matter at a pH of 6-7.5. At this pH range, most nutrients are more easily assimilated by the plant roots. It is often grown in shallow to medium-deep or light to medium-textured soils, which have high water holding capacity after rain (Carter *et al*., 1989). Sorghum requires short days and long nights. After germination, growth and development are significantly influenced by temperature and length of day (Kazungu *et al*., 2023).

2.6. Importance of Seed Priming

Seed priming is a process of controlled hydration of seeds to activate pre-germinative metabolic activities without radical emergence, followed by drying them back to their original moisture content to enhance the seed germination process effectively *(Devika et al.*, 2021). This enables more efficient germination once the seeds are sown by creating a physiological state. It is a pre-sowing treatment that offers the possibility to improve post-harvest seed quality and allow the release of dormancy, leading to increased final germination as well as germination speed and uniformity. It improved germination by triggering biochemical changes, including starch hydrolysis, enzyme activation, and breaking seed dormancy (Farooq *et al*., 2005).

Priming shortens the time from sowing to emergence and improves emergence uniformity by allowing DNA repair, membrane re-organization, mobilization of reserves and activation of antioxidant systems before sowing(Tounekti *et al*., 2020). It has been used to improve germination, reduce seedling emergence time, and improve stand establishment and yield. It is the best solution for germination-related problems, especially when crops are grown under unfavorable conditions. Many priming techniques have evolved, which are being utilized in many crops nowadays. It can enhance rates and percentage of germination and seedling emergence, which ensures proper stand establishment under a wide range of environmental conditions (Singh *et al*., 2015).

The primed seeds typically show higher final germination, higher vigor indices, longer roots and shoots, and greater seedling dry weight than unprimed seeds. These improvements result in better field stand establishment and higher grain yield under a wide range of environments (Wondimu Teshome *et al*., 2018). Laboratory and field studies demonstrate that seed priming can correct low vigor and non-uniform field emergence, in which sorghum often suffers. Soaking seeds for 10 h in water, GA_3, KCl or thiamine significantly increased field emergence and grain yield in both spring and fall seasons compared with non-primed seeds, confirming priming as an effective technique to improve stand establishment and yield across environments(Al-baldawi and Hamza, 2017). Similar gains in vigor and viability have been reported when sorghum seeds of different varieties were primed with water, hot water, and with KNO_3 at 1.5% (Andayani *et al*., 2023). For six Ethiopian grain sorghum varieties, priming in $ZnSO_4$, urea and water increased final germination up to 6%, emergence by 20%, seedling length by 12.5%, and vigor indices by 33–50% relative to unprimed seed (Wondimu Teshome *et al*., 2018).

2.6.1. Physiological and biochemical aspects of seed priming

Priming places seeds in an advanced pre-germinative physiological state, enabling several metabolic processes to begin before visible germination occurs. During early imbibition, important physiological activities are initiated, including membrane reorganization, repair of desiccation damage, reactivation of respiration, mobilization of stored reserves, and partial progression through the cell cycle prior to radicle emergence. As a result, primed seeds exhibit faster and more synchronized water uptake and re-imbibition, which shortens the lag phase before radicle protrusion and reduces the exposure of germinating seeds to unfavorable soil conditions (Paparella *et al*., 2015; Santo *et al*., 2021)

Priming also enhances the activity of hydrolytic enzymes, such as amylases and proteases, which mobilize starch and protein reserves. This process ensures a more rapid supply of energy to the embryo and developing seedling. In addition, improved repair of DNA and cellular structures during imbibition helps maintain genome integrity and promotes stronger seedling vigor (Paul *et al*., 2021). Priming further modulates germination-related hormonal networks, particularly the antagonistic interaction between abscisic acid (ABA) and gibberellins (GA), as well as DOG1-mediated ABA signaling, thereby favoring timely germination under sub-optimal moisture and temperature conditions (Paparella *et al*., 2015; Devika *et al*., 2021).

A key biochemical characteristic of primed seeds is the strengthening of antioxidant and stress-defense systems. Under stresses such as salinity and drought, priming increases the activity of antioxidant enzymes, including superoxide dismutase, catalase, and peroxidases. These enzymes improve the detoxification of reactive oxygen species and enhance membrane stability during germination. Priming also promotes the accumulation of compatible solutes, such as proline and soluble sugars, which support osmotic adjustment under low water potential (Ibrahim, 2016).

At the molecular level, priming induces changes in gene expression and chromatin organization that resemble stress memory responses**.** Exposure to mild, sub-lethal stress during priming seeds enables them to respond more effectively to subsequent, more severe stress conditions. This response involves altered expression of genes related to ABA signaling, heat-shock proteins, antioxidant enzymes, and autophagy pathways. Such mechanisms support a “bet-hedging” strategy in which slightly slower growth under ideal conditions is offset by greater survival and productivity under stress(Srivastava *et al*., 2021). These physiological and molecular responses are particularly important for sorghum cultivation in dryland environments, where recurrent drought and high temperature stresses frequently affect crop establishment and productivity (Yahaya and Shimelis, 2022).

2.6.2. Methods of seed priming

To revitalize seeds and reduce environmental pressures, a variety of seed priming techniques have been created. Under normal and stressful conditions, seed priming methods like hydro-priming, osmopriming, solid matrix-priming, and hormonal/botanical priming have been used to speed up germination, seedling growth, and yield in the majority of crops (Basra *et al*., 2003).

Hydro-priming

Hydro-priming involves pre-sowing seed soaking in water for 6-24 hours (Donaldson *et al*., 2001). It 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 because it doesn't require the use of any additional chemicals as a priming agent, which promotes faster and more uniform germination while repairing metabolic damage caused by desiccation (Tanwar *et al*., 2023).

Hydro priming decreases the mean germination time while increasing germination percentage, uniformity, and seedling vigor by shortening the lag phase before germination and synchronizing metabolic processes. In dryland and semi-arid environments, where delayed and uneven emergence often leads to poor stand establishment and yield loss in sorghum, hydro priming is recognized as a low-cost and farmer-friendly practice that enhances field establishment and helps the crop escape early drought stress (Shehzad *et al.*, 2012). It significantly increases final germination percentage, germination rate index, reduces mean germination time, total seedling length, root length, shoot length, seedling dry weight, and vigor indices as compared with non-primed seed (Shehzad *et al.*, 2012; Dembélé *et al*., 2021).

Hydro-priming with different water sources in Mali (distilled, tap, river, well, rain) significantly improved final germination percentage, germination rate index, root and shoot length, and seedling dry weight for nine genotypes; well and river water gave the best responses (Dembélé *et al*., 2021). A two-year field experiment conducted under semi-arid conditions in Iran demonstrated that seed hydro-priming significantly improved forage sorghum performance. Hydro-primed seeds increased dry matter yield by 23.6%, water-use efficiency by 24.5%, crude protein yield by 24%, and digestible dry matter and metabolizable energy yields by about 22% compared with direct planting. These improvements were mainly attributed to faster seedling emergence and enhanced early plant development (Mirahki *et al*., 2023).

Similarly, maize grown under Mediterranean arid conditions shows that hydro-priming can enhance seedling vigor, grain yield and crop water productivity under deficit irrigation, demonstrating a general mechanism by which improved early establishment translates into higher yield and water productivity in water-limited systems (El-sanatawy *et al*., 2021). In general, hydro-priming has positive effects on seed germination, seedling growth, and yield in a variety of crop plants, such as sorghum (Dembélé *et al*., 2021), chickpea (Abebe Sori, 2016), and wheat (Basra *et al.*, 2003), both under ideal and adverse environmental conditions.

Osmotic priming

Instead of pure water, osmotic priming includes soaking seeds in an osmotic solution with a low water potential. Because osmotic solutions have a low water potential, water enters the seeds slowly, allowing for progressive seed imbibitions and the activation of the early stages of germination while preventing radicle protrusion (Girolamo and Barbanti, 2012). This method enhances metabolic processes and improves germination rates under stress conditions, making it effective for various crops (Devika *et al*., 2021).

Application of cow urine, besides improving the soil texture and working as a plant hormone, has also been reported to correct the micronutrient deficiency. Being organic, it is also likely to increase the fertilizer use efficiency. The uric acid in the urine acts as a fertilizer and hormone. Cow urine has antibacterial, antifungal, and antiviral properties; hence, it is the most effective secretion of animal origin with multitudinous therapeutic values. It also purifies and enhances soil fertility (Pradhan *et al.*, 2018).

A laboratory study evaluating priming of sorghum seeds with botanicals and animal wastes (including cow urine, neem and parthenium extracts, coconut water, lantana) showed that all priming treatments improved germination and seedling vigour over hydro-priming control. Coconut water 3% gave the highest germination and vigour indices, but cow urine 3% was consistently the next best treatment, outperforming hydro priming for germination percentage, root and shoot length, total seedling length and vigour index in both tested sorghum genotypes (Amarnath *et al*., 2018). Similarly in maize, cow-urine seed priming significantly improved field emergence, number of cobs per plant, and grain yield. Grain yields obtained from hydro-priming and cow-urine priming (approximately 7.5–8.3 t ha^{-1}) were comparable to those achieved with GA_3 treatment and were higher than those from unprimed seeds, highlighting the potential of cow-urine priming as a simple and farmer-friendly technology (Timsina and Marahatta, 2024).

Botanical priming

A variety of naturally occurring chemicals that promote growth, including seed weed extract, sorghum water extract, and moringa leaf extract, which contains plant-growth regulators (Bakhtavar *et al*., 2015). Botanical seed priming studies in sorghum indicate that plant extracts and other natural inputs can significantly enhance seed physiological quality and early seedling growth. An organic priming experiment conducted on sorghum varieties M35-1 and SPV-1411 evaluated several botanical extracts, including *Parthenium*, neem, custard apple, and *Calotropis*, along with the animal-based formulation panchagavya (3%). All organic treatments significantly improved germination percentage, seedling length, fresh and dry seedling weight, and vigor index compared with the unprimed control. Among the treatments, custard apple leaf extract (3%) produced the highest values, followed by panchagavya, indicating that botanical priming can effectively enhance early seedling growth and may serve as a viable alternative to conventional chemical priming (Kale *et al.*, 2019).

Similarly, a recent study on sorghum cultivar Paiyur-2 evaluated moringa leaf extract (MLE) priming (3% for 8 h) in comparison with micronutrient and chemical priming agents such as KNO_3, thiourea, zinc sulphate, and neem extract. The results showed that MLE (3%) produced the highest germination percentage, seedling length, seedling dry weight, and vigor indices. Seedling vigor index-I reached approximately 2944 under MLE treatment compared with about 2373 in the untreated control, while vigor index-II also recorded its maximum value with MLE priming. These findings demonstrate that MLE priming substantially improves both seedling growth and biomass accumulation, suggesting its effectiveness as a simple and low-cost technique to improve germination and early crop establishment in sorghum(Kumar *et al*., 2021).

Field studies further support the positive effects of MLE on sorghum performance. Research conducted in Pakistan on late-sown forage sorghum evaluated MLE seed priming and foliar applications, alone or in combination, compared with $CaCl_2$ and water treatments. All priming treatments improved emergence characteristics, including reduced time to 50% emergence and mean emergence time, as well as enhanced seedling growth. However, the combined application of MLE seed priming and MLE foliar spray produced the greatest improvements in plant height, stem diameter, leaf area, fresh and dry plant weight, and ultimately fresh forage and dry matter yield (Zeeshanmazher *et al.*, 2017). Additional studies comparing sorghum water extract, MLE, and water treatments also reported that MLE applications improved plant growth, chlorophyll content, crude protein, and total ash while reducing crude fibre content, thereby enhancing both forage yield and nutritional quality (Ahmad *et al*., 2016). *Moringa oleifera* leaves are a rich source of natural crop growth enhancers of zeatin, ascorbate, phenolic compounds, calcium, and potassium (Basra *et al.*, 2011). Under cooling conditions, priming maize seeds with moringa leaf extract decreases mean germination time while improving germination count, germination index, and seedling growth by raising chlorophyll content, amylase activity, and total sugar contents (Bakhtavar *et al*., 2015).

2.7. Importance of Seed Coating

Seed coating is an advanced process that applies a precise amount of active ingredients to the seed surface without altering its original shape to enhance germination, vigour, and overall seed quality. The primary goal of seed coating is to protect seeds from pests and soil, air, and seed-borne pathogens, along with providing nutrients to seeds to promote growth. It is composed of diverse materials, which are classified into four categories based on their origin and composition. Those are synthetic chemicals, natural products, biological agents, and ground-extracted minerals. Based on specific function, chemical makeup, and coating techniques, they are categorized into inoculant coating, protective coating, polymer coating, and nutritive coating (Rocha *et al*., 2019; Afzal *et al.*, 2020). Seed coating is a technique used to deliver plant growth-promoting substances directly to seeds in order to enhance their quality and performance (Rocha *et al.*, 2019).

Protective coating is a type of seed coating where several fungicides or other natural materials are used as coating agents to protect seeds from pathogen infestation carried from soil and seed (Özer and Co, 2016). Seed coating with plant growth-promoting bacteria like Azospirillum, Azotobacter, Pseudomonas, and Bacillus significantly improves the growth and development of seedlings by producing phytohormones such as auxin, cytokinin, gibberellin, and Indole Acetic Acid (IAA) (Singh *et al*., 2013).

Polymers used in seed coating are combined with active agents of insecticides and fungicides to enhance the seed's resistance to pests and diseases during its vulnerable early growth stage and for boosting seedling vigor (Elzein *et al.*, 2006). Polymer coating improves seed quality, prevents ageing and fungal invasion, acts as a protective coating, and regulates temperature (Javed *et al*., 2022). The purpose of active ingredients is to protect and enhance seed and seedling performance in terms of germination, growth, and development. The mode of action of the active ingredient dictates its role in the protection and enhancement. Active ingredients are biostimulants, plant nutrient protectants from abiotic and biotic stress, and inoculants. Seed protectants are the most widely used group of ingredients for controlling pathogens and pests at the time of sowing (Afzal *et al*., 2020).

Depending on the kind of material used in the coating formulation, seed coating can serve a variety of purposes including providing seeds with a favorable environment that will allow them to germinate and grow quickly (growth stimulants, nutrients), effective disease and pest management by uniform disinfection, effective use of biological resources, low requirement for fertilizers, and low trace element consumption, protecting seeds from stresses (drought, salt, flooding, etc.) by covering them with organic matter and moisture-absorbing compounds and altering the emergence timing of buds using temperature-sensitive polymers, and blossoming mother and father lines simultaneously (Yadav and Chandanshiv, 2017).

Thiram-based mixtures coating in sorghum increased grain yield by a median 199 kg ha^{-1} across on-farm trials in Burkina Faso (Zida *et al*., 2016). Similarly in Ethiopia, seed dressing of sorghum with Thiram and Apron plus fully prevented covered smut and increased yield by 13–30% and 20–26% over untreated seed (Asfaw Azanaw *et al.*, 2020)**.** Polymer coating combined with thiram and imidacloprid helped maintain higher seed quality during storage, with germination remaining around 75–76%, along with higher vigor index and field emergence (79–81%) after 10 months of storage, while keeping seed infection levels very low (Rao *et al*., 2017). Similarly, polymer coatings containing Thiram in soybean improved field emergence and grain yield per plant compared with treatments using fungicide alone or non-polymer coatings (Hilli *et al.*, 2021).

2.8. Role of Priming and Coating Materials on Seed Germination

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 (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. It significantly boosts agricultural productivity and ensures greater crop resilience (Marthandan *et al.*, 2020).

According to Adamčík *et al*. (2016), primed sorghum seeds exhibited a high germination percentage (95%) and the shortest mean germination time (3.5 days) compared to the control. Seed priming significantly enhanced the vigor of sorghum, especially by improving germination and emergence under low-temperature conditions relative to untreated seeds.

Moringa leaf extract (MLE) priming significantly enhanced the speed and uniformity of rice seedling emergence. It improves the time to start emergence by 23%, emergence index by 75%, mean emergence time by 3.58%, and final emergence percentage by 46% compared to the untreated seed. In addition to emergence parameters, all priming agents tested in the study contributed to improvements in plant physiological traits, such as seedling growth, chlorophyll content, gas exchange attributes, and antioxidant enzyme activities. These enhancements were especially notable under water-deficit conditions, suggesting the priming treatments helped plants cope with abiotic stress. Among the treatments, MLE-primed seeds consistently demonstrated the greatest improvement across all measured traits, both under normal and drought-stressed environments. The superior performance of MLE is likely attributed to its rich content of natural growth stimulants such as zeatin, vitamins, and antioxidants, which play crucial roles in promoting early vigor and stress resilience. Therefore, MLE can be considered a promising biostimulant for improving rice seedling establishment and overall growth (Khan *et al*., 2022).

Priming sorghum seeds with various sources of water resulted in significant improvements in germination percentage, mean germination time, germination rate index, seedling root index, and seedling dry weight as compared to the unprimed seeds. These improvements suggest that seed priming effectively promotes early seed metabolic activities and accelerates seedling establishment. These enhancements can be attributed to several physiological and biochemical mechanisms, like the rapid mobilization and translocation of nutrients from the cotyledons to the developing embryo, facilitated by the activation of hydrolytic enzymes during the priming phase. This early activation allows for quicker and more efficient use of stored food reserves once germination begins, resulting in more vigorous seedling growth. Additionally, primed seeds are known to exhibit a higher rate of water uptake (imbibition), which plays a critical role in initiating metabolic processes essential for germination. Another mechanism associated with seed priming is the repair of mitochondrial DNA (mtDNA) damage, which often accumulates during seed aging or dormancy. By restoring the integrity of mitochondrial function, priming improves energy production and enhances the seed's ability to resume active growth, contributing to the higher germination percentage and improved seedling performance (Dembélé *et al.*, 2021).

Final germination percentages, significantly influenced by the interaction between priming media and priming duration, ranged from 92% to 97.4%. Among the treatments, seeds primed with water (hydro-priming), zinc, and nitrogen exhibited the highest germination percentages, while unprimed seeds showed the lowest values. The maximum germination index (26.2) was recorded in seeds primed with nitrogen and zinc for 10 hours, followed by seeds primed with water for the same duration. In contrast, unprimed seeds displayed the lowest germination index (24.2). Compared to unprimed seeds, seedling height was increased by 10%, 11%, and 12.5% after 10 hours of priming with nitrogen, zinc, and water, respectively. Among the varieties, Melkam, primed for 10 hours, produced the tallest seedlings (29.5 cm), followed by Teshale and Dekeba. Relative to the control, seedling height was increased by 13.6%, 13.2%, and 12.6% in Teshale, Dekeba, and Melkam, respectively. The highest seedling dry weight (16.7 mg) was observed in seeds primed with nitrogen and zinc for 10 hours, followed by water-primed seeds, while unprimed seeds had the lowest seedling dry weight. Final germination was significantly influenced by the interaction between priming medium and priming duration, with values ranging from 92% to 97.4%. Hydro-priming, zinc, and nitrogen treatments produced higher germination percentages and germination indices compared with unprimed seeds. The highest germination index (26.2) and seedling dry weight (16.7 mg) were obtained from nitrogen and zinc priming for 10 hours, followed by hydro-priming, whereas the control treatment showed the lowest performance. Seedling height also improved with priming, increasing by 10–12.5% after 10 hours of treatment, with the Melkam variety recording the tallest seedlings (29.5 cm). Overall, priming enhanced seedling height by 12.6–13.6% across varieties relative to unprimed seeds (Wondimu Teshome *et al*., 2018).

Seed coating with biological and chemical agents has been shown to significantly enhance seed quality, emergence potential, and seedling vigor in various crops (Taylor *et al*., 2004). Appropriate concentrations of coating agents can positively influence plant growth and physiology under diverse environmental conditions (Berto *et al*., 2021). Improved vigor and stress tolerance have been observed in coated rice seeds under direct seeding and chilling stress (Wang *et al*.,2016) and coated tomato seeds (Javed and Afzal, 2020).

2.9. Role of Priming and Coating Materials on Field Establishment and Yield of Sorghum

According to Adamčík *et al*. (2016), primed seed produced the highest average plant population (25.5 plants/m²), as compared to the untreated control (23.4 plants/m²). Osmopriming reduced the number of days to 50% emergence by 17%, while hydropriming shortened the time to 50% flowering by 16% compared to untreated seeds. However, the days to 50% emergence were similar between seeds treated with water and those treated with 0.5% KH_2PO_4, likely because primed seeds require minimal additional imbibition before initiating germination. Seed yield was significantly higher in plots sown with primed seeds compared to unprimed ones. Specifically, water priming and 0.5% KH_2PO_4 priming increased seed yield by 15% and 3%, respectively, over unprimed seeds. Moreover, water priming resulted in an 11% higher yield than 0.5% KH_2PO_4 priming in chickpeas (Abebe Sori 2016).

Seed coating has been shown to significantly enhance stand establishment and yield in various crops. According to Javed and Afzal (2020), coating tomato seeds resulted in improved field emergence and uniform seedling development, contributing to better crop stand and early growth performance. Similarly, Wang *et al*. (2016) reported that seed coating in rice positively influenced germination rate, emergence uniformity, and early seedling establishment. The coated seeds of wheat increased the yield compared to the uncoated seed (Dimkpa *et al.*, 2020). Application of different fungicides as seed coating agents restricts the fungal infestation during storage, thereby resulting in improved seed quality and yield potential of rice (Thobunluepop, 2009). Additionally, wheat seeds treated with endophytic fungi exhibited increased seed weight per spike, higher seed count, and improved quality (Colla *et al.*, 2015). Another study found that coating rice seeds with a combination of thiamethoxam and chlorantraniliprole led to a notable increase in yield (Lanka *et al*., 2017).

Wheat seeds coated with the combination of Dynamic 200FS and Disco™ AG Red L-431 exhibited superior performance, producing the highest number of seeds per spike (56.52) and the greatest grain yield (4.70 t ha^{-1}). Similarly, seeds primed with cow urine and coated with the same treatment combination also showed good performance, recording 55.91 seeds per spike. In contrast, untreated seeds and seeds coated only with Dynamic 200FS showed the lowest seed number per spike and grain yield. The improved performance of coated seeds is attributed to the enhanced environmental adaptability provided by the polymer–fungicide coating combination (Abebe Worku *et al*., 2017).

Chapter 3: MATERIAL AND METHODS

3.1. Description of the Study Area

The field experiment was conducted at Metema and West Armachiho districts during the 2023 main cropping season. Both districts are located in the West Gondar administrative zone of Amhara National Regional State, Ethiopia, which is a high-potential area for sorghum production. The study districts have a monomodal rainfall (Mekuanint Tariku, 2022).

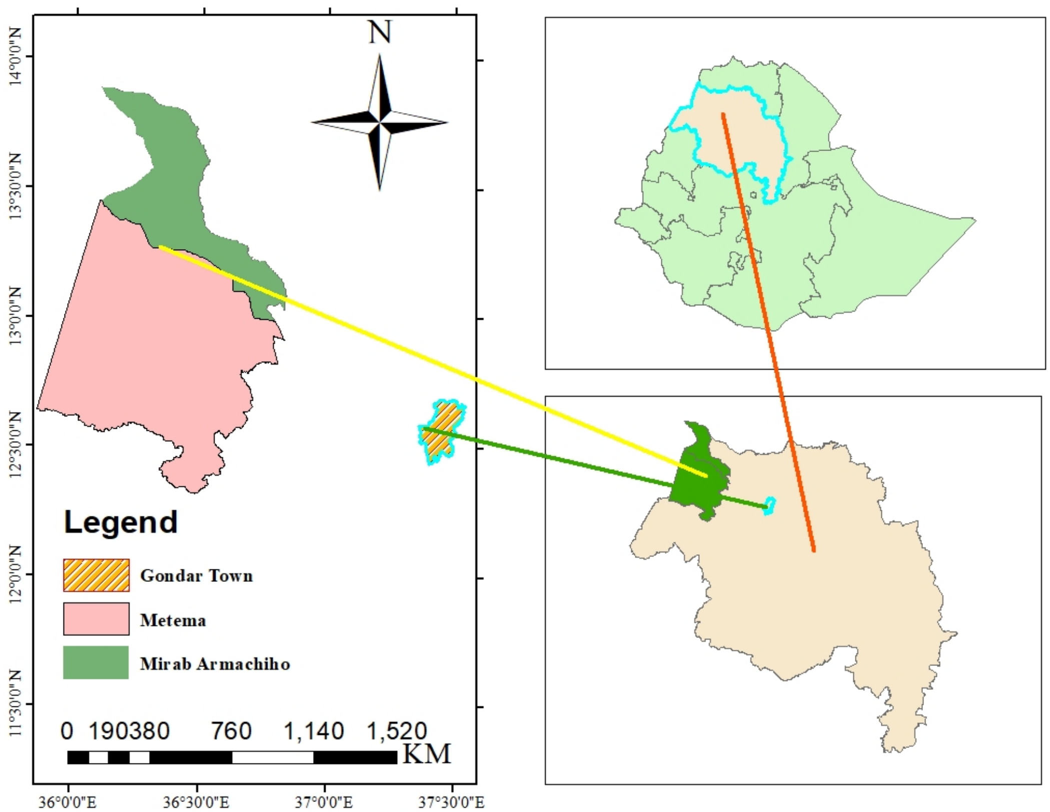

Figure 3.1. Map of study areas

Metema is located about 890 km northwest of Addis Ababa and 340 km West of Bahir Dar (Figure 3.3). The site is located at 12.57°N latitude, 36.15°E longitude, and 760 meters above sea level. The rainy months extend from June until the end of September. The soil had dark brown clay loam texture, low salinity, neutral pH, and medium CEC (Sisay Ambachew and Assefa Sintayehu 2020).

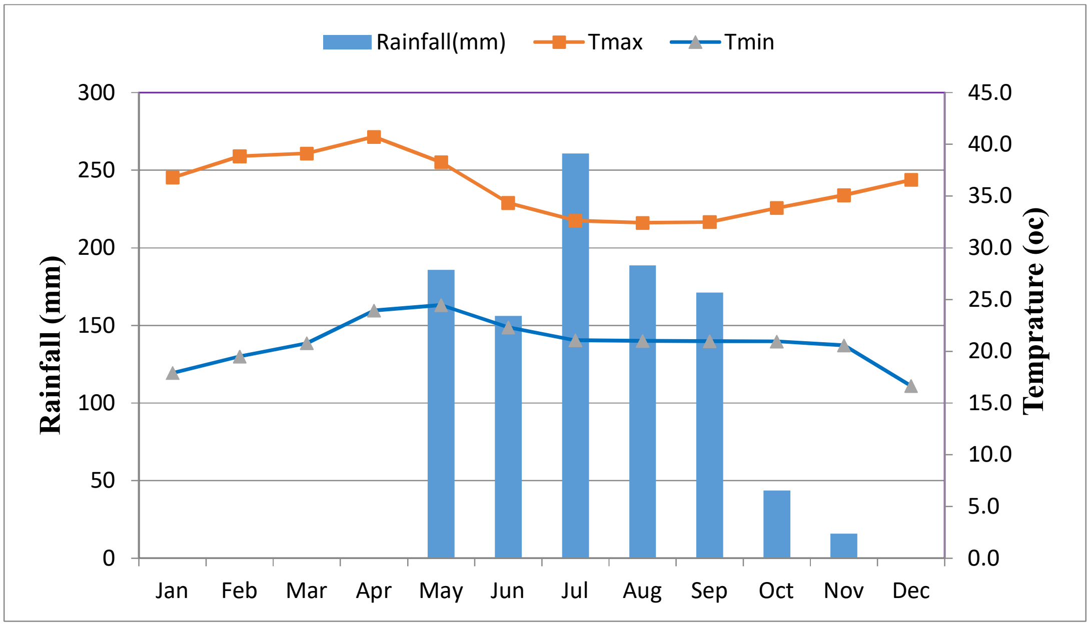

Figure 3.2. Rainfall and temperature data of the Metema district during the 2023 cropping season (Ethiopian Meteorological Institute, 2023)

The West Armachiho district is located 935 km from Addis Ababa and 385 km from Bahir Dar (Figure 3.3). The altitude of the study area ranges from 550-1600 m.a.s.l., and its latitude and longitude are 14.9 °N and 37.02 °E, respectively (Addisu Gize *et al*., 2020). The daytime temperature is very high from March to May, reaching up to 43 (Yibeltal Aschale *et al*., 2018). The area receives an annual rainfall ranging from 625 to 1100 mm. The soil is characterized as brown clay loam to light vertisol in texture.

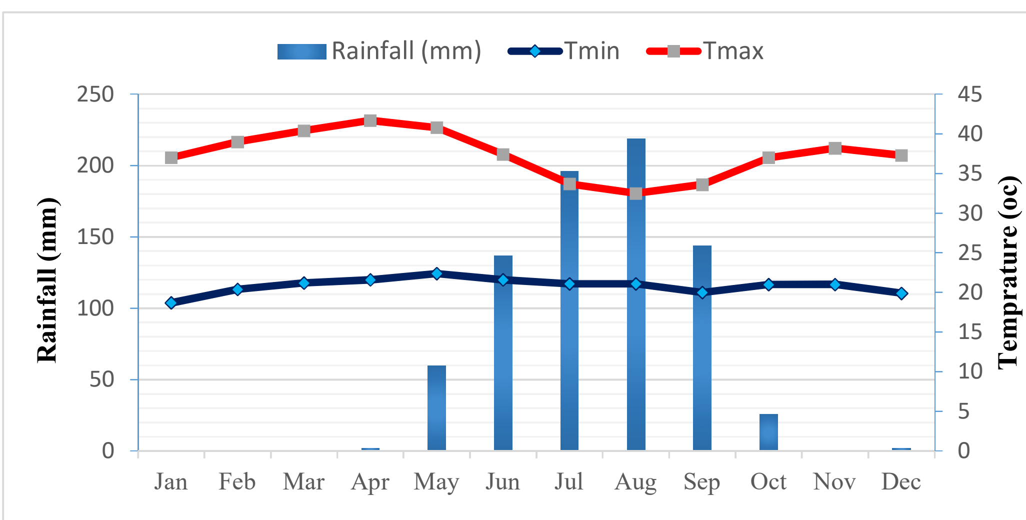

Figure 3.3. Rainfall and temperature data of the West Armachiho district during the 2023 cropping season (Ethiopian Meteorological Institute, 2023)

Table 3.1. The physical and chemical properties of the soils of the study sites

No.	Experimental Site	pH	Org mat.	Available P/PPM	Total N	CEC Cmol/kg	Texture (Hydrom.)
1	Metema	6.66	1.709	6.913	0.085	60.86	Light vertisol
2	West Armachiho	6.715	0.8555	8.3075	0.0705	52.7507	Clay loam

Source (GARC stations profile 2021. Unpublished)

3.2. Experimental Materials, Design, and Management

3.2.1. Experimental Materials

The most adaptable sorghum variety in Metema and west Armachiho areas, called Melkam, with a basic seed class that was obtained from Gondar Agriculture Research Center (GARC), Technology Multiplication and Seed Research Directorate, was used for this experiment. Due to the wide adaptation of the variety to the high potential and moisture-deficient lowland areas, GARC multiplies early generating seed widely to address the seed shortage. As a result, the variety was selected for this experiment to improve its productivity and seed quality.

Table 3.2. Description of Melkam Variety

Variety	Year of release	Rainfall (mm)	Altitude (m.a.s.l)	Agro-ecology	Yield tone ha^{-1}	Released by
Melkam	2009	500-800	<1600	Lowland	3.5-5.8	MARC

MARC=Melkassa Agricultural Research Center (MoARD, 2009).

Four priming treatments of control (unprimed), hydro priming (Tap water), Moringa Leaf Extract(MLE) (botanical priming) and cow urine (Osmo-priming), and the coating treatments used were control (uncoated), thiram (Thiram Granuflo), Apron star (20% thiamethoxam + 20% metalaxyle + 2% defenconazole), and Dynamic 400 FS (thiram + carbofuran) for treatment combinations.

3.2.2. Laboratory experiment

A laboratory experiment was conducted in 2023 at the Gondar Agricultural Research Center seed laboratory according to International Seed Testing Association (ISTA) 2014 guidelines. The experiment was designed using four priming treatments (tap water, Moringa Leaf Extract (MLE), cow urine and control and four coating treatments (Thiram, Apron Star, Dynamic 400 FS) and control in factorial combination (Table 3.3). The treatment was laid out in a Completely Randomized Design (CRD) with four replications, having a total of 16 treatment combinations (Table 3.3). Four hundred seeds were counted from each treatment and divided into four replicates of one hundred seeds. Subsequently, 100 seeds were sown on each experimental unit in plastic germination boxes containing a sand medium. The sand was thoroughly cleaned, sterilized, and moistened before being used. Germination was conducted at room temperature for ten days, with recording of the results according to ISTA guidelines (ISTA, 2014).

3.2.3. Field experiment designs and management

The experiment was conducted during the 2023 main cropping season in high-potential areas of West Gondar at Metema and West Armachiho district GARC research stations. The field experiment consisted of a factorial combination of four priming treatments (tap water, Moringa Leaf Extract (MLE), cow urine and control and four coating treatments (Thiram, Apron Star, Dynamic 400 FS) and control in factorial combination (Table 3.3). 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 and net plot sizes were 13.5 m^2 and 9 m^2 respectively. The two outer rows of each side were used as the buffer row, while the four central rows were used for agronomic data collection. The space between blocks and plots was maintained at 1.5 m and 1m, respectively.

The experimental land was prepared before planting by using a tractor-mounted disk plow for the first plow, a disk harrow for the second plow, and leveled manually for sowing. The date of planting was July 5, 2023, with a seed rate of 12 kg ha^{-1}. The seed was sown by drilling across the slope manually using 0.75m spacing between rows, and thinning was done after two weeks of emergence to maintain 0.15m plant spacing. 100 kg ha^{-1}DAP and 100 kg ha^{-1} urea was used. A full dose of DAP and half the amount of urea were applied at planting. The remaining 50 kg ha^{-1} urea was applied as top dressing at the knee height stage. Hand weeding was done during the early development stage, during the mid-development stage, before heading, and after the heading stage. Harvesting was done manually on the head and the stalk separately using hand sickles at the harvest maturity stage. Data were collected from each plot across the treatments by using appropriate sampling and analytical procedures. A net area of each plot consisting of 4 central rows of 3 m length and 3 m width (9 m^2) was used for data collection and measurement. Phenological parameters, yield, and yield-related components were collected from the field on the plant and net plot bases.

3.3. Experimental Treatment Preparation Procedures

Fresh cow urine was collected in a sterile container from a local bride of cow, filtered, and stored in an airtight container for 7 days. The cow urine is used for organic seed priming, where 10 ml of cow urine was added to 100 ml of water to get a 10% solution (Kumar *et al.*, 2017). The seed weighed for each treatment was soaked with tap water, and 10% fermented cow urine, based on the ratio of seed weight to solution volume, was kept at 1:5 (Farooq *et al.*, 2006). The primed seeds were soaked with tap water, and the cow urine was soaked for 12 hours overnight (Abebe Worku *et al.*, 2017). After that, the seeds were dried under shade conditions to attain their original weight.

Preparation of Moringa leaf extraction was performed according to Price (2007). Fresh *Moringa oleifera* leaves were collected directly from a mature tree at the Metema district GARC irrigation station and air-dried in a shaded place. After drying, the leaves were grinded and made into powder form. At a weight-to-volume ratio of 1:10, the powder was weighed and combined with tap water. Then, the mixture was shaken for four hours by an electrical stirrer and kept in the dark at room temperature for 24 hrs. Afterward, it was filtered through double layers of moistened cotton cloth. The seed was soaked for 8 hours in closed containers during the night. The ratio of seed weight to solution volume was kept at 1:5 (Farooq *et al.*, 2006). The primed seed was dried at room temperature in a shaded area on a double layer of cotton cloth until it returned to its original moisture content.

In the cases of coating the seeds was coated using its respective factory recommendation just before planting with Dynamic 400FS at 5 ml kg^{-1} of seed, apron star 2.5 g kg^{-1} (Syngenta, 2023) and Thiram 80% WP coated in 3 g kg^{-1} of seed (USEPA, 2015) through mixing with water at 6ml kg^{-1} of seed according to the treatments set up using manually.

3.4. Data Collection

3.4.1. Data collected from a laboratory experiment

Germination percentage: The number of normal and abnormal seedlings was counted 10 days after sowing to determine germination percentage (ISTA, 2014). Total germination percentage was determined by using the formula.

$$\mathrm{GP}(\%) = \frac{\text{Total number of Normal seedlings}}{\text{Total number of seeds planted}} \mathrm{x}100$$

Speed of germination:

The seeds showing radical protrusion were counted daily from the third day after sowing until no further germination was observed. The speed of germination was calculated by using the following formula(Mangure, 1962).

$$\text{SPG} = \frac{\text{Number of germinated seeds}}{\text{Number of days to first count}} + \cdots + \frac{\text{Number of germinated seeds}}{\text{Number of days to final count}}$$

Shoot and root length of seedlings (cm): Shoot and root lengths were determined by measuring the average shoot and root length of ten randomly selected seedlings in centimeters after completion of the germination period from each treatment. The shoot and root lengths of the seedlings were measured from the point of the embryo attachment to the tip of the shoot and root, respectively, using a ruler.

Seedlings' dry weight (g): Seedling dry weight was determined from ten randomly selected seedlings, which were used for measuring shoot and root lengths of seedlings. The seedlings were placed in paper bags, dried at 80 ^{0}C for 24 hours in an oven, weighed, and expressed in grams.

Seedling Vigor Index I (SVI 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 = Germination Percentage*Seedling length (root length + shoot length)

Seedling Vigor Index II (SVI 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 = Seedling Dry Weight * Germination Percentage

3.4.2. Data collected from the field experiment

Phenological parameters

Days to 50% emergence (DE): The number of days was recorded from sowing up to the date 50% of the plants had appeared above ground on a plot basis.

Days to 50% heading (DH): It was recorded by counting the number of days from the date of sowing until 50% of the plants in a plot produce heads above the sheath of the flag leaf.

Days of 90% maturity (DAM): The number of days from sowing to physiological maturity when at least 90% of heads are fully mature and when 85% of the crop stands; stems, leaves, and floral bracts changed to light yellow color were recorded on a plot basis.

Growth, yield, and yield components

Plant height (PH): Plant height in centimeters was measured from ground level to the top of the spike of ten randomly taken plants from all central rows of the plot and recorded as the average height per plant.

Head/Panicle length (PL): The main spikes from ten sample plants of each plot were measured in centimeters and averaged to represent the spike length.

Head width/Panicle diameter (HW): the width of ten randomly selected heads in centimeters in each plot

Head weight (HWT): the weight of ten randomly selected heads from the middle four rows in each plot in grams, and averaged.

Grain yield (Kg/ha): Harvested all the heads of the plants found in the net plot area. After harvesting, sun-drying, threshing, and cleaning were done, the weight of the grain was measured by using a sensitive balance, and the moisture content of the grain was measured by using an automatic moisture tester. The weighted grain was converted to kilograms per hectare by adjusting for 12.5 % standard moisture content by using the following formula.

$$\mathrm{GY} = \frac{100 - \text{grain actual moisture content}}{100 - \text{standard moisture content } (12.5\%)} \text{ x actual yield kg ha} - 1$$

Above-ground dry biomass yield (ADBY): Above-ground dry biomass yield was recorded by weighing the harvested Stover and all the heads harvested for grain yield before threshing by using a spring balance after sun-drying to a constant weight in the net plot.

Stover yield (STY): Stover yield was determined by subtracting grain yield from the total above-ground dry biomass yield.

Thousand seed weight (TSW): A sample of 1000 randomly selected seeds/grains was taken from the bulked grain yield of each plot and weighed to determine the thousand seed weight for each treatment in grams.

Harvest index: Harvest index was calculated as the ratio of grain yield to above-ground dry biomass yield and expressed as a percentage.

$$\mathrm{HI} = \frac{\text{Grain yield (kg ha} - 1)}{\text{Above} - \text{ground dry biomass yield (kg ha} - 1)} \text{ x } 100$$

3.5. Data Analysis

The Statistical analyses for both laboratory and field experiments were carried out in R Studio (R Core Team, 2015), an interface for the R software program (version 4.4.2), and interpretations were drawn following the procedure described by Gomez and Gomez (1984). The least significant 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 tested using the Shapiro-Wilk test. According to these tests, all laboratory and field parameters are normal. To combine the two locations, homogeneity of variance was tested using the Bartlett test method, which results in homogeneity in all parameters. As a result, a combined analysis was done for the field experiment of the two locations.

3.6. Partial Budget Analysis

The economic Analysis was carried out by using the CIMMYT Partial Budget Methodology (CIMMYT, 1988), in which the market prices in Ethiopian Birr (ETB) for inputs (Priming and Coating materials) at the time of sowing and for outputs (grain yield and Stover yield) at the time of harvest under local market conditions were used to calculate the cost of cultivation and gross benefits. The actual average grain yield and Stover yield were adjusted to 10% downward due to management differences to reflect the difference between the experimental yield and the yield that farmers could expect from the same treatment (CIMMYT, 1988).

The average grain price per kg and Stover yield were the benefit and the total variable cost was considered only the costs that vary between treatments, including the cost price per kg of Thiram, and Apron Star; the cost price of Dynamic 400 FS per litter; and labor cost for collection and preparation of Moringa leaf extract and cow urine solution as well as the labor cost to prime and coat the seed were considered the Ethiopian Birr (ETB) for the economic analysis. The cost of Dynamic 400 FS was 2,300 ETB per liter, and the cost of Thiram and Apron Star were 3,200 and 5,000 ETB per kg, respectively. The cost of Labor to collect and prepare the solution of MLE and cow urine was 300 ETB, to prime seeds with water, MLE, and cow urine, and to coat seeds with Dynamic 400 FS, Thiram, and Apron Star was 250 ETB each. Fixed costs and operational costs, including labor, seed, land preparation, and others, were assumed to be constant across all treatments. During the 2023 harvest season, the prices of sorghum grain and Stover in the study area were ETB 35.5 kg^{-1} and ETB 0.75 kg^{-1}, respectively.

Following the CIMMYIT partial budget method, total variable cost, gross benefit, and net benefit were calculated based on the following formula.

$$\text{Total variable cost (TVC)} = \sum_{i=1}^{n} \text{Ci}$$

Where: Ci = cost of the *i*th variable input (e.g., coating material, labor); n = number of variable cost components.

Gross Benefit (GB)= GB=(grain yield (kg ha^{-1})× price of grain (ETB kg^{-1}))+(stover yield (kg ha^{-1})× price of stover (ETB kg^{-1}))

Net Benefit (NB)= Gross Benefit (GB) - Total Variable Cost (TVC)

Treatments were arranged in total variable cost increase order, and dominance analysis was performed to exclude dominated treatments from the marginal rate of return analysis to recommend economically profitable treatments for future application to sorghum production in the study area. The marginal rate of return, which refers to net income obtained by incurring a unit cost of priming, coating, and its application, was calculated by dividing the net increase in yield of sorghum due to priming and coating MRR (%)=(ΔNB/TVCΔ)×100. In the partial budget analysis methodology, treatments exhibiting more than the minimum MRR (> 100%) were considered for the comparison of their NB (CIMMYT, 1988). A treatment with above 100% MRR and the highest net benefit is recommended as the most profitable one (CIMMYT, 1988).

Chapter 4: RESULTS AND DISCUSSION

4.1. Results of Laboratory Experiment

4.1.1. Effect of priming and coating on seed germination parameters of sorghum

Germination percentage

The analysis of variance showed that both the main effects of priming ($P < 0.01$) and coating ($P <0.01$) revealed highly significant differences, and their interaction ($P < 0.01$) also showed a highly significant difference in the germination percentage of sorghum (Appendix Table 7.2). The highest germination percentage (94.25%) was recorded on the interaction effects of seeds primed by MLE and coated by Apron Star, while the lowest germination percentage (76.25) was recorded from the control treatment (Table 4.1).

Based on this result, seeds primed by MLE and coated by Apron Star resulted in a 28 % increase in germination percentage compared to the control. The observed increase may be due to primed seeds that can rapidly imbibe and stimulate the seeds' metabolism, enhancing the germination rate, which can lead to the production of large and uniform seedlings in combination with the fungicides, which protect the seed from disease and pests (Jakhar *et al*., 2024).

The primed seeds increase germination rate, enhance germination uniformity, and result in higher germination percentage in sorghum (Shehzad *et al*., 2012). This has been attributed to metabolic repair during imbibitions and the buildup of germination-enhancing metabolites (Basra *et al*., 2005). Research results reported that the highest germination percentage (95.5%) was obtained from Moringa leaf extract primed seed (Kumar *et al*., 2021), and maximum seed germination percentage (99%) was recorded from seeds treated by carboxin 37.5 + thiram 37.5 WS (Anitha and Jahagirdar, 2015). This promotes seed emergence due to the fact that MLE is a rich source of zeatin, ascorbic acid, Ca, K, and other mineral contents, which regulate the seed germination and seedling establishment-related metabolism (Basra *et al*., 2011). Similarly, seeds coating and priming with Zn resulted in a significant increase in germination percentage and improved seedling growth in all Zn concentrations in comparison with untreated seeds and hydro-priming alone (MOHAMMED and PEKŞEN, 2020). Similarly, Lawal *et al*., (2025) reported that moringa leaf extract priming significantly increased final germination percentage of sorghum seeds up to ~93.3 % compared to control, confirming the positive impact of MLE on germination traits (seed germination percentage, index, and seedling vigor) under laboratory conditions. Similarly, seed priming has been widely documented to enhance germination performance even under challenging conditions by improving membrane integrity, antioxidant capacity, and imbibition efficiency. In rice, primed seeds exhibited improved germination percentage, speed, and uniformity across temperature ranges, consistent with enhanced metabolic readiness prior to germination (Habibi *et al*., 2025).

Seed coatings by Apron Star, which typically contain fungicides and protectant ingredients, help reduce pathogen infection and physical damage during germination. Coatings also facilitate better seed-to-soil contact and can modulate water uptake rates, supporting more synchronous germination (Habibi *et al*., 2025). Similarly, highest germination (98%) was recorded in fungicide coated seeds, where as the lowest (92%) was found in the control treatment in wheat crop (Sultana *et al*., 2025).

In contrast to this result, the highest germination percentage (91.5%) was obtained from seeds hydro-primed with water for 12 hours. Conversely, the lowest germination percentage (64%) was recorded from the treatment combination in which seeds were primed with water and subsequently treated/coated with Dynamic and Disco in sesame (Yalew Tizazu *et al*., 2019).

Table 4.1. The interaction effect of priming and coating on the germination percentage of sorghum

	Coating Materials			
Priming Materials	Control	Thiram	Apron Star	Dynamic
Control	76.25^{f}	85.25^{de}	92.00^{ab}	85.00^{e}
HP	79.00^{f}	91.75^{abc}	92.75^{ab}	88.50^{cd}
MLE	83.75^{e}	93.25^{ab}	94.25^{a}	90.75^{bc}
CU	85.75^{de}	91.75^{abc}	92.75^{ab}	87.00^{de}
CV(%)				2.7

Note: - HP = Hydro Priming, MLE = Moringa Leaf Extract, CU = Cow Urine, CV = coefficient of variation, LSD = Least Significant Difference at 5% level of significance, Means followed by the same letters are not significantly different at 5% level of probability.

Speed of germination

The analysis of variance revealed that the speed of germination of sorghum was significantly influenced by the main effects of priming ($P < 0.01$) and coating ($P < 0.01$), as well as by their interaction ($P < 0.05$) (Appendix Table 7.2). The highest germination speed (25.85) was observed from the combined application of MLE and Apron Star, whereas the lowest germination speed (18.98) was recorded in the control treatment (Table 4.2). Seed priming enhances the rate of metabolism, which results in an increased speed of germination and emergence (Ashraf *et al.,* 2008; Shehzad *et al*., 2012). Due to readily available food during germination, primed seeds are better able to complete the process of germination in a shorter time (Farooq *et al*., 2006). Similarly, rice seed coating positively influences the early seedling establishment (Wang *et al*., 2016).

Shoot length and Root length

The analysis of variance indicated that both shoot length and root length of sorghum seed were significantly affected by the main effects of priming ($P < 0.01$), coating ($P <0.01$), and by their interaction ($P < 0.05$) (Appendix Table 7.2). The highest shoot length (13.54 cm) and root length (17.01 cm) were exhibited on the interaction effects of MLE and Apron Star, where as the lowest shoot length (10.23 cm) and root length (10.74 cm) were recorded from the control treatment (Table 4.2).

Inline to this finding both the main and interaction effect of priming and fungicide coating was significant in shoot length and root length of rice seed. The highest shoot and root length was recorded in primed and coated seed than the control after 7 DAS, 14 DAS, and 21 DAS (Macaisa *et al*., 2016). According to Kumar *et al.* (2021), the highest root and shoot length were recorded in Moringa leaf extract primed seed, followed by Neem leaf extract, while the minimum was recorded at the control treatment. Similarly, Kumar *et al*. (2014) found that the highest root and shoot lengths were recorded in fungicide and polymer-coated seeds compared to the control in pigeon pea. Khan *et al*. (2022) also reported that even though all the priming materials enhance the fresh and dry biomasses and the shoot and root lengths of rice seedlings, the maximum result was observed in fresh Moringa leaf extract primed seed. Yasmeen *et al*. (2013) have found that seed priming improved seedling length attributes. The highest increment in shoot length was found in primed seed than the control. The shoot length also showed improvement in priming compared to the control.

Table 4.2**.** The interaction effect of priming and coating on the speed of germination, shoot length, and root length

Treatments		Seed Physiological Parameters		
Priming	Coating	SG	SL	RL
Control	Control	18.975^{i}	10.23^{g}	10.74^{e}

	Thiram	21.125^{gh}	12.69^{bcd}	15.78^{b}
	Apron Star	22.875^{de}	13.34^{a}	14.54^{c}
	Dynamic	20.600^{h}	12.28^{de}	12.29^{d}
HP	Control	20.775^{h}	11.23^{f}	11.90^{d}
	Thiram	25.375^{abc}	13.47^{a}	14.43^{c}
	Apron Star	25.775^{ab}	12.54^{bcd}	15.31^{bc}
	Dynamic	23.075^{d}	12.46^{cd}	12.54^{d}
MLE	Control	$21.825f^{g}$	11.7^{ef}	11.99^{d}
	Thiram	25.375^{abc}	13.03^{abc}	15.69^{b}
	Apron Star	25.850^{a}	13.54^{a}	17.01^{a}
	Dynamic	23.075^{d}	12.57^{bcd}	12.01^{d}
CU	Control	22.225^{ef}	12.11^{de}	12.29^{d}
	Thiram	24.900^{c}	12.96^{abc}	14.89^{bc}
	Apron Star	25.700^{abc}	13.11^{ab}	15.16^{bc}
	Dynamic	22.825^{de}	12.61^{bcd}	12.91^{d}
CV(%)		2.5	3.32	5.59

Note: - HP = Hydro Priming, MLE = Moringa Leaf Extract, CU = Cow Urine, SG = Speed of Germination, SL =Shoot Length, RL =Root Length, CV = Coefficient of Variation, LSD = Least Significant Difference at 5% level of significance, Means followed by the same letters are not significantly different at 5% level of probability.

Seedling dry weight

The analysis of variance result revealed that the main effects of coating ($P < 0.05$) significantly influenced seedling dry weight. However, the main effects of priming and the interaction effect between priming and coating were not significant ($P > 0.05$) (Appendix Table 7.2). The result shows that a coated seed gives better seedling dry weight than uncoated seeds (Table 4.3). Supporting to this study Muhammad *et al.*, (2025) found that pelleting red clover seeds increased seedling dry weight by 21% compared to uncoated seeds. Similarly, Bicakci *et al*. (2018) reported that seed coating increases the rootlet dry weight than the control in Alfalfa crop. In line with this finding, Kumar *et al*. (2014) found that the highest seedling dry weight was recorded in fungicide and polymer-coated seeds compared to the control in pigeon pea. Additionally, biostimulant coatings on ryegrass seeds resulted in significantly higher seedling dry weight than controls (Qiu *et al.*, 2020).

Table 4.3. The main effect of coating on Seedling Dry Weight

Coating Materials	Seedling Dry Weight(g)
Control	0.0201[b]
Thiram	0.0212[a]
Apron Star	0.0218[a]
Dynamic	0.0212[a]
CV (%)	6.69

Note: CV = coefficient of variation, Means followed by the same letters are not significantly different at 5% level of probability.

Vigor index I and Vigor index II

The analysis of variance result revealed that both vigor index I and vigor index II were significantly affected by the main effects of priming ($P < 0.01$), coating ($P <0.01$), and by their interaction ($P < 0.05$) effects (Appendix Table 7.2). The highest vigor index I (2880.26) was exhibited on the interaction effects of MLE and Apron Star, while the lowest vigor index I (1590.02) was recorded from the control treatment (Table 4.4). On the other hand, the highest vigor index II (2.161) was exhibited on the combination of the seed that was not primed (control) with coating by Apron Star. But, it does not show a significant difference in the interaction effects of MLE and Apron Star (2.026) treatment combination, while the lowest vigor index II (1.41) was recorded from the control treatment (Table 4.4).

Result reported from Kumar *et al.* (2021), the mean performance of Vigor index I maximum (2943.63) result was reported from Moringa leaf extract, and the minimum (2373.31) was recorded from the control. A similar result was obtained in Vigor index II, the maximum was Moringa leaf extract, and the minimum was recorded in the control. Similarly, Kumar *et al.*

(2014) found that the highest Vigor index (3117.86) was recorded in fungicide and polymer-coated seeds than in the control (2766.43).

In contrast to the present finding, Yalew Tizazu *et al. (*2019) reported that seeds coated with Dynamic and Disco produced the highest seedling vigor index (928.48). Conversely, the lowest vigor index (447.5) was observed when hydro-primed seeds were combined with Dynamic and Disco treatments. This difference suggests that the interaction between seed priming and coating treatments can influence seedling vigor differently, and that the effectiveness of coating materials may vary depending on the priming method applied. It also indicates that some treatment combinations may not always produce additive benefits, possibly due to physiological or chemical interactions between the priming process and the coating materials, which may affect seed metabolism, germination behavior, and early seedling growth.

Table 4.4. The effect of priming and coating on vigor index I and vigor index II

Treatments		Seed Physiological Parameters	
Priming	Coating	VI I	VI II
Control	Control	1598.02^{g}	1.41^{g}
	Thiram	2427.7^{c}	1.77^{def}
	Apron Star	2564.9^{bc}	2.161^{a}
	Dynamic	2087.07^{de}	1.77^{def}
HP	Control	1828.04^{f}	1.62^{f}
	Thiram	2560.29^{bc}	1.95^{b}
	Apron Star	2582.3^{b}	1.97^{b}
	Dynamic	2212.18^{d}	1.90^{bcde}
MLE	Control	1984.62^{e}	1.73^{ef}
	Thiram	2677.1^{b}	1.98^{b}
	Apron Star	2880.26^{a}	2.026^{ab}
	Dynamic	2230.67^{d}	1.91^{bcd}
CU	Control	2092.75^{de}	1.78^{cdef}
	Thiram	2554.19^{bc}	1.996^{ab}
	Apron Star	2623.41^{b}	1.95^{bc}
	Dynamic	2217.71^{d}	1.89^{bcde}

CV(%)	4.43	6.37

Note: - HP = Hydro Priming, MLE = Moringa Leaf Extract, CU = Cow Urine, VI I = Vigor Index I, VI II =Vigor Index II, CV = Coefficient of Variation, Means followed by the same letters are not significantly different at 5% level of probability.

4.2. Results of the Field Experiment

4.2.1. Effect of priming and coating on phenological parameters

Days to 50% emergence

The analysis of variance result revealed that both the main effects of priming ($P <0.01$) and coating ($P <0.01$) significantly affected days to 50% emergence; however, its interaction was not significant ($P > 0.05$) (Appendix Table 7.5). The result indicates that for the days to 50% emergence, seeds that are not primed (control) recorded the longest duration to emerge (5.8 days), whereas primed seeds resulted in the shortest duration of emergence. Similarly, the seed that was not coated (control) records the longest day to emergence (5.5 days) than coated seeds (Table 4.5). Seed priming reduces approximately 21% days to 50 % emergence as compared to the control (Unprimed seed). Similarly, seed coating can reduce approximately 1 day to 50 % emergence as compared to the control (Uncoated seed) (Table 4.5).

In line with the findings of this study, Wondimu Teshome *et al*. (2014) reported that the primed seeds had taken the shortest day of 50% emergence as compared to unprimed seeds in sorghum. This is due to the primed seeds can complete early metabolic activities faster, requiring less water uptake before germination begins, which accelerates radicle protrusion and emergence (Paparella *et al*., 2015). Similarly, Mokhtari and Emeklier, (2018) found that primed seeds require 9.75 days for 50% emergence, whereas the control requires 24 days. Abebe Worku *et al*. (2017) also state that an earlier 50% emergence (6.33 days) was observed on water primed seed, followed by cow urine alone, than the other treatment combinations in the wheat crop. This significant performance of priming treatments was probably due to the early completion of metabolic activities, making the seed ready for radicle protrusion. Hence, primed seed requires little further imbibition before the germination process starts; as a result, the seed needs less time to germinate, which has reduced the number of days required for seedling emergence (Murungu and Madanzi, 2010).

Days to 50% heading

The analysis of variance result revealed that both the main effects of priming ($P <0.01$) and coating ($P <0.01$) significantly affected days to 50% heading; however, their interaction was not significant (P > 0.05) (Appendix Table 7.5). Seeds that are primed and coated showed the shortest days to 50 % heading, while the control showed the longest days to 50% heading (78.5 days) in priming and (77.2 days) in coating (Table 4.5). Seed priming reduces approximately 7.5%, days to 50 % heading as compared to the control (Unprimed seed). Similarly, seed coating can reduce the approximate 4.2 days, 50 % heading date as compared to the control (Uncoated seed) (Table 4.5). Wondimu Teshome *et al*. (2014) reported that the primed seeds had taken the shortest day of 50% heading as compared to unprimed seeds. Abebe Worku *et al*. (2017) also state that the earlier heading (67.50 days) was observed on water primed seed, followed by cow urine alone, than the other treatment combinations in the wheat crop. Priming can reduce days to 50% heading by approximately 7.5%, while coating reduces it by about 4.2 days, indicating that priming has a stronger effect on accelerating heading (Chaudhary *et al.,* 2025). Priming reduces the number of days to 50% heading in the sorghum crop. 73.75 days were taken to 50% heading in primed seed, whereas 91 days were taken to head in unprimed(control) seed (Mokhtari and Emeklier, 2018).

Days to 90% maturity

The analysis of variance result shows that both the main effects of priming (P <0.01) and coating (P <0.01) significantly affected days to 90% maturity; however, their interaction was not significant (P > 0.05) (Appendix Table 7.5). A similar trend was observed for maturity date; seeds primed by tape water showed the shortest 90% maturity date of 109.9 days, but there is no significant difference between priming materials (hydro, MLE, and Cow urine), whereas the control exhibited the longest 90% maturity date of 116.5 days(Table 4.5). In case of coating, the shortest days to 90% maturity (109.95 days) was recorded in Apron star-coated seed, even though there is no significant difference between coating materials (Thiram, Apron star, and Dynamic 400 FS), and the longest days to maturity was observed in the control plot (114.6 days) (Table 4.5). This indicates that seed priming reduces approximately 5.66% days to 90% maturity, as compared to the control (Unprimed seed). Similarly, seed coating can reduce the approximate 4.65 days in 90 % maturity date as compared to the control (Uncoated seed) (Table 4.5).

In line with the findings of this study, Wondimu Teshome *et al*. (2014) reported that priming materials significantly affected the emergence and phenology of sorghum. The primed seeds had taken the shortest day of 90% maturity dates as compared to unprimed seeds. In priming, Abebe Worku *et al*. (2017) state that earlier 90% maturity (112.83 days) was observed on water primed seed, followed by cow urine alone, than the other treatment combinations in the wheat crop.

Table 4.5. Main effect of priming and coating on field emergence and phenological parameters of sorghum.

Priming Materials	DE(days)	DH(days)	DM(days)
Control	5.8^{a}	78.5^{a}	116.5^{a}
Hydro priming	4.6^{b}	72.6^{b}	109.9^{b}
Moringa leaf Extract	4.7^{b}	73.3^{b}	110.1^{b}
Cow Urine	4.58^{b}	72.8^{b}	110.5^{b}
Coating Materials			
Control	5.5^{a}	77.2^{a}	114.6^{a}
Thiram	4.7^{b}	73.5^{b}	110.7^{b}
Apron Star	4.6^{b}	73.5^{b}	109.95^{b}
Dynamic	4.9^{b}	73^{b}	111.6^{b}
CV (%)	12.77	4.67	3.66

Note: - DE = Days to 50% emergence, DH = Days to 50% heading, DM = Days to 90% maturity, CV = Coefficient of Variation, Means followed by the same letters are not significantly different at 5% level of probability.

4.2.2. Effect of priming and coating on yield and yield-related traits of sorghum

Plant height

The analysis of variance result showed that both the main effects of priming ($P < 0.01$) and coating ($P < 0.001$) significantly influence plant height; however, their interaction was not significant ($P > 0.05$) (Appendix Table 7.6). The tallest plant (190.4 cm) was recorded in the Moringa leaf extract primed seed, while the shortest plant (184.07 cm) was recorded at the control treatment (Table 4.6). In terms of coating, the tallest plant (190 cm) was recorded in Apron star-coated seed, while the shortest plant (181 cm) was recorded at the control treatment (Table 4.6).

According to Wondimu Teshome *et al*. (2014), report primed seeds record a significantly longer plant height. Similarly, Mokhtari and Emeklier, (2018) reported that primed seeds record longer plant height (235.9-257.9 cm) than the control (154.9-161.4 cm) in different locations. This is due to the result of earlier emergence, uniform and vigorous seedlings that gave a stronger and more energetic start, which enables the crop to utilize the available resources efficiently, grow rapidly, and resist moisture stress better than unprimed seeds (Farooq *et al*., 2006).

Table 4.6. Main effect of priming and coating on plant height of sorghum at Metema and West Armachiho sites

Priming Materials	Plant Height (cm)
Control	184.07^{b}
Hydro priming	186.95^{ab}
Moringa Leaf Extract	190.4^{a}
Cow Urine	187.3^{ab}
LSD (0.05)	3.61
Coating Materials	
Control	181^{b}
Thiram	189.5^{a}
Apron Star	190^{a}
Dynamic	188.3^{a}
CV (%)	3.34

Note: CV = Coefficient of Variation, Means followed by the same letters are not significantly different at 5% level of probability.

Head length

The analysis of variance result revealed that head length was significantly affected by the main effects of priming ($P < 0.01$), coating ($P < 0.01$), and their interaction ($P < 0.01$) (Appendix Table 7.6). The longest head length (31.7cm) was exhibited on the interaction effects of MLE and Apron Star, while the shortest head length (26.95cm) was recorded from the control treatment (Table 4.7).

A larger number of grains with more than 100 grain weight were obtained from MLE primed plants, which resulted in a higher grain yield per plant. Wheat seeds coated with endophytic fungi exhibited increased seed weight per spike, higher seed count, and improved quality (Colla et al., 2015). Similarly, Abebe Worku *et al*. (2017) found that treated seeds gave the maximum number of seeds per spike and number of tillers as compared to untreated seeds.

Head Width

The analysis of variance result revealed that head width was significantly affected by the main effects of priming ($P < 0.01$), coating ($P < 0.01$), and their interaction ($P < 0.01$) effects (Appendix Table 7.6). The widest head (10.85cm) was scored on the interaction effects of MLE and Apron Star, while the narrow panicle length (7.72 cm) was recorded from the control treatment (Table 4.7).

According to Mousavi *et al.* (2012) report seed priming of maize with different priming materials has increased ear diameter, ear length and grains per ear; this is due to the enhanced activity of enzymes in sucrose metabolism of the primed seeds.

Head weight

The analysis of variance result revealed that head weight was significantly affected by the main effects of priming ($P < 0.01$), coating ($P < 0.01$), and their interaction ($P < 0.01$) effects (Appendix Table 7.6). The highest head weight (93.1g) was measured on the interaction effects of MLE and Apron Star, while the lowest head weight (76.37g) was recorded from the control treatment (Table 4.7).

Similarly, Mokhtari and Emeklier (2018) reported that primed seeds record the highest panicle seed yield per plant (g/plant), varying from 63.09-78.21g in two different test locations. While the lowest was in control, treatment varied from 22.51-36.72g. In line with this study, Wondimu Teshome *et al*. (2014) reported that seed priming had a profound effect on the mean head weight of grain sorghum varieties. The primed seed resulted in higher head weight than that of controls. Based on his findings, the maximum mean head weight was recorded in the Melkam variety.

Table 4.7. Interaction effect of priming and coating on yield-related traits of sorghum at Metema and West Armachiho sites

Treatments		Yield-related components		
Priming	Coating	HL (cm)	HW (cm)	HWT (g)
Control	Control	26.95^{h}	7.72^{h}	76.37^{h}
	Thiram	28.87^{efg}	9.5^{def}	84.7^{ef}
	Apron Star	29.65^{bcde}	9.85^{bcde}	83.67^{fg}
	Dynamic	28.82^{efg}	9.15^{efg}	80.42^{gh}
HP	Control	28.3^{fg}	8.62^{g}	78.48^{h}
	Thiram	30.55^{abc}	10.25^{abc}	88.78^{bcde}

	Apron Star	29.47^{bcdef}	9.5^{def}	92.47^{ab}
	Dynamic	29.3c^{def}	8.97^{fg}	86.78^{cdef}
MLE	Control	27.7^{gh}	9^{fg}	78.38^{h}
	Thiram	30.2^{bcd}	9.55^{cdef}	89.12^{abcd}
	Apron Star	31.7^{a}	10.85^{a}	93.1^{a}
	Dynamic	30.18^{bcd}	10.1^{bcd}	90.25^{abc}
CU	Control	29.27^{def}	9.08^{fg}	84.38^{fg}
	Thiram	29.4b^{cdef}	9.07^{fg}	92.63^{ab}
	Apron Star	30.62^{ab}	10.42^{ab}	89.72^{abc}
	Dynamic	28.88^{efg}	9.12^{efg}	85.35^{def}
CV		3.61	6.88	4.21

Note: - HP = Hydro Priming, MLE = Moringa Leaf Extract, CU = Cow Urine, HL = Head Length, HW =Head Width, HWT = Head Weight, CV = Coefficient of Variation, Means followed by the same letters are not significantly different at 5% level of probability

Above-ground dry biomass yield

Combined analysis of variance showed highly significant ($P < 0.01$) variation in biomass yield, both the main and interaction effects among the treatments (Appendix Table 7.7). Similar to the other yield-related parameters, the highest aboveground dry biomass (16.95 ton ha^{-1}) was obtained on the MLE primed seed and Apron Star coated seed, while the lowest (10.28 ton ha^{-1}) was at the control treatment (Table 4.8).

In line with this finding, Abebe Worku *et al*. (2017) reported that all primed and coated seeds gave the highest above-ground dry biomass yield compared to the untreated seeds. Wondimu Teshome *et al*. (2014) found that the highest biological yield was obtained from primed seed of sorghum, which was 6.8% higher than the control treatment. This observed improvement is due to priming, which improves the speed and uniformity of germination, promotes vigorous seedling establishment, and enhances plant growth and yield. This strong seedling establishment also increases competitiveness against weeds, improves tolerance to environmental stresses, and ultimately maximizes biomass and grain yield (Farahani and Maroufi, 2011).

Stover yield

A combined analysis of variance indicated that the Stover yield of sorghum was significantly ($P < 0.01$) affected by the main and interaction effects of priming and coating materials

(Appendix Table 7.7). The highest Stover yield (12.58 ton ha^{-1}) was obtained at an application of MLE priming with Apron star coating, while the lowest Stover yield (7.18 ton ha^{-1}) was produced at the control treatment (Table 4.8). Abebe Worku *et al*. (2017) reported that all primed and coated seeds gave the highest stover yield as compared to the untreated seeds. Similarly, Mousavi *et al.* (2012) reported that priming increases the stover yield of maize as compared to the control.

Grain yield

A combined analysis of variance indicated that the grain yield of sorghum was significantly ($P < 0.05$) affected by the main and interaction effects of priming and coating materials (Appendix Table 7.7). The highest grain yield (4364.92 kg ha^{-1}) was obtained at an application of MLE priming with Apron star coating, which is statistically not different from MLE priming with Thiram coating, and the lowest grain yield (3105 kg ha^{-1}) was produced at the control treatment (Table 4.8). An application of MLE priming with Apron star coating ensured an increase in yield of 28.86% over the control due to improvement in the yield-attributing characters of the treated plants. This increment is due to priming enables early emergence, good stand establishment, deeper roots, uniformity in emergence, initiation of reproductive organs, better competition with weed, early flowering and maturity, resistance to environmental stresses (Amin *et al*., 2012) and seed coating is better for introducing fungicides to protects the seeds from seed-borne and soil- borne pathogens, enables the seed to germinate as a healthy seedling, minimize the negative effect of early and terminal moisture on seed germination, improve stand establishment and increase yields (Gesch and Archer, 2005; Sarath *et al.,* 2007).

Similarly, seed priming with nutrient solutions dramatically improved the grain yield of sorghum by 19.6% (Wondimu Teshome *et al*., 2014). Seeds treated by fungicides and biocontrol agents play a vital role in increasing germination percentage and result in proper plant stand and healthy seedlings, which were found effective in increasing yield by 10-15% besides controlling the disease as compared to the control (Anitha and Jahagirdar, 2015).

In line with the findings of Bdliya *et al.* (2010), seeds treated with Apron Star and emulsified Neem seed oil spray result in the highest grain yield. Hence, Apron Star is used as seed dressing to protect seeds from soil-borne pathogens and seedlings from both soil- and airborne pathogens. Abebe Worku *et al*. (2017) also report that the highest grain yield was obtained from coated seeds, whereas the lowest grain yield was recorded from untreated seeds. Similarly, all the priming treatments showed better yield than the non-primed seed (Yasmeen *et al*., 2013), seed coating increased the yield of wheat (Dimkpa et al., 2020) and rice (Lanka *et al*., 2017).

Harvest index

A combined analysis of variance result showed that harvest index was significantly ($P < 0.05$) affected by the main and interaction effects of priming and coating materials (Appendix Table 7.7). The control treatment gave the maximum harvest index (32.97%) but it has no statistical difference among seed primed by tape water coated with Thiram (32%) and seeds primed by cow urine without coating (31.7%) while the lowest harvest index (28.02%) was at MLE primed seed with Apron star coated seed treatment combination followed by seed primed by MLE and uncoated seed (Table 4.8). The results of this study, however, are not in line with Wondimu Teshome *et al*. (2014), who found that the primed seed had a significantly increased harvest index compared to the control. Other results also showed that priming increases the harvest index of maize (Mousavi *et al.*, 2012) and wheat (Abebe Worku *et al*., 2017).

Table 4.8. Combined ANOVA for the interaction effect of priming and coating on yield and yield-related traits of sorghum

Treatments		Yield and Related Parameters			
Priming	Coating	ADBY(t/ha)	STY(t/ha)	GY(kg/ha)	HI
Control	Control	10.28^{j}	7.18^{g}	3105.73^{k}	32.97^{a}
	Thiram	12.48^{ghi}	8.9^{ef}	3578.15^{fghi}	29.43^{cde}
	Apron Star	12.65^{gh}	8.87^{ef}	3765.7^{defg}	28.98^{de}
	Dynamic	12.47^{ghi}	8.83^{ef}	3628.45^{efgh}	27.93^{e}
HP	Control	11.53^{i}	8.27^{f}	3252.1^{jk}	30.8^{abcd}
	Thiram	13.13^{fg}	9.3^{de}	3836.17^{cdef}	32^{ab}
	Apron Star	14.93^{bc}	10.83^{bc}	4091.4^{bc}	30.47^{bcd}
	Dynamic	13.73^{def}	9.95^{cd}	3780.4^{def}	29.63^{cde}
MLE	Control	$11.6h^{i}$	8.28^{f}	3320.85^{ijk}	28.05^{e}
	Thiram	15.83^{b}	10.83^{ab}	4198.3^{ab}	28.92^{de}
	Apron Star	16.95^{a}	12.58^{a}	4364.92^{a}	28.02^{e}
	Dynamic	14.55^{cd}	10.58^{c}	3968.15^{bcd}	30.07^{bcde}

CU	Control	12.03^{hi}	8.52^{ef}	3507.02^{ghij}	31.7^{abc}
	Thiram	14.37^{cde}	10.52^{c}	3854.87^{cde}	28.55^{de}
	Apron Star	14.52^{cd}	10.52^{c}	3992.83^{bcd}	28.95^{de}
	Dynamic	13.37^{efg}	9.9^{cd}	3481.82^{hij}	29.3^{de}
CV(%)		6.83	8.79	6.14	6.84

Note: HP = Hydro Priming, MLE = Moringa Leaf Extract, CU = Cow Urine, ADBY = *Above Ground Dry Biomass Yield, STY =Stover Yield, GY = Grain Yield, HI = Harvest Index, CV = Coefficient of Variation, Means followed by the same letters are not significantly different at 5% level of probability.*

Thousand-seed weight

The analysis of variance result showed that both the main effects of priming ($P < 0.01$) and coating ($P < 0.05$) significantly influence thousand seed weight; however, their interaction was not significant ($P > 0.05$) (Appendix Table 7.7). Minimum (27.8 g) and maximum (28.59 g) 1000-seed weights were recorded from the hydro primed seed and the MLE primed seed, respectively (Table 4.9).

In the case of coating, the Dynamic-treated seed recorded the highest (28.76 g) thousand-seed weight, and the lowest (28.03 g) thousand-seed weight was recorded from the control treatment (Table 4.9). In line with this finding, Mokhtari and Emeklier (2018) reported that primed seeds record the highest thousand seed weight compared to the control. Kumar *et al*. (2014) also reported that the highest 1000-seed weight was recorded in fungicide and polymer-coated seeds compared to the control treatment. The increase in kernel weight due to seed priming was attributed to improved dry matter allocation to developing grains, resulting from enhanced crop growth rate and greater leaf area index at different growth stages (Farooq *et al*., 2006).

Table 4.9. Combined ANOVA for the main effect of priming and coating on the thousand-seed weight of sorghum

Priming Materials	Thousand Seed Weight (g)
Control	28.5^{ab}
Hydro priming	27.8^{c}
Moringa leaf Extract	28.59^{a}
Cow Urine	28.05^{bc}

Coating Materials	
Control	28.03[b]
Thiram	28.12[b]
Apron Star	28.04[b]
Dynamic	28.76[a]
CV (%)	3.16

CV = Coefficient of Variation, Means followed by the same letters are not significantly different at 5% level of probability.

4.3. Partial Budget Analysis Result

According to the partial budget analysis, all primed and coated seeds provide a greater net benefit than the control. However, seeds primed by Moringa leaf extract and coated by Apron star gives the maximum net benefit (ETB 146999.7 ha^{-1}) with above acceptable level of the marginal rate of return (116792.1 %), followed by MLE primed seed with Thiram coated treatment gives net benefit of (ETB 140531.8 ha^{-1}) with the marginal rate of return (1187.745 %), while the lowest net benefit (ETB 104076.1 ha^{-1}) was obtained from the control treatment (Table 4.11). The second-highest marginal rate of return (36660.42%) was found at the unprimed seed coated by Apron Star (Table 4.11).

According to the dominance analysis on net benefits of the experimental result, treatments of MLE X Control, HP X Dynamic, CU X Thiram, CU X Dynamic, and CU X Apron star were dominated by other treatments, hence, eliminated from further economic analysis (Table 4.10). In a partial budget analysis, it is expected that farmers require a minimum rate of return of 100%, representing an increase in net return of at least 1 birr for every 1 birr invested, to be satisfactorily moved to adopt a recommended new agricultural technology (CIMMYT, 1988). Based on the MRR and net benefit result, the treatment that receives seeds primed by Moringa leaf extract and coated by Apron star had the maximum net benefit (ETB 146999.7 ha^{-1}) with an above acceptable level of the MRR (116792.1 %) (Table 4.11) is recommended for sorghum growers in the west Gondar zone and other similar agro-ecologies.

Table 4.10. Partial budget analysis of adjusted grain and Stover yield, TVC, gross benefit, net benefit, and Dominance analysis

Treatments	GY	AGY	STY	ASTY	GB	TVC	NB	Dominance
Control	3105.73	2795.2	7180	6462	104076.1	0	104076.1	
HP X Control	3252.1	2926.9	8270	7443	109487.2	250	109237.2	
Control X Thiram	3578.15	3220.3	8900	8010	120328.2	365.2	119963	
Control X Dynamic	3628.45	3265.6	8830	7947	121889.1	388	121501.1	
Control X Apron star	3765.7	3389.1	8870	7983	126300.3	400	125900.3	
MLE X Control	3320.85	2988.8	8280	7452	111691.4	550	111141.4	D
CU X Control	3507.02	3156.3	8520	7668	117799.7	550	117249.7	
HP X Thiram	3836.17	3452.6	9300	8370	128844.8	615.2	128229.6	
HP X Dynamic	3780.4	3402.4	9950	8955	127501.5	638	126863.5	D
HP X Apron star	4091.4	3682.3	10830	9747	138031.9	650	137381.9	
MLE X Thiram	4198.3	3778.5	10830	9747	141447	915.2	140531.8	
CU X Thiram	3854.87	3469.4	10520	9468	130264.7	915.2	129349.5	D
MLE X Dynamic	3968.15	3571.3	10580	9522	133922.7	938	132984.7	
CU X Dynamic	3481.82	3133.6	9900	8910	117925.3	938	116987.3	D
MLE X Apron star	4364.92	3928.4	12580	11322	147949.7	950	146999.7	
CU X Apron star	3992.83	3593.5	10520	9468	134670.3	950	133720.3	D

HP=Hydro Priming, CU=Cow Urine, MLE = Moringa Leaf Extract, GY=Grain yield (kg ha^{-1}), AGY = Adjusted grain yield (kg ha^{-1}), STY=Stover yield (kg ha^{-1}), ASTY = Adjusted Stover yield (kg ha^{-1}), GB = Gross benefit (ETB ha^{-1}), TVC= Total variable cost (ETB ha^{-1}), NB= Net benefit (ETB ha^{-1}), D = Dominated.

Table 4.11. Marginal rate of return (MRR) analysis result

Treatments	TVC	NB	MC	MB	MRR (%)
Control	0	104076.1			
HP X Control	250	109237.2	250	109237.2	43694.88
Control X Thiram	365.2	119963	115.2	10725.75	9310.547
Control X Dynamic	388	121501.1	22.8	1538.1	6746.053
Control X Apron star	400	125900.3	12	4399.25	36660.42
CU X Control	550	117249.7	150	-8650.65	-5767.1
HP X Thiram	615.2	128229.6	65.2	10979.95	16840.41
HP X Apron star	650	137381.9	34.8	9152.3	26299.71
MLE X Thiram	915.2	140531.8	265.2	3149.9	1187.745
MLE X Dynamic	938	132984.7	22.8	-7547.15	-33101.5
MLE X Apron star	950	146999.7	12	14015.05	116792.1

HP =Hydro Priming, CU=Cow Urine, MLE= Moringa Leaf Extract, TVC= Total variable cost (ETB ha^{-1}), NB= net benefit (ETB ha^{-1}), MC= Marginal cost, MB=Marginal benefit, MRR=Marginal rate of return (%)

Chapter 5: CONCLUSION AND RECOMMENDATIONS

5.1. Conclusion

The findings of this study clearly demonstrated that both seed priming and seed coating, individually and in combination, significantly enhance sorghum productivity under lowland agro-ecological conditions in Northwestern Ethiopia by improving seed germination quality, early field performance, and final yield.

The combined analysis of laboratory and field experiments revealed that the interaction between priming and coating treatments had a significant effect on most germination parameters, seedling vigor indices, and yield-related traits. Seeds primed with Moringa leaf extract (MLE) consistently showed superior germination percentage, faster germination speed, longer shoot and root length, and higher seedling vigor indices compared to unprimed seeds and other priming treatments.

Similarly, seed coating treatments significantly influenced seed germination quality, field establishment and yield performance. Among the coating materials, Apron Star and Thiram were more effective in improving seedling emergence, protecting seedlings from early-season pests and diseases, and enhancing yield and yield components. The combined use of priming and coating resulted the highest germination quality, grain yield, biomass yield, harvest index, and overall field performance than the control. Specifically, seeds primed with Moringa leaf extract (MLE) and coated with Apron Star resulted in the highest germination percentage (94.25%), and most vigorous seedlings. This treatment combination also led to earlier emergence, faster crop development, improved stand uniformity, superior grain yield (4,364.92 kg ha^{-1}), biomass yield, harvest index, and overall field performance across both study locations.

Partial budget analysis showed that seeds primed with MLE and coated with Apron Star generated the highest net benefit and an acceptable marginal rate of return, indicating that the technology is not only agronomically effective but also economically viable for producers. The combination of MLE priming with Thiram coating also provided comparable benefits, making it a viable alternative where Apron Star is unavailable

The study confirmed that integrating simple, locally available priming agents with protective seed coatings is an effective, practical, and profitable approach which can substantially mitigate constraints related to poor seed quality and erratic field conditions, thereby contributing to enhanced sorghum productivity in rain-fed systems.

5.2. Recommendations

Based on the result of this study, it is recommended that sorghum seeds should be primed with Moringa leaf extract (MLE) and coated with Apron Star before planting to enhance seed germination, field establishment, grain yield, and economic returns in the lowland areas of Northwestern Ethiopia and other similar agroecologies. Where Apron Star is not readily available, MLE priming combined with Thiram coating can be used as an effective alternative.

Since the current study was conducted during a single cropping season, in a few locations, and using one sorghum variety, further research should be conducted across multiple seasons, different sorghum varieties, and wider agro-ecological zones under varying climatic and soil conditions to strengthen the recommendations. Additional studies on the optimal concentrations, soaking durations, and long-term storage effects of primed and coated seeds on seed storage, soil health, and microbial activity are also suggested. Explore the efficacy of other locally available botanical extracts and organic priming options to broaden accessible choices for smallholder farmers. The mechanisms of the interactions among factors of seed priming and seed coating with fungicide for good seed quality, seedling establishment, and yield need further study.

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7. APPENDIXES

Appendix Table 7.1. Shapiro-Wilk normality test for the seed germination quality parameters of Sorghum.

Traits	W Value	P Value	Normal (p>0.05)
Germination Percentage (GP)	0.9602	0.6652	Yes
Speed of Germination (SG)	0.9533	0.5440	Yes
Shoot Length (SL)	0.9140	0.1351	Yes
Root Length (RL)	0.9412	0.3636	Yes
Seedling Dry Weight (SDW)	0.9472	0.4468	Yes
Vigor Index I (VI1)	0.9036	0.0918	Yes
Vigor Index II (VI2)	0.8787	0.0370	No

Appendix Table 7.2. The mean square value of the analysis of variance for the seed physiological qualities parameters of Sorghum.

Traits	Source of Variation			
	Priming (DF=3)	Coating (DF=3)	Priming * Coating (DF=9)	Error (DF=48)
GP	103.02^{***}	410.81^{***}	16.84^{**}	5.48
SPG	35.71^{***}	52.85^{***}	0.92^{*}	0.33
SL	1.193^{***}	11.163^{***}	0.903^{***}	0.172
RL	2.12^{***}	58.48^{***}	2.17^{**}	0.59
SDW	0.0051^{ns}	0.0801^{*}	0.036^{ns}	0.019
VI I	219410^{***}	2067032^{***}	37028^{**}	10544
VI II	0.0612^{**}	0.4385^{***}	0.0490^{**}	0.0141

*DF= degree of freedom; GP = Germination Percentage; SPG = Speed of Germination; SL =Shoot Length; RL = Root Length; SDW = Seedling Dry Weight; VI I =Vigor Index I, VI II = Vigor Index II; ns, *, ** and *** = non-significant, significantly different at 5 %, 1% and 0.1%, respectively*

Appendix Table 7.3. Shapiro-Wilk normality test for phonological, yield and yield-related traits of Sorghum

Traits	W Value	P Value	Normal (p>0.05)
DE	0.980	0.1483	Yes
DH	0.972	0.09171	Yes
DM	0.982	0.2392	Yes
PH	0.977	0.08989	Yes
HL	0.980	0.1521	Yes
HW	0.989	0.6266	Yes
HWT	0.984	0.3433	Yes
ADBY	0.966	0.0647	Yes
STY	0.977	0.09211	Yes
GY	0.987	0.5189	Yes
TSW	0.98812	0.5467	Yes
HI	0.989	0.6408	Yes

DE= days to emergence; DH= days to heading; DM=days to maturity; PH=plant height; HL=Head length; HW=Head Width; HWT=Head Weight; ADBY= Above Ground Dry Biomass Yield; STY= Stover Yield; GY=Grain Yield; HI= Harvest Index; TSW= Thousand Seed Weight.

Appendix Table 7.4. Bartlett test of homogeneity of variances for phonological, yield and yield-related traits of Sorghum

Traits	K-squared Value(DF=1)	P Value	Significance	Homogeneity
DE	1.9009	0.168	Non Significant	Homogeneous

DH	0.64888	0.4205	Non Significant	Homogeneous
DM	0.062168	0.8031	Non Significant	Homogeneous
PH	0.15618	0.6927	Non Significant	Homogeneous
HL	1.3882	0.2387	Non Significant	Homogeneous
HW	0.12145	0.7275	Non Significant	Homogeneous
HWT	0.15887	0.6902	Non Significant	Homogeneous
ADBY	0.0035611	0.9524	Non Significant	Homogeneous
STY	0.095455	0.7574	Non Significant	Homogeneous
GY	3.7209	0.05373	Non Significant	Homogeneous
TSW	2.868	0.09036	Non Significant	Homogeneous
HI	0.27445	0.6004	Non Significant	Homogeneous

DE= days to emergence; DH= days to heading; DM=days to maturity; PH=plant height; HL=Head length; HW=Head Width; HWT=Head Weight; ADBY= Above Ground Dry Biomass Yield; STY= Stover Yield; GY=Grain Yield; HI= Harvest Index; TSW= Thousand Seed Weight.

Appendix Table 7.5. The combined analysis of variance for phenological and growth parameters of Sorghum at Metema and West Armachiho

Source of Variation	DF	Traits		
		DE	DH	DM
Location	1	0.375^{ns}	10.01^{ns}	0.37^{ns}
Replication	2	0.135^{ns}	18.87^{ns}	52.67^{ns}
Priming	3	8.194^{***}	187.93^{***}	239.93^{***}
Coating	3	4.528^{***}	90.04^{***}	100.6^{**}
Replication* Location	2	0.031^{ns}	3.04^{ns}	2.63^{ns}
Priming *Location	3	0.069^{ns}	0.18^{ns}	0.82^{ns}
Coating *Location	3	0.069^{ns}	0.07^{ns}	0.49^{ns}
Priming * Coating	9	0.130^{ns}	2.45^{ns}	0.89^{ns}
Priming *Coating*Location	9	0.134^{ns}	0.38^{ns}	0.78^{ns}
Error	60	0.394	12.06	16.72
CV (%)		12.77	4.68	3.66

*DF= degree of freedom; HE= days to emergence; DH= days to heading; DM=days to maturity;, ns, *, ** and *** = non-significant, significantly different at 5 %, 1% and 0.1%, respectively.*

Appendix Table 7.6. The combined analysis of variance for yield-related traits of Sorghum at Metema and West Armachiho

Source of Variation	DF	Traits			
		PH	HL	HW	HWT
Location	1	2464.4***	3.961 ns	9.754***	14.6 ns
Replication	2	13.4 ns	1.127 ns	0.203 ns	8.3 ns
Priming Materials	3	163**	7.935***	2.787***	236.7***
Coating Materials	3	422.2***	22.749***	9.932***	523.4***
Replication*Location	2	165.1*	0.358ns	0.053ns	58.6*
Priming *Location	3	0.2 ns	0.265ns	0.332 ns	5.9 ns
Coating *Location	3	19.1ns	0.488ns	0.033 ns	2.3 ns
Priming * Coating	9	54.3ns	3.278**	1.584***	36.5**
Priming *Coating*Location	9	21.9ns	0.692 ns	0.628 ns	29.7*
Error	60	39.1	1.123	0.42	13.1
CV (%)		3.34	3.61	6.88	4.21

*DF= Degree of Freedom; PH=Plant Height; HL=Head length; HW=Head Width; HWT=Head Weight; ns, *, ** and *** = non-significant, significantly different at 5 %, 1% and 0.1%, respectively.*

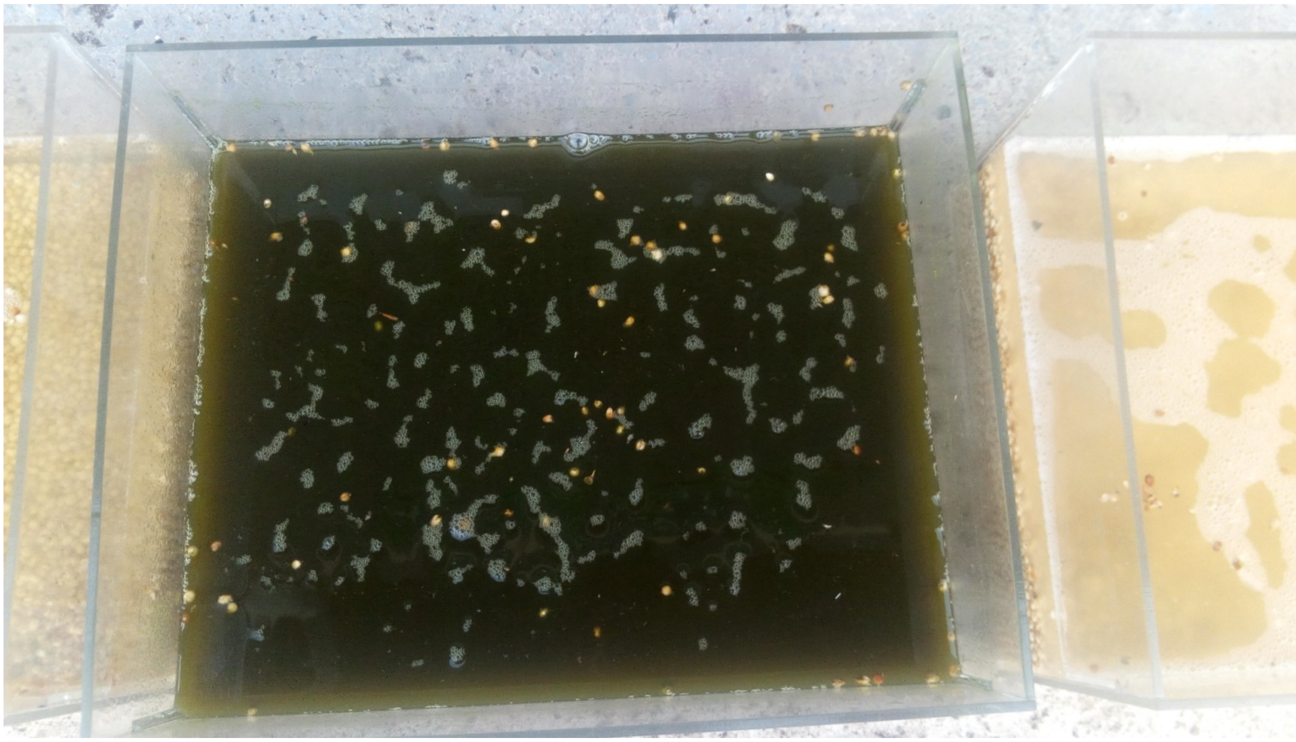
Appendix Table 7.7. The combined analysis of variance for yield and yield-related traits of Sorghum at Metema and West Armachiho

Source of Variation	DF	Traits				
		ADBY	STY	GY	TSW	HI
Location	1	107.95***	89.71***	894073***	65.01***	0.143 ns
Replication	2	0.44 ns	0.3 ns	18875 ns	3.89*	0.177 ns
Priming	3	30.83***	22.03***	792980***	3.32**	15.543*

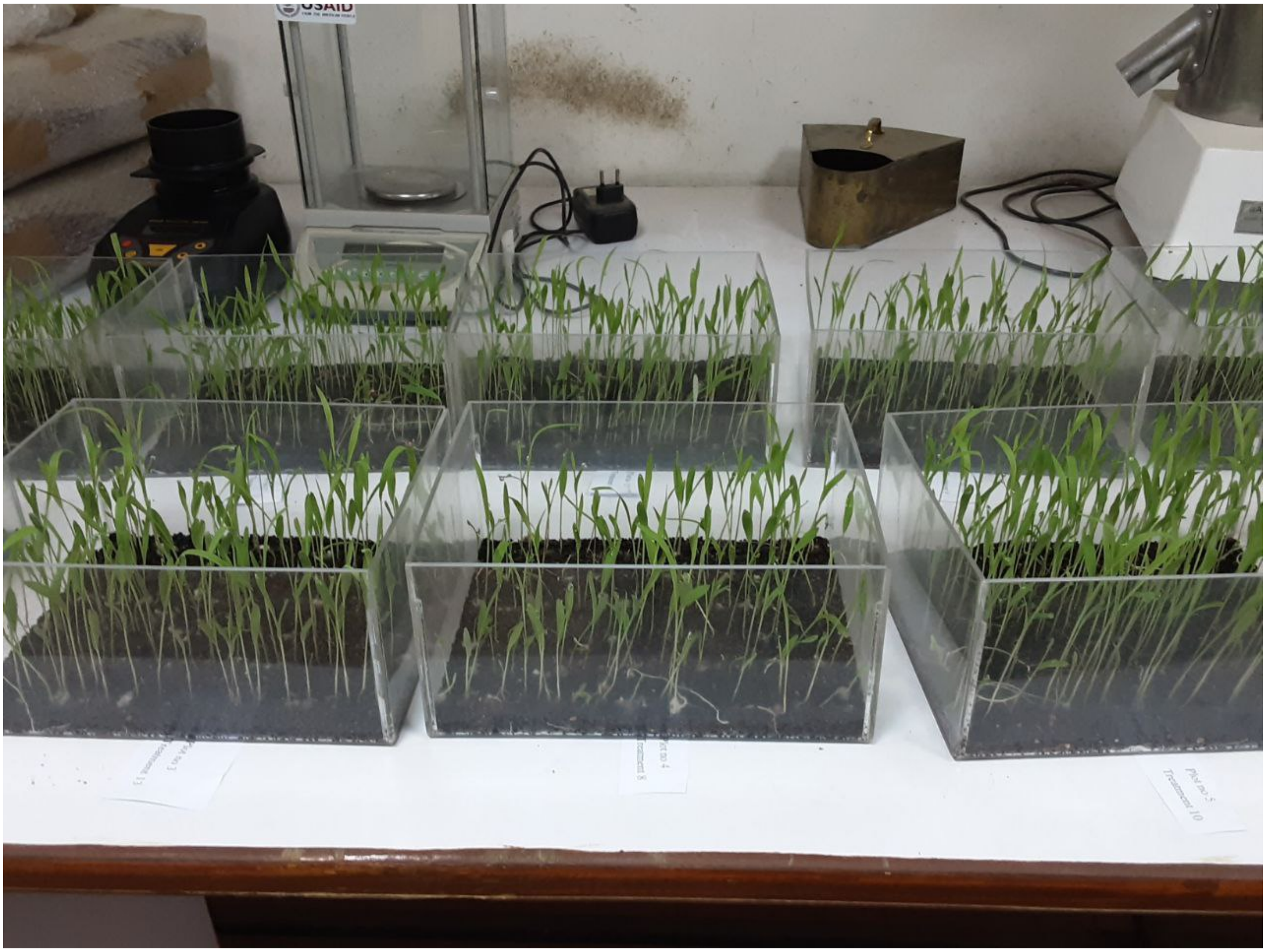
Coating	3	50.65***	30.73***	2493683***	2.96*	15.377*
Replication*Location	2	0.12^{ns}	0.14^{ns}	125653^{ns}	2.26^{ns}	6.318^{ns}
Priming *Location	3	1.58^{ns}	1.49^{ns}	9742^{ns}	1.54^{ns}	19.041**
Coating *Location	3	0.46^{ns}	0.11^{ns}	174272*	3.86**	12.051*
Priming * Coating	9	2.93**	2.13**	130819*	1.57^{ns}	11.993**
Priming *Coating*Location	9	1.05^{ns}	0.98^{ns}	45331^{ns}	0.89^{ns}	8.489*
Error	60	0.84	0.72	52570	0.80	4.135
CV (%)		6.83	8.79	6.14	3.16	6.84

*DF = Degree of Freedom ; ADBY= Above Ground Dry Biomass Yield ; STY= Stover Yield ; GY=Grain Yield ; HI= Harvest Index ; TSW= Thousand Seed Weight ; CV= Coefficient of Variation ; ns, *, ** and *** = non-significant, significantly different at 5 %, 1% and 0.1%, respectively*

APPENDIX FIGURES



Appendix Figure 1. Priming of the seed



Appendix Figure 2. Laboratory experiment performance

Appendix Figure 3. Experimental field preparation and sowing

Appendix Figure 4. Field performance during the emergence stage

Appendix Figure 5.Field performance during thinning at West Armachiho Station

Appendix Figure 6.Field performance during thinning at Metema Station

Appendix Figure 7.Field performance of the trial at the heading stage

Appendix Figure 8. Field performance of the trial at the maturity stage at West Armachiho station

Appendix Figure 9. Field performance of the trial at the maturity stage at Metema station

Appendix Figure 10. Data measurement and recording of the control plot before harvest

Appendix Figure 11. Data measurement and recording of the treated plot before harvest

Appendix Figure 12. Harvesting of mature plots

Appendix Figure 13. Harvesting of the head/panicle

BIOGRAPHICAL SKETCH

The author, Mr. Sintayehu Asmare, was born from his father, Ato Asmare Fekadu, and his mother, W/ro Workie Ayalew, on July 14, 1991, in Beyeda district, North Gondar Zone of Amhara Region, Ethiopia. He attended his elementary education at Janbelew Elementary School from 1998 to 2006 and senior secondary and preparatory education at Dilyibza Senior Secondary and Preparatory School from 2006 to 2010. After completing his Secondary and Preparatory School, he enrolled at Wollo University in 2010 after passing the Ethiopian School Leaving Certificate Examination and graduated on July 4, 2013, with a Bachelor of Science in Plant Science.

After graduation, he joined the Beyeda district Agriculture office in October 2013, and served as a Keble crop production expert and district soil fertility management expert for 3 years. In January 2017, he joined Gondar Agricultural Research Center (GARC), where he served as a Junior and Assistant Researcher in seed research and multiplication of early generation seeds at the Technology Multiplication and Seed Research Directorate. Later, in October 2022, he enrolled at Bahir Dar University College of Agriculture and Environmental Sciences to pursue his M.Sc. in Seed Science and Technology through the regular program.