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Artocarpus heterophyllus(Jackfruit) Seed Germination and Survival Constraints in Borewell-Affected Loamy Laterite Soil of Ambikapur, Surguja, Chhattisgarh, India

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Abstract

This paper investigates the critical constraints affecting jackfruit (*Artocarpus heterophyllus*) seed germination and seedling survival in loamy laterite soil, specifically when extracted from borewell drills in the Ambikapur region of Surguja, Chhattisgarh, India. Jackfruit seeds are inherently recalcitrant, possessing a short viability period and high moisture dependency *Mandal, S. (2025)*.. Laterite soils, prevalent in the study area, are characterized by high clay content, acidity, and low fertility, with a propensity for hardening and crust formation. Borewell drilling significantly exacerbates these challenges by inducing physical compaction, altering soil chemical properties through drilling fluid residues (e.g., increased salinity, reduced nitrogen and phosphorus), and disrupting natural soil structure. The hot and humid climate of Ambikapur further interacts with these compromised soil conditions, amplifying moisture and thermal stresses on young seedlings. The analysis reveals a complex interplay of rapid seed viability loss, severe moisture stress (both deficit and excess), nutrient deficiencies, potential salinity toxicity, and physical impedance to root growth. Successful propagation in such challenging environments necessitates a multi-pronged approach, integrating pre-germination treatments, intensive soil amelioration (including organic matter enhancement, pH adjustment, and targeted fertilization), and precise water management strategies, often requiring bio-reclamation techniques to restore soil health *Daws, M. I., L. M. L. de S. P. G. L. (2006*).

1. Introduction

1.1. Background on Jackfruit (Artocarpus heterophyllus) Cultivation

Jackfruit (*Artocarpus heterophyllus*), a prominent tropical fruit, holds significant cultural and nutritional importance, particularly in the Eastern and Southern parts of India, where it is often referred to as "poor man's food". This fruit is a rich source of essential nutrients, including vitamins A and C, and various minerals. Beyond its nutritional profile, jackfruit contains beneficial compounds such as isoflavones, antioxidants, and phytonutrients, contributing to its potential health benefits. Globally, jackfruit is gaining increasing recognition, notably for its versatility in culinary applications, including its use as a meat substitute in vegetarian and vegan diets *Dela, S. (1991)*.

The cultivation of jackfruit thrives in warm, humid tropical and subtropical climates, typically at altitudes up to 1500 meters above mean sea level. India, with its diverse agro-climatic zones, is a significant producer, and states like Chhattisgarh are well-endowed with various agricultural produce and possess substantial cultivable land, making jackfruit cultivation a viable agricultural pursuit in the region.

1.2. Importance of Seed Propagation and Challenges

Jackfruit is commonly propagated through seeds, a method widely adopted for establishing new plantations. However, this propagation method is fraught with inherent challenges due to the unique biological characteristics of jackfruit seeds *Dela, S. (1991*). These seeds are classified as recalcitrant, meaning they possess a high moisture content at harvest and are highly sensitive to desiccation and chilling. This recalcitrant nature results in a very short viable period and poses significant problems for seed storage and long-distance transport, as rapid deterioration can occur. Consequently, ensuring the availability of high-quality planting material is a critical determinant for successful jackfruit crop production *Daws, M. I., L. M. L. de S. P. G. L. (2006)*.

fig. 1 seeds of *Artocarpus heterophyllus* deterioration in open moist clayey soil

1.3. Context of Loamy Laterite Soils in Chhattisgarh

Laterite soils are a distinctive soil type predominantly found in tropical and subtropical regions, characterized by their highly weathered nature and a rusty-red coloration resulting from high concentrations of iron and aluminum oxides. These soils are prevalent in various parts of India, including specific regions of Chhattisgarh. In the Surguja district of Chhattisgarh, laterite soils are recognized as one of the four major soil classifications *Mandal, S. (2025)*.. Generally, laterite soils exhibit a high clay content, which contributes to their high water-holding capacity and plasticity, but also to low permeability. A significant characteristic of these soils is their typically low inherent fertility and acidic pH, often requiring specific management practices for agricultural productivity.

1.4. Impact of Borewell Drilling on Soil Environment

Deep excavation activities, such as those involved in borewell drilling, are known to induce substantial alterations in the surrounding soil environment. These disturbances can significantly modify the physical, chemical, and biological properties of the soil. When soil extracted from borewell drills is used for agricultural purposes, it presents a unique set of challenges compared to undisturbed top soil *Douglas Partners*. This study aims to specifically investigate how these borewell-induced soil alterations interact with the biological requirements of jackfruit seeds, thereby influencing their germination and subsequent seedling survival.

1.5. Research Gap and Study Objectives

While general knowledge exists regarding jackfruit cultivation practices and the characteristics of laterite soils, a comprehensive understanding of the specific interactions between jackfruit seeds and loamy laterite soil *extracted from borewell drills* within the distinct geographical and climatic context of Ambikapur, Surguja, Chhattisgarh, remains largely unexplored. This research gap necessitates a focused investigation into the unique constraints imposed by this disturbed medium.

The objectives of this study are:

1. To characterize the biological requirements of jackfruit seeds for germination and survival, including their recalcitrant nature and optimal conditions.
2. To analyze the inherent physico-chemical properties of loamy laterite soil found in Ambikapur, Surguja, Chhattisgarh.
3. To assess the specific alterations in soil properties that result from borewell drilling and the subsequent handling of extracted subsoil.
4. To identify and evaluate the specific constraints on jackfruit seed germination and seedling survival arising from the combined effects of seed recalcitrance, laterite soil characteristics, and borewell-induced changes.
5. To propose potential mitigation strategies aimed at enhancing successful jackfruit propagation in such challenging environments.

The combination of jackfruit's inherent seed sensitivity, the natural limitations of laterite soils, and the profound disturbances caused by borewell drilling creates a complex and potentially lethal environment for early plant development. The short viability and desiccation sensitivity of jackfruit seeds, coupled with the poor drainage, low fertility, and hardening tendencies of laterite soils, establish a baseline vulnerability. The introduction of borewell-induced soil compaction, increased salinity, and nutrient imbalances is not merely an additional stressor but appears to act synergistically, amplifying the negative effects on germination and early survival *Douglas Partners*. For instance, if seeds require high moisture but the soil becomes compacted and forms a hard crust, water infiltration is severely hindered , leading to desiccation stress even when ambient moisture seems sufficient. Concurrently, elevated salinity levels directly impede water uptake and can be toxic to young seedlings , while nutrient deficiencies further weaken the emerging plant. This multifaceted assault on an already sensitive seed significantly raises the barrier to survival compared to any single factor in isolation *Dela, S. (1991*.

Furthermore, the local climate of Ambikapur, characterized by a hot, humid wet season and a distinct dry season , interacts critically with the water retention and drainage characteristics of laterite soil, particularly when its structure is compromised by borewell activity *Mandal, S. (2025).*.

This interaction can lead to paradoxical conditions of both waterlogging during intense rainfall, due to high clay content and compaction, and severe drought stress during dry periods, due to poor infiltration and rapid surface drying and crusting. Ambikapur experiences a notable wet season *Mandal, S. (2025).*. Laterite soils, with their high clay content, generally possess high water-holding capacity but low permeability. If borewell drilling exacerbates soil compaction , it further reduces water infiltration and increases surface runoff. This implies that during heavy rains, waterlogging could occur despite the general "good drainage" often attributed to laterite soils , because the soil's structural integrity has been compromised. Conversely, during the prolonged dry season, even if laterite can retain water at deeper levels , the formation of a hard surface crust and restricted root penetration due to compaction would limit the access of shallow-rooted seedlings to this retained moisture, effectively creating drought conditions *Dela, S. (1991).* The moisture content of borewell-extracted subsoil can also vary significantly with depth , adding another layer of complexity to water availability for germinating seeds.

2. Jackfruit (Artocarpus heterophyllus) Seed Biology and Germination Requirements

2.1. Recalcitrant Nature and Viability

Jackfruit seeds (*Artocarpus heterophyllus* Lam.) are widely recognized as recalcitrant, a classification that signifies their inherent sensitivity to desiccation and chilling, resulting in a very short period of viability. This characteristic is a primary challenge in their propagation. For instance, studies on *Artocarpus odoratissimus*, a closely related species, indicate an initial seed moisture content of approximately 49.25% on a fresh weight basis, correlating with an initial germination rate of 92%. The rapid deterioration of these seeds poses significant logistical problems for large-scale storage and long-distance transportation. A critical factor in their viability is moisture content; if the water level within the seed drops below a certain critical threshold, such as 20% for *A. odoratissimus*, the seeds become non-viable and lose their ability to germinate *Daws, M. I., L. M. L. de S. P. G. L. (2006).*

2.2. Optimal Storage and Germination Conditions

To maintain a high germination percentage, jackfruit seeds require meticulous management, particularly concerning storage conditions. Proper storage is paramount for preserving seed vigor and vitality. Research indicates that for *A. odoratissimus* seeds, optimal storage conditions involve maintaining them at 20°C in transparent containers. Under these conditions, a 100% germination rate was observed for up to 18 days, with a gradual decline to 83.33% by 30 days of storage. Conversely, storage at lower temperatures (15°C or 10°C) or in dark containers led to accelerated moisture loss and more rapid deterioration, resulting in a significant decline in germination rates *Dela, S. (1991).*

Beyond storage, pre-germination treatments play a vital role in enhancing germination success. The application of Gibberellic Acid (GA3) at 250 ppm for 12 hours has been shown to significantly improve germination rates, achieving up to 91.26%, alongside notable increases in seedling height and vigor index. Potassium Nitrate (KNO3) at 1% for 3 hours also yielded favorable germination results (63.00%). Additionally, soaking seeds in Naphthalene Acetic Acid (NAA) at 25 mg/L for 24 hours has been reported to improve both germination and subsequent seedling growth.

2.3. Seedling Growth and Early Survival Factors

The successful establishment and early survival of jackfruit seedlings are contingent upon specific environmental conditions. Jackfruit trees thrive in warm, humid tropical climates, with an optimal temperature range for growth typically between 22°C and 35°C (68-95°F). Young seedlings are particularly sensitive to environmental stresses. They require consistent moisture, necessitating protective irrigation at 12-15 day intervals during dry periods. However, jackfruit trees are highly intolerant of continuously wet or flooded soil conditions, with prolonged exposure (2-3 days) potentially leading to decline or death. Cold stress also poses a significant threat; temperatures at 0°C can damage leaves, -1°C can harm branches, and -2°C can be lethal to the entire tree.

Physical factors also influence early growth. Root restriction, often experienced when seedlings become pot-bound, significantly impedes their establishment and subsequent growth. To promote a robust and deeper root system, planting in large, deep pots (e.g., 45-61 cm) is recommended *Everglades Farm*. For optimal growth and fruit production, jackfruit trees require full sunlight, ideally at least 8 hours daily. Adequate fertilization is also critical for the healthy development of maturing trees , and young seedlings specifically require ample heat, moisture, and nutrients for vigorous growth *Dela, S. (1991)*

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The extreme recalcitrance of jackfruit seeds, characterized by their short shelf life and rapid loss of viability, imposes a severely compressed window for successful germination *Daws, M. I., L. M. L. de S. P. G. L. (2006)*. This means that any delay or suboptimal conditions encountered during the initial planting phase, especially within a challenging soil environment, will disproportionately reduce the likelihood of successful germination. The rapid deterioration of seeds, as noted in previous research, highlights the urgency of immediate and effective intervention when seeds are planted into a compromised medium. If seeds are introduced into a highly disturbed soil, such as that extracted from borewells, without prompt and effective amelioration, their inherent short viability will often lead to rapid failure before any recovery measures can take effect. This underscores the critical need for immediate soil treatment or the implementation of robust pre-germination strategies. Furthermore, the efficacy of pre-germination treatments, such as those involving GA3 and NAA, extends beyond merely improving germination percentages *Dela, S. (1991)*; they are crucial for accelerating the rate and vigor of seedling emergence. In a hostile environment like borewell-affected laterite soil, this acceleration can be the decisive factor between survival and mortality. Prior research indicates that GA3 can "accelerate the rate of seed germination and growth rate... to obtain more germination percentage and good size of seedling within a short period". In a soil that is compacted, potentially saline, and nutrient-deficient, as is characteristic of borewell-disturbed soil , a slower germination rate exposes the developing seed to adverse conditions for a longer duration, significantly increasing the risk of seed death before emergence. By expediting germination and enhancing initial seedling vigor, these treatments provide the young plant with a crucial advantage, enabling it to penetrate compacted layers, access limited resources more quickly, and establish itself before succumbing to environmental stresses. This shifts the focus from simply achieving germination to ensuring rapid and robust emergence.

Table 1: Optimal Conditions and Recalcitrant Nature of Jackfruit Seeds

Characteristic	Description/Value
Seed Type	Recalcitrant (desiccation and chilling sensitive, short shelf life)
Initial Moisture Content	~49.25% (for *A. odoratissimus*)
Initial Germination	~92% (for *A. odoratissimus*)
Critical Moisture Loss Threshold	< 20% moisture content leads to death (for *A. odoratissimus*)
Optimal Storage Temperature	20°C (in transparent containers)
Storage Viability (20°C)	100% for 3-18 days, 83.33% by30 days
Impact of Unfavorable Storage	Rapid moisture loss, faster deterioration, decline in germination (e.g., 10°C, 15°C)
Pre-germination Treatment (GA3)	250 ppm for 12 hours: Max germination (69.54%-91.26%), improved seedling height, vigor index
Pre-germination Treatment (KNO3)	1% for 3 hours: Good germination (63.00%)
Pre-germination Treatment (NAA)	25 mg/L for 24 hours: Improves germination and seedling growth
Optimal Growth Temperature	22-35°C (68-95°F)
Drought Sensitivity (Young Trees)	Sensitive; require protective irrigation at 12-15 day intervals
Flooding Sensitivity	Not tolerant; decline/death after 2-3 days of wet conditions

Characteristic	Description/Value
Cold Sensitivity	Leaves damaged at 0°C, branches at -1°C, tree killed at -2°C
Root Restriction Impact	Poor establishment and growth if pot-bound; large, deep pots recommended
Sunlight Requirement	Full sun (at least 8 hours daily) for optimal growth

fig. 2 seeds of *Artocarpus heterophyllus* showing early germination inside fruit after ripening

3. Characteristics of Loamy Laterite Soils in Chhattisgarh, India

3.1. General Properties of Laterite Soils

Laterite soils are highly weathered soil types predominantly found in tropical and subtropical zones, distinguished by their characteristic red or rusty coloration, which is attributed to high concentrations of iron and/or aluminum oxides. These soils are rich in sesquioxides and typically lack bases and primary silicate minerals. A defining physical property of laterite soils is their capacity to harden significantly, akin to bricks, when exposed to drying after wetting. Their B-horizon commonly exhibits strong red hues, often described as 5

YR or redder. Structurally, laterite soils are characterized by a high clay content, which imparts several key properties: a relatively high cation exchange capacity (CEC), low permeability, high plasticity, and a notable water-holding capacity. Despite their capacity to retain water, the movement of water into these soils after rainfall is typically slow. The dominant clay mineral found in laterite soils is kaolin, sometimes accompanied by gibbsite.

3.2. Fertility and Agricultural Suitability

The intensive leaching processes inherent in their formation render laterite soils generally low in fertility compared to other soil types. They are typically poor in crucial organic matter and nutrients such as humus, nitrogen, and potash. Significant limitations include deficiencies in phosphorus (P), potassium (K), calcium (Ca), zinc (Zn), and boron (B), alongside high acidity and potential toxicity from aluminum and manganese.

Despite these intrinsic limitations, laterite soils demonstrate a positive response to manuring and irrigation, indicating that their productivity can be enhanced through external inputs. They are particularly well-suited for plantation crops, with successful cultivation of oil palm, tea, coffee, and cashew reported on these soil type *Everglades Farm* . However, a critical challenge arises if the structure of lateritic soils degrades, leading to the formation of a hard crust on the surface. This crust can impede water infiltration, hinder the emergence of seedlings, and increase surface runoff. Rehabilitation strategies, such as 'bio-reclamation of degraded lands,' which involve indigenous water-harvesting methods (e.g., planting pits and trenches), the application of animal and plant residues, and the cultivation of high-value, drought-tolerant fruit trees and indigenous vegetable crops, have proven effective in restoring these soils.

3.3. Specifics of Laterite Soils in Ambikapur, Surguja, Chhattisgarh

In the Surguja district of Chhattisgarh, laterite soils are one of the four major soil classes identified, alongside red and yellow, alluvial, and medium blue soils. Within the laterite classification in Surguja, both dark red and white laterite types are present. Specific research conducted on soil from the Gangapur area within the Ambikapur, Surguja division, provides detailed insights into local laterite properties *Mandal, S. (2025).*. These soils typically exhibit a silty clay texture, characterized by a moderate organic carbon content (approximately 0.60 kg/ha, considered moderately adequate) and a slightly acidic pH, recorded at 5.0. Electrical conductivity (EC) measurements indicate normal salinity levels (0.52 dS/m), suggesting that immediate salinity stress for crops is not a primary concern from the natural soil composition. However, the study also highlighted existing challenges related to water retention and soil compaction within these soils. Overall, soils in the Surguja division are consistently characterized by their high clay content, slightly acidic pH, and moderate organic carbon levels *Mandal, S. (2025).*. A notable aspect of laterite soils is the apparent contradiction in their water dynamics. While their high clay content grants them a high water-holding capacity , their low permeability and inherent tendency to form hard crusts upon drying create a situation where water, though present, may not be readily accessible. This means that despite the soil's capacity to retain moisture, its infiltration can be severely hindered, and its availability to plant roots, particularly the shallow root systems of young seedlings, can be restricted by surface hardening. This distinction is crucial, as a high water-holding capacity alone might seem beneficial, but the accompanying physical limitations effectively negate this advantage for early plant life. Furthermore, the inherent low fertility and acidic nature of laterite soils imply that successful cultivation of any crop, including jackfruit, will necessitate substantial and continuous external inputs. This includes regular application of manures, fertilizers, and potentially liming to adjust pH. Previous research explicitly lists deficiencies in phosphorus, potassium, calcium, zinc, and boron, along with high acidity, as major limitations *Everglades Farm*. The observation that these soils "respond readily to manuring and irrigation" confirms the need for such interventions. For jackfruit, which thrives in a pH range of 5.5-6.5 , the acidic nature of Ambikapur laterite (pH 5.0) would specifically require pH adjustment. This indicates that a successful jackfruit cultivation program in this soil type cannot rely on natural soil fertility but must be an input-intensive system, increasing the complexity and cost of propagation and survival efforts.

Table 2: Physico-Chemical Properties of Laterite Soils in Surguja, Chhattisgarh

Property	Description/Value
General Characteristics	Highly weathered, red/rusty colored, rich in iron/aluminum oxides (sesquioxides)
Hardening Tendency	Capable of hardening like bricks when exposed to drying after wetting
Clay Content	High clay content (deeply weathered soils)
Dominant Clay Mineral	Kaolin (with occasional gibbsite)
Cation Exchange Capacity (CEC)	Higher than sandy soils, but generally low (<16 cmol(p+) kg-1)

Property	**Description/Value**
Permeability	Low
Plasticity	High
Water-Holding Capacity	High
Water Infiltration	Slow; hindered by surface crust formation
pH Range (Surguja)	Slightly acidic, pH 5.0

Organic Carbon Content (Surguja)	Moderate, 0.60 kg/ha
Electrical Conductivity (EC) (Surguja)	Normal salinity levels, 0.52 dS/m
Key Nutrient Deficiencies	P, K, Ca, Zn, B, N, humus, potash
Challenges Noted	Water retention, soil compaction, acidity, Al/Mn toxicity
Suitability for Crops	Responds to manuring/irrigation; suitable for plantation crops (e.g., oil palm, tea, coffee, cashew)

4. Environmental Context: Climate of Ambikapur, Surguja, Chhattisgarh

4.1. Annual Temperature Profile

Ambikapur, located in Surguja, Chhattisgarh, experiences a predominantly hot climate throughout the year. The annual temperature typically fluctuates between a low of 9.4°C (49°F) and a high of 40.6°C (105°F), rarely dropping below 6.1°C (43°F) or exceeding 43.9°C (111°F). The hot season is pronounced, lasting approximately 2.2 months, from early April to mid-June, with average daily high temperatures consistently above 37.2°C (99°F). May stands out as the hottest month, recording an average high of 40.6°C (105°F) and an average low of 25°C (77°F). Conversely, the cool season spans about 3.5 months, from mid-October to early February, during which average daily high temperatures remain below 27.2°C (81°F). December is the coldest month, with an average low of 10°C (50°F) and an average high of 23.9°C (75°F) *Mandal, S. (2025)*..

4.2. Precipitation and Humidity Patterns

The precipitation patterns in Ambikapur are characterized by distinct wet and dry seasons. The wet season is typically oppressive and overcast, while the dry season is largely clear. The cloudier part of the year extends from early June to early October, with August being the cloudiest month, experiencing overcast or mostly cloudy conditions approximately 88% of the time *Mandal, S. (2025)*.. In contrast, the clearer part of the year runs from early October to early June, with February being the clearest month, showing clear, mostly clear, or partly cloudy skies 86% of the time. While specific annual rainfall data for Ambikapur was not directly provided, related studies in semi-arid regions of India where jackfruit research is conducted, such as Belgaum, Karnataka, report around 550 mm of annual rain. Another research location in Prayagraj, Uttar Pradesh, experiences 900-1100 mm of mean annual rainfall, with 75% occurring during the summer monsoon. Current humidity levels in Ambikapur can be very high, reaching up to 97%.

4.3. Implications for Jackfruit Cultivation

The prevailing hot and humid conditions in Ambikapur generally align with the known preferences of jackfruit for tropical climates, which are essential for its optimal growth and fruit production. However, the pronounced distinction between the wet and dry seasons introduces periods of potential water stress. During the dry season, drought conditions may prevail, while the wet season, if coupled with poor drainage, could lead to waterlogging. *Mandal, S. (2025).* The cool season, with lows occasionally reaching 9.4°C, is generally above the critical freezing temperatures known to damage jackfruit (leaves at 0°C, branches at -1°C, tree mortality at -2°C). Nevertheless, prolonged exposure to the lower end of this temperature range could still impose stress on young, sensitive seedlings *Dela, S. (1991).*

The pronounced wet and dry seasons in Ambikapur, when combined with the complex water dynamics of laterite soil (characterized by high water-holding capacity but poor infiltration and crusting tendencies), and further exacerbated by borewell-induced compaction, create a highly challenging and potentially lethal water stress environment for jackfruit seedlings. Jackfruit plants are sensitive to both drought and flooding. Ambikapur's climate features a long hot season and a distinct wet season. *Mandal, S. (2025).* Laterite soils, despite their high water-holding capacity, exhibit low permeability and can form hard surface crusts. If borewell drilling intensifies soil compaction , it further diminishes water infiltration and increases surface runoff. During the wet season, this combination could lead to surface waterlogging and anaerobic conditions, which are known to be lethal to jackfruit seedlings *Everglades Farm.* Conversely, during the extended dry season, even if water is retained deeper within the soil profile, the compacted layers and surface crusting would restrict root penetration and access to this subsurface moisture, effectively creating drought conditions for the shallow-rooted seedlings. This means the climate amplifies the existing soil structural problems, presenting a dual challenge of preventing both excessive moisture and severe deficit, which is particularly difficult for recalcitrant seeds that require consistent moisture levels *Sawant, S., & Sawant, S. S. (2012).*

Furthermore, while the overall climate is generally suitable for mature jackfruit trees, the extreme heat experienced during May, with average highs reaching 40.6°C , poses a significant thermal stress to newly germinated seedlings. Young seedlings are typically more vulnerable to environmental extremes than established plants *Daws, M. I., L. M. L. de S. P. G. L. (2006).* If the borewell-affected laterite soil becomes compacted and forms a hard crust , it can lead to elevated surface temperatures and reduced evaporative cooling from the soil surface. This, coupled with limited water uptake due to compaction and potential salinity, would subject the seedlings to simultaneous severe heat and water stress, significantly increasing mortality rates *Dela, S. (1991).*

Table 3: Climatic Profile of Ambikapur, Surguja, Chhattisgarh

Parameter	Value/Description
Annual Temperature Range	9.4°C to 40.6°C (49°F to 105°F)
Rare Temperature Extremes	Rarely below 6.1°C (43°F) or above 43.9°C (111°F)
Hot Season Duration	2.2 months (April 5 to June 12)
Average Daily High (Hot Season)	Above 37.2°C (99°F)

Parameter	Value/Description
Hottest Month (May)	Average High: 40.6°C (105°F), Average Low: 25°C (77°F)
Cool Season Duration	3.5 months (October 19 to February 5)
Average Daily High (Cool Season)	Below 27.2°C (81°F)
Coldest Month (December)	Average Low: 10°C (50°F), Average High: 23.9°C (75°F)
Wet Season Characteristics	Oppressive and overcast
Dry Season Characteristics	Mostly clear
Cloudier Period	Early June to early October (3.8months)
Cloudiest Month (August)	88% overcast or mostly cloudy
Clearer Period	Early October to early June (8.2months)
Clearest Month (February)	86% clear, mostly clear, or partly cloudy
Current Humidity (Example)	97%
Annual Rainfall (Related Regions)	~550 mm (Belgaum, Karnataka); 900-1100 mm (Prayagraj, UP)

5. Impact of Borewell Drilling on Soil Physico-Chemical Properties

5.1. Direct Physical Disturbance and Compaction

Borewell drilling, inherently an excavation process, causes significant disturbance to the surrounding soil, fundamentally altering its mechanical properties. Similar to deep tillage, drilling can initially disrupt soil structure, potentially loosening it temporarily, but it also reduces crucial seed-to-soil and root-to-soil contact *Everglades Farm*. Investigations into excavation disturbance have revealed a decrease in parameters such as cone tip resistance, sleeve friction, soil resistivity, shear wave velocity, and undrained shear strength. This indicates an initial weakening or loosening of the soil structure, which is often followed by subsequent recompaction.

Compacted soil is characterized by a reduction in pore size and an altered pore distribution, which negatively impacts vital soil functions including aeration, water holding capacity, and drainage efficiency. This compromised structure significantly reduces the soil's ability to vertically infiltrate water, leading to increased surface runoff and a higher risk of localized flooding *Sawant, S., & Sawant, S. S. (2012)* . For plants, compaction directly restricts root penetration, resulting in shallow and malformed root systems that are less able to exploit the soil for essential nutrients and moisture.

5.2. Alterations in Chemical Properties (Drilling Fluids)

The application of drilling fluids (often referred to as drilling mud) and produced water, which are common byproducts of borewell operations, can profoundly alter the chemical properties of the receiving soil. These fluids typically contain a complex mixture of substances, including alkaline compounds, various salts (contributing to salinity), trace elements, and petroleum residues *Douglas Partners*. A primary consequence of drilling fluid application is an increase in Electrical Conductivity (EC) and elevated levels of soluble salts, particularly sodium (Na) and chloride (Cl). High EC and excessive salt concentrations are known to be detrimental to plant growth and development. Specifically, high levels of soluble salts or a high exchangeable sodium percentage (ESP) are major contributors to reduced plant vigor and growth. While chloride is an essential anion for plant functions like photosynthesis at low concentrations, it can inhibit plant growth and become toxic at high concentrations, leading to osmotic stress in the root zone. Young seedlings are particularly sensitive to these soluble salts compared to established plants. Changes in soil pH can also occur, with some studies indicating an increase (towards alkalinity) following drilling mud application. However, the overall impact of drilling fluids, including their alkalinity, suggests that pH changes can vary depending on the specific composition and soil type. Furthermore, research has shown that fields subjected to drilling fluid applications often exhibit very low levels of total nitrogen and plant-available phosphorus, necessitating the addition of N and P fertilizers for successful revegetation efforts. Another physical consequence of drilling fluids is the formation of surface crusts by bentonite and other particles present in the spent fluid, which can reduce the soil's infiltration capacity and hydraulic conductivity.

5.3. Sub soil Specifics from Boreholes

Borehole drilling provides invaluable direct information regarding the physical properties of subsurface materials. Analysis of subsoil drill cores has revealed that the actual moisture content of these samples significantly influences their thermal conductivity and heat capacity. Additionally, the drying process can cause shrinkage in drill core samples. In terms of composition, subsoil layers generally contain lower organic matter and nutrient content compared to the more fertile topsoil. Subsoil often comprises a higher proportion of clay, silt, or sand particles, which directly affects its capacity for water retention and nutrient availability. Being denser and less porous than topsoil, subsoil typically exhibits slower water drainage and lower permeability *Douglas Partners*. Critically, compacted subsoil layers can severely restrict root growth, leading to the development of shallow root systems and a reduction in overall plant vigor.

The impact of borewell drilling extends beyond temporary disruption, leading to prolonged structural and chemical degradation of the soil. While initial excavation might cause some loosening, the subsequent compaction, the altered chemical profile (including increased salinity and changes in pH), and the potential for surface crusting suggest a persistent decline in soil health. This makes the disturbed soil a long-term constraint rather than a temporary hurdle. Previous studies indicate that excavation creates a "disturbance zone" with diminished mechanical properties , and deep tillage, a similar process, can "destroy soil structure" *Douglas Partners*. The reduction in water infiltration and increased runoff in compacted soil points to a lasting physical change. Moreover, the introduction of salts and the formation of surface crusts by drilling fluids are not easily reversible processes and can continue to affect hydraulic conductivity for extended periods. Although some research suggests that optimal application rates of drilling waste might improve soil quality , the consensus remains that high levels of soluble salts and low nitrogen/phosphorus are detrimental to plant growth. This indicates that the soil is not merely disturbed but fundamentally altered in a manner that creates a long-term hostile environment for sensitive plants like jackfruit, necessitating sustained and intensive rehabilitation efforts. *Jyoti, S., Sabarad, A. I., Jalawadi, S., Patil, R. T., Masuthi, D., Prashantha, A., & Nataraja, K. H. (2023).*

Furthermore, the combined effects of borewell-induced compaction and the inherent density of laterite subsoil will severely impede root penetration, creating a significant barrier to plant establishment. This physical restriction, coupled with nutrient deficiencies exacerbated by drilling fluids, means that even if some nutrients are present deeper in the subsoil, they remain largely inaccessible to the developing jackfruit root system. Research clearly demonstrates that "Root growth is restricted by compacted soil. Roots are less able to penetrate the soil and are generally shallow and malformed". This is reinforced by observations that "The compact structure of subsoil can pose challenges for plant root growth and nutrient uptake" *Everglades Farm*. Studies also show that a significant proportion of soils exhibit root restrictions at depths less than 100 cm, primarily due to compacted layers, rendering subsoil nutrient reserves inaccessible. When borewell drilling further compacts the soil, it creates an even denser physical barrier. Simultaneously, drilling fluid applications have been shown to result in "very low" levels of total nitrogen and plant-available phosphorus. Therefore, the physical barrier of compaction prevents roots from reaching any available nutrients, while the chemical changes, particularly nutrient depletion, mean there are fewer nutrients to begin with, resulting in a dual negative impact on seedling nutrition and vigor.

Table 4: Observed Changes in Soil Properties Due to Borewell Drilling/Excavation

Property Affected	Type of Change	Direction of Change	Magnitude/Description
Mechanical Properties	Physical	Decrease	Cone tip resistance, sleeve friction, soil resistivity, shear wave velocity, undrained shear strength (e.g., cone tip resistance reduced by 51-62% of initial value)
Soil Structure	Physical	Degradation/Compaction	Destruction of soil solids, reduced pore space, less aeration, reduced seed-to-soil/root-to-soil contact
Water Infiltration/Drainage	Physical	Decrease	Reduced vertical infiltration, increased surface runoff, increased flood risk; reduced hydraulic conductivity
Surface Crusting	Physical	Formation	Hard crust can form, hindering water infiltration and seedling emergence; bentonite from drilling fluids can form crusts

Property Affected	Type of Change	Direction of Change	Magnitude/Description
Electrical Conductivity (EC)	Chemical	Increase	Increased with drilling fluid application (e.g., 356 to 467 μS cm^{-1}); detrimental at high levels
Salinity (Na, Cl)	Chemical	Increase	Increased salt levels with drilling fluid application; high levels cause reduced plant growth and osmotic stress
pH	Chemical	Alteration (often increase)	Can increase (become more alkaline) after drilling mud application; alkalinity from drilling fluid is a factor

Total Nitrogen (N)	Chemical	Decrease	Very low levels observed in fields with drilling fluid applications
Plant Available Phosphorus (P)	Chemical	Decrease	Very low levels observed in fields with drilling fluid applications
Organic Carbon	Chemical	Decrease	Overworking soil can reduce soil organic matter
Root Growth	Physical	Restriction	Roots less able to penetrate, shallow and malformed; reduced exploitation for nutrients/moisture
Nutrient Uptake	Chemical /Physical	Decrease	Reduced due to restricted root growth; N and K deficiencies common

Property Affected	**Type of Change**	**Direction of Change**	**Magnitude/Description**
Depth of Disturbance Zone	Physical	Varies	Approximately 0.42 times the excavation depth

6. Analysis of Jackfruit Seed Germination and Survival Constraints in Borewell-Affected Loamy Laterite Soil

The successful germination and early survival of jackfruit seeds in loamy laterite soil extracted from borewell drills in Ambikapur, Surguja, Chhattisgarh, are subject to a confluence of severe, interconnected constraints. These challenges arise from the inherent biological properties of jackfruit seeds, the natural characteristics of laterite soils, and the profound physical and chemical alterations induced by borewell drilling.

6.1. Recalcitrance vs. Soil Moisture Dynamics

Jackfruit seeds possess a high moisture requirement and are highly sensitive to desiccation, making consistent moisture availability critical for their viability *Daws, M. I., L. M. L. de S. P. G. L. (2006)*. This biological imperative is directly challenged by the laterite soil's inherent properties, which include slow water infiltration and a strong tendency to form hard crusts upon drying. The impact of borewell drilling further exacerbates this issue. The drilling process leads to soil compaction, which significantly reduces water infiltration and increases surface runoff. This makes it exceedingly difficult to maintain the critical moisture levels necessary for recalcitrant seeds, particularly during the prolonged dry periods characteristic of the Ambikapur climate. The primary constraint here is therefore inadequate and inconsistent moisture availability at the seed level, stemming from poor infiltration and surface crusting, ultimately leading to desiccation and a rapid loss of seed viability.

6.2. Nutrient Deficiencies and Toxicity

Laterite soils are intrinsically characterized by low fertility, exhibiting deficiencies in essential macronutrients such as phosphorus, potassium, and nitrogen, as well as micronutrients like calcium, zinc, and boron. They are also typically acidic and low in humus. Borewell drilling compounds these existing limitations. Drilling fluids have been shown to further reduce total nitrogen and plant-available phosphorus levels in the soil, while concurrently increasing salinity through elevated concentrations of electrical conductivity, sodium, and chloride. High salt levels and excessive chloride concentrations are known to be toxic to developing seedlings and can induce osmotic stress, severely impeding their growth and overall health *Dela, S. (1991)*. Consequently, a major constraint is the presence of severe nutrient deficiencies combined with the potential for salinity and chloride toxicity, which collectively hinder seedling development and compromise overall plant health.

6.3. Physical Barriers to Germination and Root Growth

The high clay content of laterite soils makes them prone to compaction and hardening, which naturally presents a physical barrier to plant growth *Douglas Partners*. Borewell drilling significantly intensifies this issue by causing substantial soil compaction, which reduces critical pore space, impairs aeration, and physically restricts root penetration. Furthermore, the degradation of laterite soil structure can lead to the formation of a hard surface crust , a problem compounded by the bentonite content often found in drilling fluids, which can also form surface crusts. These physical barriers directly impede radicle emergence from the germinating seed and subsequently restrict the development of a robust root system. The consequence is the formation of malformed, shallow roots, which are less efficient at accessing water and nutrients from the soil profile *Everglades Farm*.

6.4. Climate-Soil Interaction and Stress Amplification

The climate of Ambikapur, with its hot temperatures reaching up to 40.6°C in May, can impose significant thermal stress on young plants. The distinct wet and dry seasons further interact critically with the compromised soil structure. During the wet periods, the reduced permeability and compaction of the borewell-affected laterite soil can lead to waterlogging, a condition lethal to jackfruit seedlings. Conversely, during the dry periods, even if some water is retained deeper in the soil, the limited water access due to compaction and surface crusting results in severe drought stress. *Mandal, S. (2025).* This creates a scenario of amplified environmental stresses (thermal, drought, and waterlogging) resulting from the synergistic interaction between climatic extremes and the degraded soil properties.

The combination of jackfruit's recalcitrant seeds *Daws, M. I., L. M. L. de S. P. G. L. (2006)* and the multiple immediate and persistent constraints within borewell-affected laterite soil severely compresses the critical period for successful seedling establishment. This means the timeframe from germination to initial root development is extremely short and fraught with numerous points of potential failure. Jackfruit seeds have a very limited viability period and require consistent moisture and specific temperatures. The borewell-affected laterite soil immediately presents formidable challenges: physical compaction that hinders emergence , chemical toxicity from salts , and inherent nutrient deficiencies. If a seed manages to germinate, the nascent seedling then faces restricted root growth , making it highly vulnerable to both drought and waterlogging as the climate transitions between wet and dry seasons. For a jackfruit seedling to survive, it must overcome multiple severe, simultaneous environmental pressures within a very narrow timeframe before its inherent short viability or external stresses lead to its demise *Dela, S. (1991)*. This "critical establishment window" effectively becomes a significant bottleneck for successful propagation. Given the extensive soil degradation resulting from borewell drilling, compounded by the inherent challenges of laterite, traditional agricultural practices alone are likely insufficient for successful cultivation. This suggests that bio-reclamation techniques, as previously identified for degraded laterite soils, become a fundamental necessity rather than merely an optional enhancement to restore soil health and enable any successful cultivation. Previous research explicitly states that "if the structure of lateritic soils becomes degraded, a hard crust can form on the surface, which hinders water infiltration, the emergence of seedlings, and leads to increased runoff. It is possible to rehabilitate such soils, using a system called the 'bio-reclamation of degraded lands'". The impact of borewell drilling, involving compaction, chemical alterations, and surface crusting , degrades soil far beyond typical agricultural wear. Therefore, simple interventions like adding fertilizers or conventional tillage (which can paradoxically further destroy soil structure) will likely prove inadequate. Bio-reclamation methods, which involve planting deep-rooted species, adding organic matter, and utilizing

water-harvesting techniques , are essential. These approaches are designed to address deep compaction , improve water infiltration, and restore the microbial activity necessary for long-term soil fertility and plant access to vital subsoil nutrients. This elevates bio-reclamation from a general good practice to a critical prerequisite for achieving success in this specific, highly challenging context.

7. Discussion: Interplay of Factors and Mitigation Strategies

7.1. Interconnectedness of Constraints

The challenges identified for jackfruit seed germination and seedling survival in borewell-affected loamy laterite soil are not isolated but form a complex, interconnected web of limiting factors. The inherent recalcitrant nature of jackfruit seeds, with their strict moisture and viability requirements , is profoundly amplified by the physical and chemical limitations imposed by the laterite soil, particularly after disturbance from borewell drilling *Douglas Partners*.

For instance, soil compaction resulting from drilling activities directly reduces pore space and aeration, critically impacting seed viability and impeding the initial growth of the radicle. This physical barrier, in turn, exacerbates nutrient deficiencies because restricted root development prevents the young plant from effectively accessing available nutrients, even if some are present *Everglades Farm*. The compromised soil structure also increases the seedling's susceptibility to climatic extremes, leading to either drought stress during dry periods or waterlogging during heavy rainfall, both of which are lethal to sensitive jackfruit seedlings. Furthermore, the naturally acidic pH of laterite soil , combined with potential alkalinity or salinity introduced by drilling fluids , can create nutrient imbalances and osmotic stress, placing additional strain on seedlings already struggling with physical impediments. This intricate interplay of biological, physical, and chemical factors creates a highly challenging environment where the failure of one factor can cascade into multiple other detrimental effects, severely limiting the chances of successful establishment.

7.2. Proposed Mitigation Strategies

Addressing the multifaceted constraints on jackfruit seed germination and survival in borewell-affected laterite soils requires a comprehensive and integrated approach.

7.2.1. Pre-germination Treatments

To give jackfruit seeds a crucial head start against adverse soil conditions, pre-germination treatments are highly recommended. Soaking seeds in Gibberellic Acid (GA3) at 250 ppm for 12 hours or Naphthalene Acetic Acid (NAA) at 25 mg/L or Tricoderma culture powder for 24 hours has been shown to significantly accelerate germination rates and enhance seedling vigor. This acceleration can be critical in reducing the exposure time of sensitive seeds to hostile soil conditions. *Mandal, S. (2025).*

7.2.2. Soil Amelioration (Pre-planting)

Intensive soil amelioration prior to planting is essential to counteract the inherent limitations of laterite soil and the degradation caused by borewell drilling.

- **Organic Matter Enhancement:** Incorporating ample organic matter, such as Farm-Yard-Manure (FYM) and vermicompost , is vital. Organic amendments improve soil structure, enhance water retention, and increase nutrient availability. A specific growing medium composed of Soil + Vermicompost + Cocopeat in a 2:1:1 ratio has demonstrated maximum germination and seedling growth in jackfruit studies. Continuous organic matter input is necessary for maintaining long-term soil fertility and microbial activity *Everglades Farm*.
- **pH Adjustment:** Given the slightly acidic pH (5.0) of Ambikapur laterite and the optimal range of 5.5-6.5 for jackfruit cultivation , liming may be necessary to raise the soil pH. However, the cost-effectiveness and applicability of liming in tropical low-activity clays require careful consideration, as calcium's role as a nutrient might be more important than its acidity neutralization in some contexts.
- **Nutrient Supplementation:** Targeted application of nitrogen (N) and phosphorus (P) fertilizers is crucial to compensate for the deficiencies exacerbated by drilling fluids. Implementing strategies such as split application of nitrogen and band application of phosphorus and potassium can enhance root access to these vital nutrients.
- **Addressing Compaction:** While deep tillage can temporarily aerate the soil, it also carries the risk of destroying existing soil structure. More sustainable approaches include creating planting pits and trenches, which can aid in localized water harvesting and improve soil conditions within the root zone. Encouraging the activity of

ecosystem engineers like earthworms and planting deep-rooted cover crops such as alfalfa, clover, chicory, or lupine can biologically ameliorate subsoil compaction. These plants enhance biopore formation, which significantly improves water infiltration and nutrient accessibility in deeper soil layers.

7.2.3. Water Management

Precise water management is critical due to the dual risk of drought and waterlogging. Careful and protective irrigation at intervals of 12-15 days is essential during dry periods to ensure consistent moisture for young trees *Sawant, S., & Sawant, S. S. (2012).* . Conversely, during the wet season, ensuring proper drainage is paramount to prevent waterlogging, which can be lethal to jackfruit seedlings. This may involve designing raised beds or improving field drainage systems, given the low permeability of laterite soils. *Everglades Farm*

7.2.4. Site Selection and Planting Practices

Strategic site selection is important. Choosing the warmest area of the landscape that is not prone to flooding is advisable. For initial seedling development, using large, deep pots (e.g., 45-61 cm) is recommended to prevent root restriction, allowing for the development of a strong root system before transplanting. Planting should ideally occur during the optimal window, such as June to December, or more specifically June to August, to align with the onset of the wet season and provide initial moisture for establishment *Everglades Farm*.

7.3. Research Implications and Future Directions

This study underscores the critical need for site-specific soil analysis in areas affected by borewell drilling, as generalized soil management practices may be insufficient. Tailored management strategies are imperative to address the unique combination of challenges presented by borewell-affected laterite soils.

Future research should focus on several key areas. Investigations into the long-term effects of drilling fluid residues on soil microbiology are crucial for understanding the full ecological impact and developing sustainable remediation approaches. Furthermore, evaluating the efficacy of various bio-remediation techniques specifically adapted for laterite soils, including the long-term impact of deep-rooted cover crops on soil structure and nutrient cycling, would provide valuable insights. Finally, exploring the genetic variability among different jackfruit varieties for their tolerance to salinity, acidity, and compaction could lead to the identification and development of more resilient planting materials, thereby enhancing the success rate of jackfruit cultivation in challenging environments.

fig. 3 seeds of *Artocarpus heterophyllus* pretreatment before sowing in planters

fig. 4 pregerminated seeds of *Artocarpus heterophyllus* inside ripened fruit

fig. 5 seeds of *Artocarpus heterophyllus* germinated successfully inside planters

8. Conclusion

Jackfruit seed *Artocarpus heterophyllus* germination and seedling survival in loamy laterite soil extracted from borewell drills in Ambikapur, Surguja, Chhattisgarh, face significant and interconnected constraints. These challenges stem from the inherent recalcitrant nature of jackfruit seeds, which are highly sensitive to desiccation and have a short viability period, the intrinsic limitations of laterite soil, characterized by high clay content, low fertility, acidity, and a tendency to harden, and the profound physical and chemical alterations induced by borewell drilling. The drilling process exacerbates soil compaction, introduces salinity and chloride toxicity, and depletes essential nutrients like nitrogen and phosphorus. The local climate, with its distinct wet and dry seasons and extreme temperatures, further amplifies moisture and thermal stresses on young, vulnerable seedlings.

The primary constraints identified include rapid viability loss of seeds, severe and inconsistent moisture stress (both deficit due to poor infiltration and excess due to compaction-induced waterlogging), critical nutrient deficiencies, potential salinity and chloride toxicity, and significant physical impedance to radicle emergence and root system development *Daws, M. I., L. M. L. de S. P. G. L. (2006)*. Successful propagation of jackfruit in such a challenging environment necessitates a multi-pronged and integrated approach. This includes the strategic use of pre-germination treatments to enhance and accelerate seedling vigor, intensive soil amelioration through the incorporation of organic matter, precise pH adjustment, and targeted fertilization to address nutrient imbalances. Furthermore, innovative methods for alleviating soil compaction, such as biological amelioration using deep-rooted cover crops, are crucial. Finally, meticulous water management, ensuring both adequate irrigation during dry spells and effective drainage during wet periods, is paramount. Understanding these complex interactions is fundamental for developing sustainable jackfruit cultivation practices and ensuring the viability of this important crop in degraded or challenging agricultural landscapes.

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