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Seed Weight Patterns During Imbibition and Germination Morpho-physiology of Four Maize (*Zea mays* L.) Seed Varieties

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Abstract

Suboptimal environmental conditions cause low imbibition rate in maize plants, thus disrupting enzyme activation and food availability for the sprouts, and inhibiting the germination process. This study aims to provide a better understanding of the imbibition pattern and physiological characteristics of germination, hopefully obtaining useful information in the development of seed processing techniques and more efficient agricultural technology. The maize seeds used in this study were the seeds of four maize varieties. The imbibition pattern was obtained by weighing the seeds from 0 to 120 hours with a 6-hour time interval. The results showed that the four varieties showed a typical three-phase imbibition pattern with almost the same time. Overall, the highest seed growth and germination was found in Jantan F1 and Paramita, which have great potential for use in seed propagation, while Baruna variety showed low seed quality and needs further evaluation for improvement.

Keywords: Germination Rate, Growth Rate, Maximum Growth Potential, Viability, Vigor Index

1. Introduction

Maize (*Zea mays* L.) is an important agricultural commodity that plays a strategic role in meeting food and feed needs in Indonesia. The use of quality seeds significantly influences the success of maize production. One important aspect in evaluating seed quality is the seed's ability to germinate. The seed germination process is a complex series of physiological and morphological events, beginning with water imbibition, which activates embryo metabolism and directs subsequent processes such as food reserve degradation, radicle growth that penetrates the seed coat, plumule development, and growth into a seedling (Leite et al., 2022). This process marks the seed's transition from dormancy to an active growth phase, which determines the success of seedling development (David et al., 2013; Jiang et al., 2016).

Imbibition is a crucial early stage in seed germination, where water absorption through the seed coat activates metabolism and enzymes necessary for embryo growth (Anwar & Prapto, 2019). The seed imbibition process is a crucial physiological event that triggers seed germination, allowing the seed to absorb water and activate metabolic

processes essential for growth. Imbibition is characterized by a water absorption pattern depicted in a triphasic curve consisting of rapid water absorption, a plateau phase, and a slower water absorption phase when the seed swells and metabolic activity begin (Pompelli et al., 2023).

The imbibition process physiologically restores the hydration state of previously dry seed cells, allowing protein synthesis and enzyme activity such as α -amylase to occur. This enzyme's role has been shown to be crucial in accelerating germination, as demonstrated in studies on local black rice seeds (Anwar & Prapto, 2019) and purple eggplant (Asih, 2021). Imbibition patterns can generally be categorized into three phases. The first is a rapid water uptake phase that causes a significant increase in seed water content, indicating initial rehydration and metabolic activation (Rachma et al., 2022). Furthermore, the second phase, or lag period, occurs when the rate of water uptake is relatively stagnant even though metabolic processes in the seed have begun; this phase is often associated with the initiation of fundamental biochemical reactions and the repair of cell membrane integrity, supporting this statement based on research on sawdust treatment of legume seeds

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(Ruliyansyah, 2011). The third phase is characterized by a significant increase in water content again, along with the emergence of the radicle as a physical manifestation of germination (Rachma et al., 2022).

The quality and speed of imbibition are influenced by the physical structure of the seed, particularly the thickness and hardness of the seed coat, which serves as the primary barrier to water entry. Various treatment techniques, such as osmo-conditioning with calcium chloride, have been shown to increase seed coat permeability while enhancing enzymatic activity and accelerating the imbibition process, resulting in faster and more simultaneous germination (Anwar & Prpto, 2019; Asih, 2021). Scarification methods through hot water soaking and plant growth regulators have been applied to soften the seed coat and facilitate water penetration, thus creating a porous structure that supports optimal water content in the seed (Hartawan, 2016).

The implications of understanding imbibition patterns are not only important for increasing germination efficiency but also for developing seed treatment techniques aimed at addressing deterioration or dormancy issues. Osmo-conditioning and priming techniques, applied to various seed types, have shown increased germination vigor and quality, even in seeds past their storage period (Anwar & Prpto, 2019; Asih, 2021). Related studies also indicate that imbibition variability can be influenced by differences in environmental potential and seed size, which in turn impacts overall germination (Rosyadita et al., 2023).

The imbibition pattern of maize seeds plays a role in determining the rate and success of germination, which in turn affects plant growth and yield. This process is strongly influenced by environmental factors and seed characteristics, such as size, weight, and water content. The study results of Rosyad et al., (2025) show that the initial water content of seeds is crucial in increasing seed production efficiency and supporting the availability of superior seeds for farmers. Understanding imbibition patterns is crucial for improving maize seed germination efficiency, which ultimately contributes to increased maize production.

Tadidik et al., (2025) studied the morphological relationship of local maize varieties in Gorontalo, but for further identification, observations of the physiological aspects of the seeds were required to provide an overview of the viability of the seeds. Identification of morpho-physiology during the germination stage can provide deeper insight into seed responses to different

environmental conditions. This study addresses the research gap in understanding the imbibition patterns and morphophysiological characteristics of maize seed germination, which was not explored in previous studies which focused only on morphological traits. The novelty of this research lies in integrating both imbibition patterns and seed morphology, offering new insights into how environmental factors and seed characteristics affect seed viability and germination. This study aims to identify imbibition patterns and analyse the morphophysiological aspects of maize seed germination. The objective of this study is to understand imbibition patterns and the morphophysiological characteristics of germination, and to obtain useful information for developing more efficient seed processing techniques and agricultural technologies.

2. Material and Methods

This research was conducted from February to April 2025 at the Seed Science and Technology Laboratory of the Department of Agronomy and Horticulture, Faculty of Agriculture, Bogor Agricultural University (6°33'33.4"S 106°43'49.0"E) at an altitude of 250 meters above sea level. The tools used in this research were: HWH DJ1002C Digital Analytical Scale, ANUMBRA Petri Dish 100 mm, GAND opaque paper 50gsm F4. The materials used were maize seeds of the Baruna (yellow sweet maize), Paramita (white glutinous maize), Jantan F1 (purple glutinous maize) and local (yellow glutinous maize) varieties. The experiment flowchart was described in Figure 1.

This experiment was designed using a completely randomized design with one factor, namely variety, with four replications. Each replication consisted of 100 seeds, with 25 seeds used for imbibition pattern observation, 25 seeds for morphological pattern observation, and 50 seeds for physiological quality observation.

The imbibition pattern was obtained by planting 50 seeds in two petri dishes with opaque paper media. Observation of the imbibition pattern was carried out by weighing the seeds planted in one petri dish from 0 to 120 hours. The pattern was created in the form of a scatter plot using MS Excel. Weighing was carried out every 6 hours. At the same time, the seeds from one petri dish were observed for morphology by documenting any changes in seedling development. The percentage of water absorption was calculated using the following formula (Baskin et al., 2006):

$$\text{Water uptake (\%)} = \frac{\text{Seed mass after soaking} - \text{seed mass before soaking}}{\text{seed mass before soaking}} \times 100\%$$

Documentation was conducted using a 55 MegaPixel (MP) camera. The seeds documented were those that were split down the middle without damaging the embryo axis. The splitting was intended to observe changes in the internal morphology of the seeds. Observations of the physiological quality of the seeds were conducted by

planting the seeds using the test method on paper and in plastic (UKDdp). Physiological quality observed included germination, vigor index, and maximum growth potential. Data analysis was carried out using the MS Office 16 program and the SAS v9.0 data processing program.

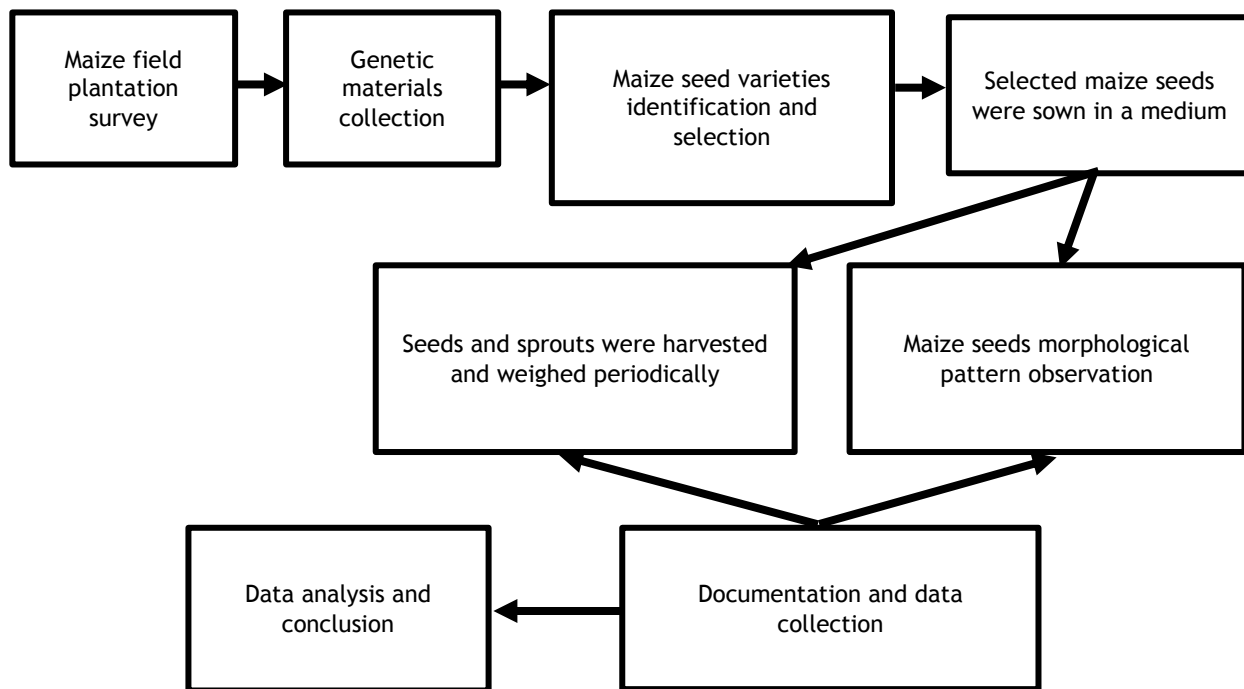


Figure 1. Maize Seed Experiment Flowchart

3. Results and Discussion

The seed imbibition pattern of four maize varieties is presented in Figure 2. The blue graph shows the overall seed weight, while the orange graph shows the seed weight difference (weight increase due to water imbibition). In general, all four varieties show a typical three-phase imbibition pattern: phase I (rapid absorption), phase II (lag phase), and phase III (rebound before germination). Phase I is characterized by a sharp spike in seed weight difference in the first 6 hours, followed by a drastic decrease in the orange graph. This indicates rapid water absorption at the beginning of imbibition. (Romero-Luna & Dávila-Ortiz G, (2019) stated that in phase I of germination, a physical process occurs, in which the seed cells experience structural damage, especially to the membrane, through the intervention of several enzymes, which hydrolyze the structural components of the cell wall, causing leakage of solutes and low molecular weight metabolites into the imbibition solution. Homogalacturonan, which is a polysaccharide in the cell wall esterified by the enzyme pectin methyl esterase, affects the porosity and elasticity of the cell wall.

The graph appears stable in phase II, where the rate of water absorption slows. In this phase, various types of metabolism reactivate, causing growth and the emergence of radicles, which leads to the development of sprouts (Han & Yang, 2015). This stage is characterized by high energy expenditure, obtained through the mobilization of reserve compounds in the form of carbohydrates, proteins, and lipids. Seed energy reserves stored in the endosperm are degraded to drive embryo growth during germination (Yu et al., 2014). The energy obtained from reserve

mobilization allows the seeds to survive until the sprouts are able to photosynthesize. After 66–72 hours, all varieties again showed an increase in seed weight and an increase in weight difference, indicating the start of phase III, which coincides with the beginning of metabolic activity and the initial potential for germination. Yuanasari et al., (2015) stated that phase I begins with the imbibition process, where the seeds absorb water quickly due to the difference in water potential between the seeds and their environment. Then, in phase II, water absorption is slow because the water potential of the seeds and their environment is balanced, but metabolism is actively taking place. In phase III, water absorption increases again where the germination process is complete with the emergence of the radicle.

The Paramita and yellow glutinous maize varieties showed the highest overall seed weights, indicating larger seed size or density compared to the Baruna and Local varieties. Weight increases in phase III tended to be sharper in the Paramita and Jantan F1 varieties, which may reflect higher initial water absorption capacity and metabolic activity. Fluctuations in weight differences in phase II are likely related to respiration or internal osmotic regulation of the seeds. Overall, these data confirm that imbibition is a dynamic, gradual process that varies across varieties, both in terms of rate and water absorption capacity.

Starch-rich seeds (such as maize in general) have a slow and gradual water absorption capacity. Starch absorbs water passively, swelling, but does not dissolve. Maize varieties with high starch content tend to show a stable and consistent increase in weight during the imbibition phase. Seeds with high sugar content tend to absorb water more quickly, due to their osmotic properties. Sweet maize or

glutinous maize varieties, which have a higher sugar content, usually show faster water imbibition in the initial phase (phase I). This is because water is drawn into the cells due to the high sugar concentration in the seeds. However, this did not occur in this study. The graph shows

that varieties with high sugar content (sweet maize) and maize with high starch content (glutinous maize) have the same initial imbibition pattern. Where initially, water entering the seeds ranged from 0.84 – 0.95 grams per 25 seeds, equivalent to 0.0336 – 0.0378 grams per seed.

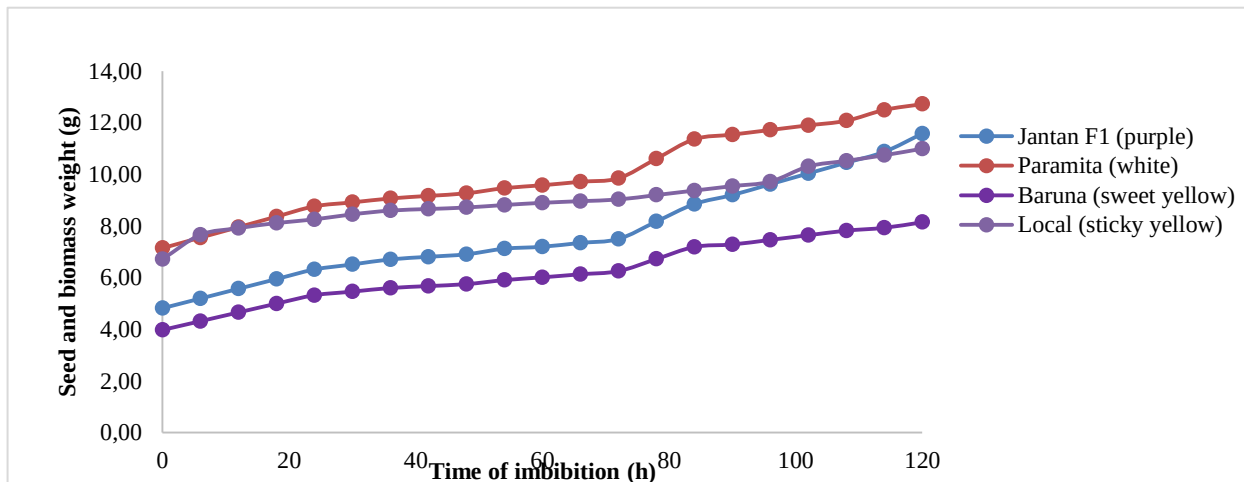


Figure 2. Imbibition patterns during germination of four maize seed varieties

The morphological pattern of maize seeds during the germination process is presented in Figure 3. The results show the stages of morphological changes in maize seeds during the germination process within a time span of 0 to 120 hours. This process illustrates the dynamics of seed organ growth and development that occur over time and accompany important physiological stages in the germination process. In the early stages (6–24 hours), the seeds appear to undergo imbibition, marked by swelling in size due to water absorption, but no significant morphological changes occur. Entering 30–36 hours, the radicle (embryonic root) begins to emerge, which is an early indication that the germination process has begun

physiologically. At 48 to 60 hours, the radicle elongates and begins to be followed by the emergence of the coleoptile (a protective structure of the plumule/embryonic shoot), indicating upward growth.

Seed development was observed to accelerate after 72 hours. Lateral roots began to form, and the plumule began to grow upward. This stage marks the transition from the germination phase to the early seedling growth phase. Rapid growth of the hypocotyl and secondary roots, as well as elongation of the first leaf, was observed between 96 and 120 hours. This development indicates that the seed has successfully completed the germination stage and entered the early vegetative growth phase.

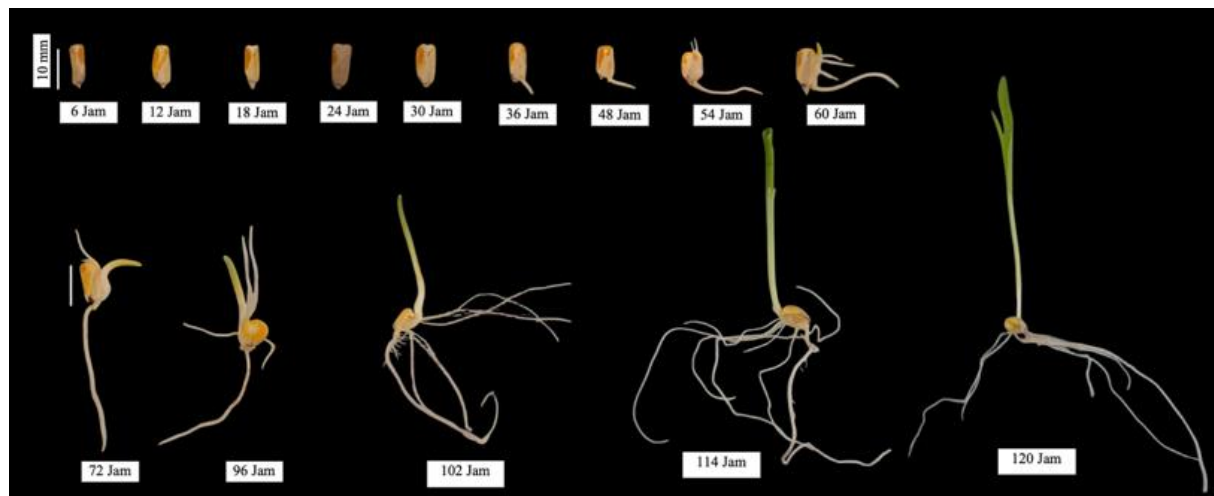


Figure 3. Morpho-physiological of Maize Seed in germination periods

The physiological quality of four maize varieties is presented in Table 1. Based on the data, the Jantan F1 and Paramita varieties showed the highest and most stable seed

quality. Both had a germination rate above 96%, a vigor index above 93%, and a maximum growth potential of 100%. In contrast, the Baruna variety showed the lowest

seed quality, with a germination rate of only 69%, a vigor index of 66%, and a maximum growth potential of 84%. All three were statistically significantly different (notation b and c) compared to the other varieties. Low germination rates can be caused by seed dormancy. (Sinaga et al., 2025) stated that dormancy persistence was observed by testing seed germination rates, which were conducted weekly until germination reached 85% or more. The local (sticky yellow) variety was in the middle position, with good performance (90% germination rate, 89% vigor, and 94% growth

potential) and was not significantly different from Paramita and Jantan F1 in both Germination Rate and Vigor Index. Local maize varieties are important to develop; this is in accordance with the statement of (Sepyanti et al., (2025) that North Sumatra local varieties can increase the availability of high-quality seeds. Overall, the highest seed quality was found in Jantan F1 and Paramita, which have great potential for use in seed multiplication, while Baruna showed low seed quality and requires further evaluation for improvement.

Table 1. Duncan's Multiple Range Test Result of Germination Rate, Vigor Index, and Maximum Growth Potential of 4 Maize Varieties

No	Variety	Germination Rate (%)	Vigor Index (%)	Maximum Growth Potential (%)
1	Baruna	69.00±4.43b	66.00±2.58b	84.00±2.83c
2	Local	90.00±2.58a	89.00±3.00a	94.00±2.58b
3	Paramita	96.00±1.63a	93.00±3.42a	100.00±0.00a
4	Jantan F1	97.00±1.00a	97.00±1.00a	100.00±0.00a

Note: Numbers followed by the same letter within a column are not significantly different, according to Duncan's Multiple Range Test (DMRT) with a significance level of $\alpha = 5\%$

Sweet maize seeds tend to be more fragile and more sensitive to environmental conditions, which can reduce the vigor index. Glutinous maize has a high starch content which tends to have high vigor due to increased hardness and seed storage life. (Yue et al., 2024) studied the physiological, biochemical, and structural changes of sweet maize seeds with seed storage time, and recorded that the results of the A89 sweet maize variety seeds had vigor indexes in the 0M (control) and 8M treatments, with average values of 56.12 and 45.22, respectively.

The results of the regression analysis showed that all variables had a very significant relationship with each other, ranging from 0.90 to 0.96 (Table 2). Germination and vigor index had the highest correlation value at 0.96. This indicates that maize seeds capable of germinating also have

the ability to grow rapidly. Zakia et al., (2021) conducted research related to invigoration techniques on sweet maize seeds and found a high correlation value between the variables Germination and Vigor Index at 0.88.

Yaghoubian et al., (2022) conducted research on bacillus strains to increase the Vigor Index of maize seeds under salinity stress conditions and obtained a very significant positive correlation value between seed germination and the Vigor Index (0.42). The results of the study by Sivritepe et al. (2016) in finding a relationship between viability tests and different vigor tests showed that normal condition germination was significantly correlated with first count, average germination time, germination index, root emergence, and electrical conductivity.

Table 2. Correlation Analysis of Growth Variables

Variable	Germination Rate	Max. Growth Potential
Max. Growth Potential	0,92**	-
Vigor Index	0,96**	0,90**

Note: ** significantly different at $\alpha = 1\%$

4. Conclusion

The results showed that all four varieties exhibited a typical three-phase imbibition pattern: phase I (rapid absorption), phase II (lag phase), and phase III (re-increase before germination) with almost the same duration. Overall, the highest seed quality was found in Jantan F1 and Paramita, which have great potential for use in seed

propagation, while Baruna showed low seed quality and requires further evaluation for improvement. This research provides valuable insights into the imbibition patterns and seed quality of different maize varieties, offering recommendations for seed selection and treatment to improve germination and crop yield.

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