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UNLOCKING SEED DORMANCY IN NUTRI-CEREALS: PHYSIOLOGICAL CHARACTERISATION AND EFFECTIVE DORMANCY-BREAKING TREATMENTS FOR CUMBU, RAGI AND SORGHUM

Varshaa K S[1] Lakshmi S[2*] Kavitha S[3] Renugadevi J[4] Chandrakumar K[5] Preetha G[6]

[1]Department of Seed Science and Technology, Tamil Nadu Agricultural University, Coimbatore 641 003, India
[2*]Directorate of Open and Distance Learning, Tamil Nadu Agricultural University, Coimbatore 641 003, India
[3]Centre for Students Welfare, Tamil Nadu Agricultural University, Coimbatore 641 003, India
[4]Department of Seed Science and Technology, Tamil Nadu Agricultural University, Coimbatore 641 003, India
[5]Centre for Plant Molecular Biology & Biotechnology, Tamil Nadu Agricultural University, Coimbatore 641 003, India
[6]Department of Seed Science and Technology, Tamil Nadu Agricultural University, Coimbatore 641 003, India
*Correspondence author: Lakshmi S - lakku_seed@yahoo.com, ORCID: https://orcid.org/0000-0002-2474-806X

ABSTRACT
Seed dormancy is a major challenge in the seed supply chain as freshly harvested, viable seeds often fail to germinate under favourable conditions, delaying seed testing, certification, multiplication and timely sowing. This study investigated the dormancy behaviour of freshly harvested cumbu (pearl millet), ragi (finger millet) and sorghum varieties through germination, tetrazolium (TZ) viability, fresh ungerminated seeds (FUS), total phenolic content and evaluation of dormancy-breaking treatments. Nine varieties comprising two cumbu, three ragi and four sorghum genotypes were assessed under laboratory conditions. Sorghum varieties exhibited high germination (82–94%), indicating negligible dormancy, whereas cumbu (8–18%) and ragi (0–4%) showed severe dormancy despite high seed viability (96–100%). High FUS percentages in cumbu and ragi further confirmed that poor germination resulted from dormancy rather than loss of viability. Ragi varieties recorded the highest total phenolic content (5.98–6.39 mg g^{-1}), suggesting a strong association between phenolic accumulation and physiological dormancy. Dormant cumbu and ragi varieties were subsequently subjected to six dormancy-breaking treatments. Dry heat treatment at 40°C for 30 min proved to be the most effective treatment, producing the highest overall mean germination (65.2%) across both crops. Potassium nitrate (0.2%) was particularly effective in ragi, while dry heat treatment for 15 min also performed well in cumbu. The findings demonstrate that dormancy in freshly harvested millets is predominantly physiological but differs between crops, necessitating crop-specific dormancy-breaking strategies. These results provide practical recommendations for seed testing laboratories, breeders and seed producers to improve germination, accelerate seed certification and enhance the efficiency of the seed supply chain.

KEYWORDS: cumbu; dry heat treatment; ragi; potassium nitrate; seed dormancy; sorghum

1. INTRODUCTION

Seed dormancy is a genetically and physiologically regulated block that prevents an otherwise viable, non-injured seed from completing germination under conditions that would normally be favourable for it. In small millets and sorghum, freshly harvested seed lots frequently display a pronounced lag between physiological maturity and germinability, a trait that has both agronomic disadvantages (poor and staggered field emergence, extended seed-testing timelines, difficulty in varietal seed multiplication) and adaptive advantages (protection against pre-harvest sprouting and staggered natural emergence in variable rainfall environments).

Cumbu (pearl millet, Pennisetum glaucum), ragi (finger millet, Eleusine coracana) and sorghum (Sorghum bicolour) are three of the most important nutri-cereals of the semi-arid tropics, valued for their climate resilience, nutritional density and importance in food and fodder security. However, breeders and seed technologists routinely observe that freshly harvested seed lots of these crops differ widely in the intensity of dormancy they express, which in turn dictates the post-harvest handling, storage duration and pre-sowing treatment required before seed can be used for certification testing or direct sowing.

A primary and immediate bottleneck in the seed supply chain of Sorghum, Cumbu, and Ragi is seed dormancy, an endogenously controlled phenomenon in which viable seeds fail to germinate even under favourable moisture, temperature, and oxygen conditions [1]. While dormancy serves as a crucial evolutionary survival mechanism to prevent pre-harvest sprouting during untimely rains [2], it presents a severe disadvantage for seed producers and farmers who require immediate seed certification, multiplication, or sowing after harvest [3]. For crops like

Cumbu and Ragi, this post-harvest rest period must be managed rapidly to make the seeds available for agricultural or industrial purposes. In cereals, dormancy can also create difficulties during seed quality testing, seed certification and timely seed distribution because freshly harvested viable seeds may show low germination in laboratory tests.

The mechanisms of seed dormancy in freshly harvested Sorghum, Cumbu, and Ragi are multifaceted and primarily physiological, specifically involving an internal hormonal imbalance [4]. This physiological dormancy is predominantly driven by endogenous biochemical inhibitors, notably high concentrations of abscisic acid (ABA) and phenolic compounds present in the glumes and seed coat, which actively suppress embryo growth and prevent early metabolic awakening (Sohn et al., 2021). In addition to hormonal regulation, other factors such as endogenous phenolic compounds [5] and, to a lesser extent, the structural characteristics of the seed covering tissues (lemma, palea, and seed coat) may contribute by limiting gas exchange, water uptake, or embryo expansion [6, 7]

In millets, dormancy can be naturally released through after-ripening during dry storage [8] Baskin & Baskin, 2020). However, the duration required for natural dormancy release may vary considerably among varieties [9] and may not be suitable when seeds need to be tested, processed or marketed soon after harvest [10]. Several physical, physiological and chemical methods have been used to break seed dormancy, including pre-chilling, specific thermal exposures, alternating temperature treatment, soaking, scarification, treatment with potassium nitrate, gibberellic acid, ethylene-releasing compounds and other growth regulators. The selection of an appropriate dormancy-breaking treatment is based on its effectiveness, practicality, cost, safety and compatibility with routine seed testing procedures. A suitable method should enhance germination of dormant but viable seeds without causing injury or artificial enhancement of weak seeds. Hence, assessing dormancy behaviour and standardising efficient dormancy-breaking methods are essential for sorghum, cumbu and ragi seeds entering the seed supply chain.

The present investigation was therefore undertaken with the objectives of (i) characterising and comparing the dormancy status of cumbu, ragi and sorghum varieties through standard germination, tetrazolium viability and fresh-ungerminated-seed (FUS) estimation, (ii) quantifying total phenolic content as a plausible biochemical correlate of dormancy, and (iii) identifying, among seven candidate treatments, the most effective dormancy-breaking treatment(s) for the dormant varieties.

2. MATERIALS AND METHODS

2.1 Plant material

Freshly harvested seeds of nine varieties belonging to three crops were used: cumbu/pearl millet – V1 and V2; ragi/finger millet – V3, V4 and V5; and sorghum – V6, V7, V8 and V9. All seed lots were harvested at physiological maturity, sun-dried to safe moisture content, cleaned, and used for testing.

Crops	Varieties
Cumbu (V1, V2)	CO 9, CO 10
Ragi (V3, V4, V5)	C0 15, ATL 1, ATL 2
Sorghum (V6, V7, V8, V9)	CO 32, CO 34, K 12, K 13

2.2 Standard germination test

Germination percentage was recorded for each variety following the International Seed Testing Association (ISTA) rolled-towel (paper towel) method under laboratory conditions, using three replicates per variety, with normal seedlings counted at the end of the prescribed test period.

2.3 Tetrazolium (TZ) viability test

Seed viability was estimated independently of germination using the 2,3,5-triphenyl tetrazolium chloride (TZ) staining test, which reveals living tissue through a red-pink formazan stain, allowing viable but dormant seeds to be distinguished from dead seeds.

2.4 Fresh ungerminated seed (FUS) count

At the termination of the standard germination test, seeds that remained firm, clean and imbibed but had not produced a normal seedling were recorded as fresh ungerminated seeds (FUS) and expressed as a percentage of the seeds set for test, serving as a direct index of dormancy intensity.

2.5 Total phenol estimation

Total phenolic content of the seed extract was estimated colourimetrically using the Folin-Ciocalteu method and expressed as mg/g on a fresh/dry weight basis, as a biochemical marker frequently associated with germination-inhibitory activity in dormant seeds.

2.6 Dormancy-breaking treatments

Because cumbu (V1, V2) and ragi (V3, V4, V5) showed pronounced dormancy in the initial screening while the sorghum varieties did not, these five dormant varieties were carried forward into a dormancy-breaking test comprising an untreated control (T0) and six pre-sowing treatments (T1-T5) (Table 1) representative of the classes commonly used to relieve physiological and seed-coat-imposed dormancy in millets.

Table 1. Dormancy breaking treatment details

Treatment	Treatment details	Treatment concentration	Treatment duration
T_0	Control (without treatment)	-	-
T_1	KNO_3	0.2%	3 hrs
T_2	GA_3	200 ppm	1 hr
T_3	Salicylic acid	100 ppm	30 min
T_4	Hot water treatment	60˚C	4 min
T_5	Dry heat treatment (Hot air oven method)	40˚C	15 mins
T_6	Dry heat treatment (Hot air oven method)	40˚C	30 mins

2.7 Experimental design and statistical analysis

All experiments were laid out in a factorial CRD as appropriate, with data subjected to analysis of variance (ANOVA). Treatment means were compared using Duncan's Multiple Range Test (DMRT); means sharing a common letter are not significantly different at p = 0.05. Critical Difference (C.D.) at 5% probability and Standard Error of difference (SE(d)) are reported for each character.

3. Results

3.1 Germination Percentage:

Germination percentage differed markedly and significantly among the nine varieties with a grand mean of 42.22%. Sorghum varieties recorded uniformly high germination (82-94%), whereas both millets showed severe dormancy: cumbu recorded only 8-18% and ragi as little as 0-4%, with V3 and V4 failing to germinate at all under standard test conditions (Table 2).

Table 2. Germination (%) of freshly harvested cumbu, ragi and sorghum varieties.

Crop	Variety	Germination (%)	DMRT Group
Cumbu	V1	8	f
Cumbu	V2	18	e
Ragi	V3	0	h
Ragi	V4	0	h
Ragi	V5	4	g
Sorghum	V6	88	b
Sorghum	V7	82	d
Sorghum	V8	86	c
Sorghum	V9	94	a
Mean = 42.22		**C.D. (5%) = 1.525**	**SE(d) = 0.72**

Means followed by the same letter (DMRT) are not significantly different at p = 0.05.

3.2 Seed viability (TZ test)

In sharp contrast to germination, tetrazolium viability was uniformly high across all nine varieties (96-100%, grand mean 98.56%), and the differences among varieties were not statistically significant (C.D. = NS; SE(d) = 1.491) (Figure 1). This confirms that the very low germination recorded in ragi and cumbu was not due to seed death but to a dormancy block in otherwise fully viable seed.

3.3 Fresh ungerminated seed (FUS) percentage

The proportion of fresh ungerminated seed closely mirrored the germination results and differed significantly among varieties. FUS was high in ragi (88-96%) and cumbu (76-92%) but low in sorghum (8-22%), providing an independent, quantitative confirmation of the dormancy intensity indicated by the germination data (Figure 1).

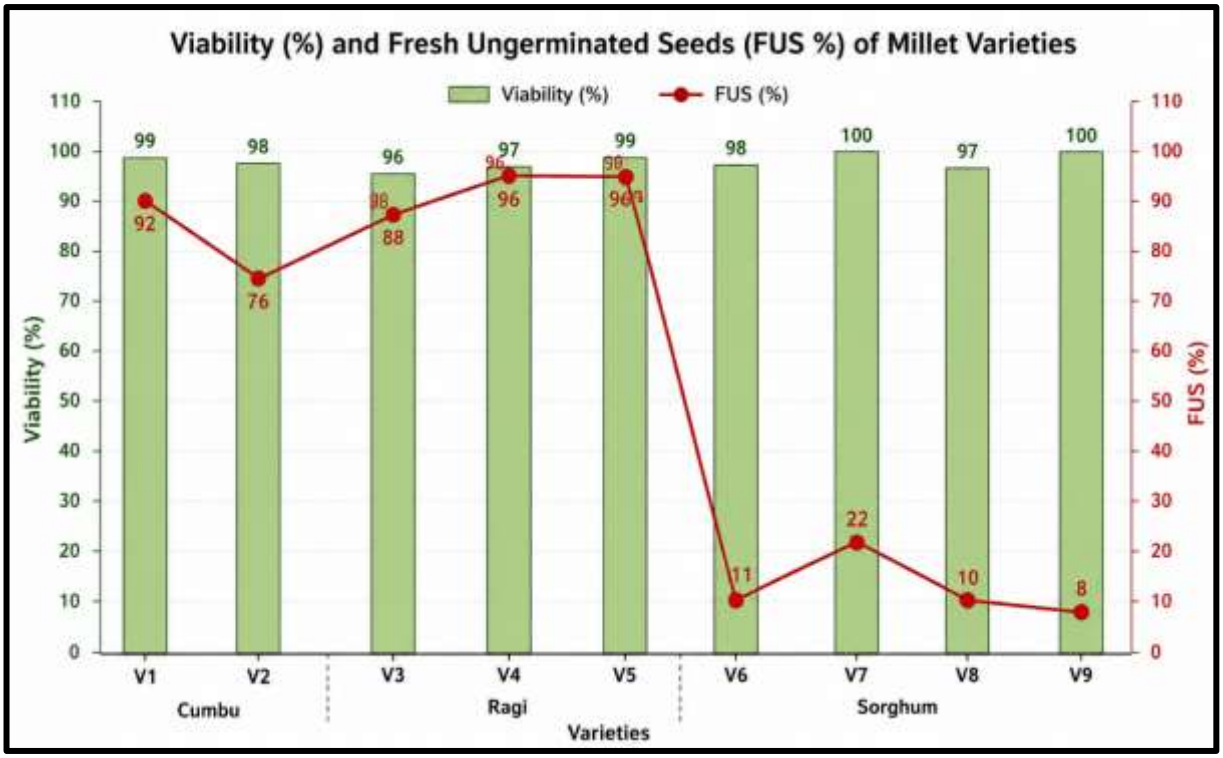

Figure 1. Seed Viability (%) and Fresh Ungerminated Seeds (FUS %) of Freshly Harvested Millet Varieties

3.4 Total phenolic content

Total phenolic content varied significantly among varieties (C.D. = 0.184; SE(d) = 0.087; grand mean 4.97 mg/g). Ragi varieties recorded the highest phenolic content (5.98-6.39 mg/g), followed by two of the four sorghum varieties, V8 and V9 (5.78 and 5.91 mg/g), while cumbu (3.34-3.65 mg/g) and the remaining sorghum varieties, V6 and V7 (3.45 and 3.97 mg/g), were comparatively low (Figure 2). The strongly dormant ragi varieties thus carried the highest phenolic load, consistent with a role for phenolics in reinforcing dormancy in this crop; however, the pattern was not fully consistent within sorghum, where V8 and V9 combined high phenolic content with high germination, suggesting that phenolic accumulation alone does not fully explain dormancy status and that additional factors are also involved.

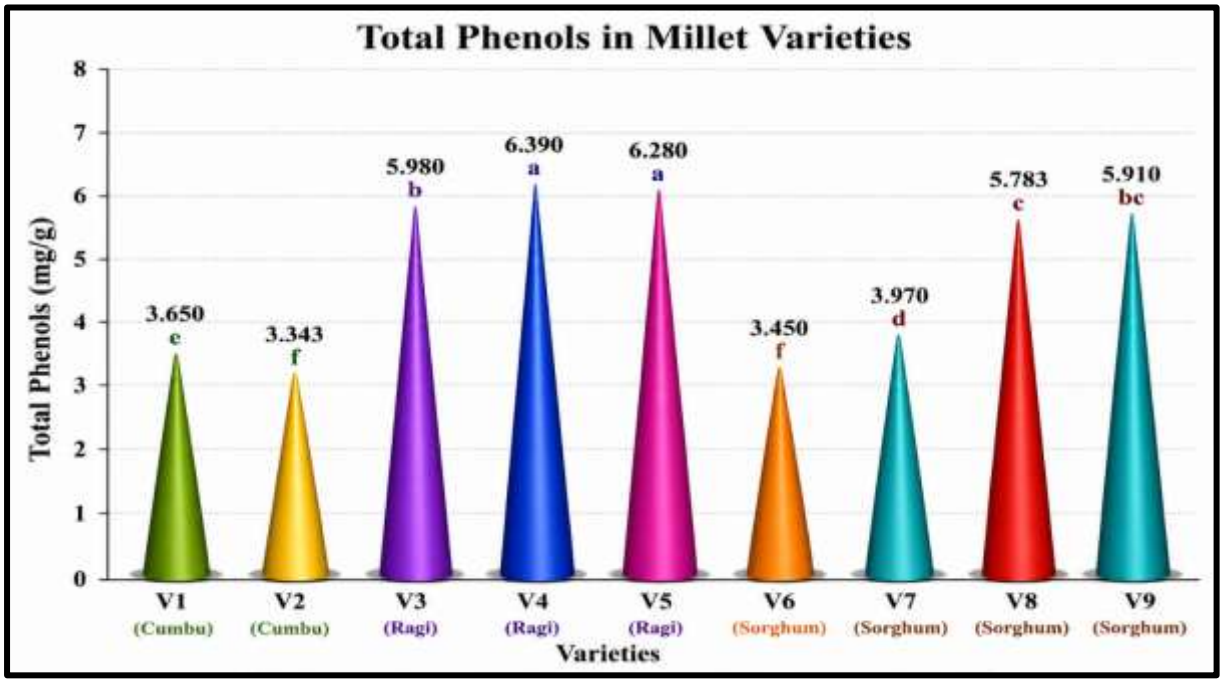

Figure 2. Total Phenol Content in Freshly Harvested Millet Varieties

3.5 Response to dormancy-breaking treatments

Due to the non-dormant nature of the sorghum varieties, the dormancy-breaking experiment was conducted only on the five dormant varieties comprising two cumbu varieties (V1 and V2) and three ragi varieties (V3, V4 and V5) using six dormancy-breaking treatments (T1–T6) along with an untreated control (T0). Analysis of variance revealed that the main effects of variety (V), treatment (T), and their interaction (V × T) were highly significant (V: C.D. = 1.198; T: C.D. = 1.417; V × T: C.D. = 3.169). The untreated control exhibited very low germination across all five varieties (mean 10.0%), confirming the presence of strong seed dormancy. Among the treatments, dry heat treatment for 30 min in a hot air oven (T6) recorded the highest overall mean germination (65.2%), making it the most effective dormancy-breaking treatment. Under T6, germination increased to 80% and 72% in the two cumbu varieties and to 62%, 72%, and 40% in the three ragi varieties. KNO_3 treatment (T1) was the second most effective treatment with an overall mean germination of 58.8% and was particularly effective in ragi, recording 84%, 86%, and 80% germination in V3, V4, and V5, respectively, whereas its effect on cumbu was comparatively lower (24% and 20%). Dry heat treatment for 15 min (T5) also produced a high overall mean germination (57.6%), showing excellent performance in cumbu (64% and 88%) and variable responses in ragi (24%, 36%, and 76%). In contrast, GA_3 (T2), salicylic acid (T3), and hot water treatment (T4) were considerably less effective, recording mean germination values of 25.6%, 23.2%, and 9.6%, respectively, and showed only limited improvement over the untreated control (Table 3).

Table 3. Germination (%) of dormant cumbu and ragi varieties in response to seven dormancy-breaking treatments (T0-T6).

Treatment	Treatment Details	V1 (Cumbu)	V2 (Cumbu)	V3 (Ragi)	V4 (Ragi)	V5 (Ragi)	Mean
T0	Control (without treatment)	14	28	0	0	8	10.00
T1	KNO_3	24	20	84	86	80	58.80
T2	GA_3	36	18	12	38	24	25.60
T3	Salicylic acid	40	24	28	8	16	23.20
T4	Hot water treatment	4	12	16	12	4	9.60
T5	Dry heat treatment 15 mins (Hot air oven method)	64	88	24	36	76	57.60
T6	Dry heat treatment 30 mins (Hot air oven method)	80	72	62	72	40	65.20
Mean		**37.43**	**37.43**	**32.29**	**36.00**	**35.43**	**35.71**

C.D. (5%): Variety (V) = 1.198, Treatment (T) = 1.417, V × T = 3.169. SE(d): V = 0.599, T = 0.709, V × T = 1.586.

DISCUSSION

The combined evidence from germination, TZ viability and FUS testing establishes unambiguously that the poor germination observed in freshly harvested cumbu and, especially, ragi seed lots is a manifestation of true seed dormancy rather than seed non-viability. Viability remained at or above 96% in every variety irrespective of crop, while germination ranged from as low as 0% (ragi V3, V4) to 94% (sorghum V9), and FUS values tracked the germination deficit almost variety-for-variety. This pattern is consistent with the well-documented tendency of small millets, and finger millet in particular, to display strong innate dormancy immediately after harvest, which gradually declines during dry after-ripening in storage. Similar observations by Mane et al. (2025) and Dubey et al. (2025) demonstrated that low germination in freshly harvested millet seeds reflects innate post-harvest dormancy, which is progressively alleviated through after-ripening and dormancy-breaking treatments. The findings collectively indicate that post-harvest physiological dormancy is a common characteristic of millets [1, 11].

The correlation of high phenolic content with high dormancy of ragi (high phenol varieties, V4 and V5 showed the least response with ragi entries in certain treatments) agrees with the widely reported effect of phenolics as germination inhibitors, which require leaching out, degradation or bypassing before germination is allowed to occur. The positive correlation between high phenol content and low germination rates is in agreement with what Delouche et al. (1964) observed [5], that phenolics are natural germination inhibitors which need to be leached, degraded or otherwise removed before germination could occur. The comparatively high phenolic content of two sorghum varieties (V8 and V9) coupled with high germination, however, suggests that phenolic load is not the only factor controlling dormancy across species, and that different species-specific thresholds, balance of inhibitory phenolics and promotive hormones (gibberellins), and possibly differences in seed-coat/pericarp anatomy all contribute to determining the net dormancy outcome. Interactions among biochemical inhibitors,

hormonal signalling, species-specific dormancy mechanisms and seed structural traits determine dormancy status [12].

The differential response to dormancy-breaking treatments is of immediate practical significance to seed technologists. The superiority of a 30-min dry heat treatment (T6) across all five dormant varieties indicates a common component of dormancy in both cumbu and ragi that can be removed by this treatment, likely an after-ripening phenomenon. The notable performance of all the dormant varieties under dry heat treatment (T6) further suggests that controlled dry heat is an effective dormancy-breaking treatment which can overcome common physiological and physical dormancy barriers of dormant seeds in accordance with the concept presented by [13]. The results suggest that the two millets differ in the main mechanism of their dormancy (embryo/physiological dormancy in ragi and a possibly higher level of seed-coat or inhibitor dormancy in cumbu) and thus require different approaches to breaking dormancy (mechanical in ragi and possibly mechanochemical in cumbu). The treatment with KNO_3 (T1) is also advantageous in ragi, as evidenced by the study that nitrate treatment for dormancy release involves water uptake ability, antioxidative metabolism, and phytohormone regulation, which facilitate germination [14]. In contrast, the better performance of dry heat treatment 30 mins (T6) was consistent with results reported by Zomer et al. (2022), who noted that the higher the temperature, the more likely that the seed dormancy threshold will be achieved, and thermal cues are important for breaking seed dormancy in responsive species [15].

Not all commonly recommended dormancy breaking treatments were effective for all the genotypes as shown by the inferior performance of GA3, Salicylic acid and Hot water treatment (T2, T3 and T4); therefore, it is imperative to validate each of these treatments for the individual genotype before implementing it as an operational treatment in a seed-testing or certification programme [1].

5. CONCLUSION

This study demonstrated that freshly harvested cumbu and ragi seed lots possess strong seed dormancy, as evidenced by high seed viability coupled with very low germination and high percentages of fresh ungerminated seeds (FUS), whereas the sorghum varieties evaluated were essentially non-dormant. The higher phenolic content observed in ragi varieties, together with their marked response to potassium nitrate treatment, suggests that physiological dormancy plays a major role in regulating germination, while cumbu exhibited a stronger response to thermal after-ripening treatments. Among the seven treatments evaluated, dry heat treatment for 30 min (T6) emerged as the most effective and consistent dormancy-breaking treatment across both dormant crops, recording the highest overall mean germination. Potassium nitrate treatment (T1) proved particularly effective for ragi, whereas dry heat treatment for 15 min (T5) showed excellent performance in cumbu and may be considered where crop-specific optimisation is desired. These findings provide practical, evidence-based recommendations for seed technologists, seed testing laboratories, and breeders by demonstrating that dormancy-breaking treatments should be selected according to the dormancy characteristics of the crop and variety rather than applying a single generic protocol across all cereal species.

6. Future Prospects

Future work should (i) characterise the hormonal profile (ABA:GA ratio) of dormant versus non-dormant genotypes to clarify the physiological basis of the crop differences observed here; (ii) extend the phenolic analysis to individual phenolic compounds (e.g., HPLC fingerprinting) to identify which specific compounds are causally linked to dormancy rather than merely co-occurring with it; (iii) evaluate the after-ripening kinetics of ragi and cumbu during normal dry storage, to determine whether natural after-ripening alone, without chemical treatment, is sufficient for certification-grade germination within an agronomically useful timeframe; and (iv) validate the dormancy-breaking treatments identified here across a wider set of varieties/hybrids and multiple seed lots/harvest seasons, and under actual field emergence conditions, to confirm that laboratory gains in germination translate into improved and more uniform field stand establishment.

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