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Electrical Conductivity as a Quantitative Indicator of Membrane Integrity and Viability in Aged Rapeseed and Mustard Seeds

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Abstract:- Seed quality assessment is essential for ensuring optimal agricultural productivity, particularly in oilseed crops like rapeseed and mustard. This study investigates electrical conductivity (EC) as a quantitative indicator of membrane integrity and viability in six Brassica varieties, comparing fresh and aged seed samples. A factorial randomized block design was employed, testing fresh seeds (harvested in the previous season) and aged seeds (stored for 24 months) under controlled conditions. EC measurements were conducted for assessing ion leakage as a reflection of membrane degradation. The results revealed a significant increase in EC values for aged seeds across all varieties, with fresh seed values ranging from 49.50 µS (Potsangbam Yella) to 99.75 µS (TS-38), while aged seed values increased to 101.50 µS (Potsangbam Yella) and 145.00 µS (TS-38), indicating a marked deterioration of membrane integrity. The average EC for fresh seeds was 65.83 µS, compared to 113.37 µS for aged seeds, highlighting substantial membrane damage in aged samples. Correlating with lower germination rates and vigour indices, the EC values were found to effectively predict seed viability. Specifically, germination rates of fresh seeds were significantly higher (up to 90%) compared to aged seeds, where the germination rate decreased by 25-40% depending on the variety. Stress tests further validated these findings, with fresh seeds (EC ≤ 70 µS) showing over 75% germination under accelerated aging and cold stress conditions, whereas aged seeds (EC ≥ 100 µS) exhibited reduced germination (< 50%). This study confirms EC as a rapid, reliable, and non-destructive tool for assessing seed quality and predicting viability loss, supporting its integration into seed quality control and breeding programs aimed at improving storage resilience and seed longevity.

Keywords:- *Electrical Conductivity; Seed Viability; Membrane Integrity; Brassica Spp; Seed Aging; Germination; Vigour Index; Storage Resilience.*

I. INTRODUCTION

The assessment of seed quality is an important factor in ensuring successful crop production, particularly in oilseed crops such as rapeseed and mustard. The viability and vigour of seeds directly influence the establishment of healthy plants, which in turn affects agricultural productivity (Hampton, 1995). As seeds age, the physiological processes that maintain their integrity deteriorate, resulting in reduced germination, vigour, and overall performance. A key aspect of this decline is the damage to the seeds cellular membranes, which leads to the leakage of ions and other solutes. This damage can be effectively quantified by measuring the electrical conductivity (EC) of seed leachates, offering a non-destructive, rapid, and reliable means of evaluating seed quality (McDonald & Wilson, 1979).

Several studies have demonstrated the correlation between membrane permeability and seed quality during aging, indicating that increased membrane damage is linked to higher EC values (Veselova & Veselovsky, 2003). The electrical conductivity method has gained popularity due to its simplicity and efficiency in detecting subtle changes in seed integrity that may not be apparent through conventional germination tests. For oil-rich seeds, such as those from Brassica species, the EC test has been shown to be a robust tool for predicting seed viability and vigor (Gugel & Falk, 2006). Specifically, in rapeseed and mustard, EC testing has proven effective in differentiating between seeds of varying quality, providing valuable insights into their potential for successful germination under various environmental conditions (Jose & Francisco, 2019). This research aims to evaluate the electrical conductivity of aged rapeseed and mustard seeds, assessing its relationship to membrane integrity and overall seed viability. And develop more efficient methods for seed evaluation and the enhancement of storage strategies for improving seed longevity.

II. MATERIAL AND METHODS

➤ *Experimental Site and Conditions*

The study was conducted at the experimental field of Pandit Deen Dayal Upadhyay Institute of Agricultural Sciences, Manipur, during the Rabi season of 2018–2019. Laboratory analyses were performed at the ICAR Seed Technology Laboratory, NEHR, Lamphelpat, Manipur. The site features a clay-loam soil with slightly acidic properties (pH 6.28), low electrical conductivity (0.05 dSm^{-1}), and moderate levels of available nitrogen, phosphorus, and potassium. Climatic conditions during the study included a

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cool winter (minimum temperature of 5.5°C) and a warm summer (maximum temperature of 32.5°C), with an average annual rainfall of 1467.5 mm.

- *Experimental Design and Seed Materials*

The experiment adopted a factorial randomized block design with four replications. Two categories of seeds—fresh and 24-month-aged—were evaluated across six rapeseed and mustard varieties, including M-27, TS-36, TS-38, PM-28, Potsangbam Yella, and Kakching Yella. Field plots measuring 4 m × 3 m were arranged with a row-to-row spacing of 30 cm and plant-to-plant spacing of 15 cm. Seed quality assessments followed ISTA (2019) protocols for germination, vigour index, and moisture content, while physiological traits, such as plant height and yield, were also measured.

- *Electrical Conductivity and Membrane Integrity Assessment*

Electrical conductivity (EC) was used as a key indicator of seed membrane integrity. Following McDonald and Wilson's (1979) protocol, 100 seeds were soaked in 100 mL deionized water for 24 hours at room temperature, and the leachate's EC was measured. Accelerated aging and cold tests were conducted to evaluate seed viability under stress conditions, while nitrogen, potassium, and calcium content in seeds were determined using standard methods, including Kjeldahl digestion and flame photometry. Statistical analysis using ANOVA determined treatment effects with significance set at $p<0.05$.

III. RESULT

The analysis of electrical conductivity (EC) values and membrane leakage provides insight into the degree of membrane deterioration and seed aging in rapeseed and mustard varieties. As shown in **Table-1**, EC values were significantly higher in aged seeds across all varieties, with fresh seed values ranging from 49.50 µS in Potsangbam Yella to 99.75 µS in TS-38, while aged seed values increased from 101.50 µS in Potsangbam Yella to 145.00 µS in TS-38. The average EC values across all varieties were 65.83 µS for fresh seeds and 113.37 µS for aged seeds. This marked increase in EC, particularly in TS-38 and Potsangbam Yella, highlights greater membrane deterioration and heightened ion leakage in these varieties. Fresh seeds, by contrast, demonstrated much lower EC values, reflecting intact membrane integrity and minimal electrolyte leakage. These results affirm a direct association between EC and membrane integrity, validating EC as a reliable indicator of seed aging and viability loss.

The data further indicate that germination rates and vigor indices were significantly higher in fresh seeds compared to aged seeds, with varieties PM-28 and M-27 showing superior performance, exhibiting high physiological quality. The germination and vigor indices were particularly strong in these fresh samples, in contrast to the marked reductions observed in TS-38 and Potsangbam Yella aged seeds. This correlation between low EC values (62.25 µS for PM-28 and 58.25 µS for M-27 in fresh seeds) and high germination and vigor indices underscores the reliability of EC in evaluating seed quality. Aged seeds, such as TS-38 with an EC of 145.00 µS and Potsangbam Yella with 101.50 µS, demonstrated reduced viability, with lower germination rates and vigor indices, further confirming that increased EC corresponds to declining seed quality.

The study's stress tests, including accelerated aging and cold conditions, underscore the predictive capability of EC in assessing seed resilience under environmental challenges. Fresh seeds from varieties TS-36 and PM-28 exhibited strong resilience, achieving over 75% germination after exposure to these stress conditions. By contrast, aged seeds with elevated EC values, particularly TS-38 (145.00 µS) and Kakching Yella (101.75 µS), showed lower germination rates, indicating reduced viability and robustness under stress. This inverse relationship between EC and performance in stress tests supports EC's role as a practical metric for predicting long-term seed viability under variable storage conditions.

Figure-1 and Plate 1 illustrate the EC testing method, emphasizing its practical application in assessing seed membrane integrity. Routine EC testing offers a rapid, non-invasive method for evaluating seed quality, serving as a predictive tool for potential nutrient loss in seeds. These findings advocate for the adoption of EC as a standardized diagnostic tool in seed viability assessments, with significant implications for breeding programs focused on improving seed storage resilience. Regular EC testing could enable seed producers to effectively monitor membrane integrity, improve quality control, and make informed decisions on genotype selection based on storage longevity, ultimately supporting sustainable agricultural practices.

IV. DISCUSSION

The results of this study underscore the utility of electrical conductivity (EC) as a reliable metric for assessing membrane integrity and seed viability in rapeseed and mustard varieties. The significant increase in EC values observed in aged seeds across all varieties, particularly in TS-38 and Potsangbam Yella, suggests that membrane deterioration due to aging induces substantial ion leakage. These findings align with previous studies, such as those by Mumtaz et al. (2003) and Rina and Wahida (2008), who reported similar EC trends with aging in pea and soybean seeds. The higher EC values in aged seeds point to oxidative damage compromising membrane structure, thus releasing cellular ions into the surrounding medium. This process of ion leakage directly impacts seed viability, making EC a valuable indicator for monitoring seed aging.

The observed variability in EC responses among genotypes also reveals a genotype-dependent resilience to aging, as seen in the lower EC increases in varieties like Potsangbam Yella compared to the notably high EC in TS-38. Such differences may be attributed to factors like lipid composition, antioxidant defense mechanisms, or seed coat integrity, as suggested by Hussein et al. (2012) in maize seeds. These genotype-specific differences highlight the importance of considering genetic diversity in seed aging studies, as certain genotypes may possess inherent traits that delay membrane deterioration, improving storability and longevity.

Additionally, the correlation between low EC values and high germination rates and vigor indices in fresh seeds, notably in PM-28 and M-27, underscores EC's potential as a predictor of seed quality. Lower EC values in fresh seeds correlate with better membrane integrity, which translates into higher viability, suggesting that routine EC measurement could serve as an efficient tool for assessing seed quality pre-storage. Furthermore, the elevated EC values in aged seeds correlate with poorer performance under accelerated aging and cold stress tests, reinforcing EC's potential as a predictive metric for stress resilience and long-term viability.

V. CONCLUSION

This study demonstrates that electrical conductivity (EC) serves as a reliable and quantitative indicator of membrane integrity and seed viability in aged rapeseed and mustard seeds. The findings reveal a strong correlation between elevated EC values and membrane deterioration, highlighting how seed aging increases ion leakage due to oxidative damage to cell membranes. Among the varieties tested, significant differences in EC were observed, with TS-38 exhibiting the highest EC in aged seeds, while Potsangbam Yella showed comparatively lower values. This variation underscores a genotype-dependent response to aging, suggesting that genetic factors such as lipid composition, seed coat integrity, and antioxidative mechanisms may influence a seed's ability to maintain membrane stability over time. Such insights into genetic resilience are valuable for improving seed longevity through targeted breeding.

The study also affirms EC as a valuable tool for evaluating seed quality. Fresh seeds with low EC values were associated with higher germination rates and vigour indices, particularly in PM-28 and M-27 varieties, indicating that lower ion leakage reflects better physiological health and viability. The clear inverse relationship between EC and germination performance highlights EC's potential as a predictor of seed quality, allowing for rapid and non-destructive viability assessments that could enhance seed storage management practices.

Moreover, the study's stress tests underscore EC's utility beyond simple viability assessment, showing its value in predicting seed resilience under environmental stresses such as accelerated aging and cold conditions. Fresh seeds with lower EC values displayed higher germination rates even after stress exposure, while aged seeds with elevated EC struggled under similar conditions. This suggests that EC can serve as an indicator of long-term seed performance, making it especially relevant for producers and researchers seeking to optimize seed quality under variable storage and environmental conditions.

The implications of these findings are significant for agriculture and seed science. Routine EC testing offers a practical, efficient method for assessing seed health, enabling seed producers to monitor aging effects in storage, identify potential declines in seed quality, and prevent the distribution of compromised seeds. Additionally, incorporating EC assessments into breeding programs could facilitate the development of storage-resilient varieties by selecting for genotypes that exhibit lower EC increases over time. Such varieties would contribute to improved seed longevity, reducing post-harvest losses and supporting sustainable agricultural practices.

In summary, this study supports the use of EC as a standardized diagnostic tool in seed viability assessment, with applications in quality monitoring, breeding, and storage management. Given its accuracy and efficiency, EC testing could become an essential component in protocols for seed health assessment, enabling the agricultural sector to improve seed quality control, optimize inventory, and enhance crop resilience through better management of seed viability

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Table 1 Effect of Ageing on Electrical Conductivity (µS) of Seeds in Different Varieties of Rapeseed and Mustard.

Varieties	**Electrical conductivity (µS)**		
	Fresh seed	**Aged seed**	**Mean**
PM 28	62.25	114.00	88.12
M 27	58.25	103.00	80.62
TS 36	64.75	115.00	89.87
Kakching yella	60.50	101.75	81.12
Potsangbam yella	49.50	101.50	75.50
TS 38	99.75	145.00	122.37
Mean	**65.83**	**113.37**	
Factor	**A**	**B**	**A X B**
SE(m)	**1.924**	**1.111**	**2.721**
C.D (0.5)	**5.561**	**3.211**	**7.857**

Mean of four replications in each treatment, A-Varieties, B-Condition (Fresh and Aged seed)

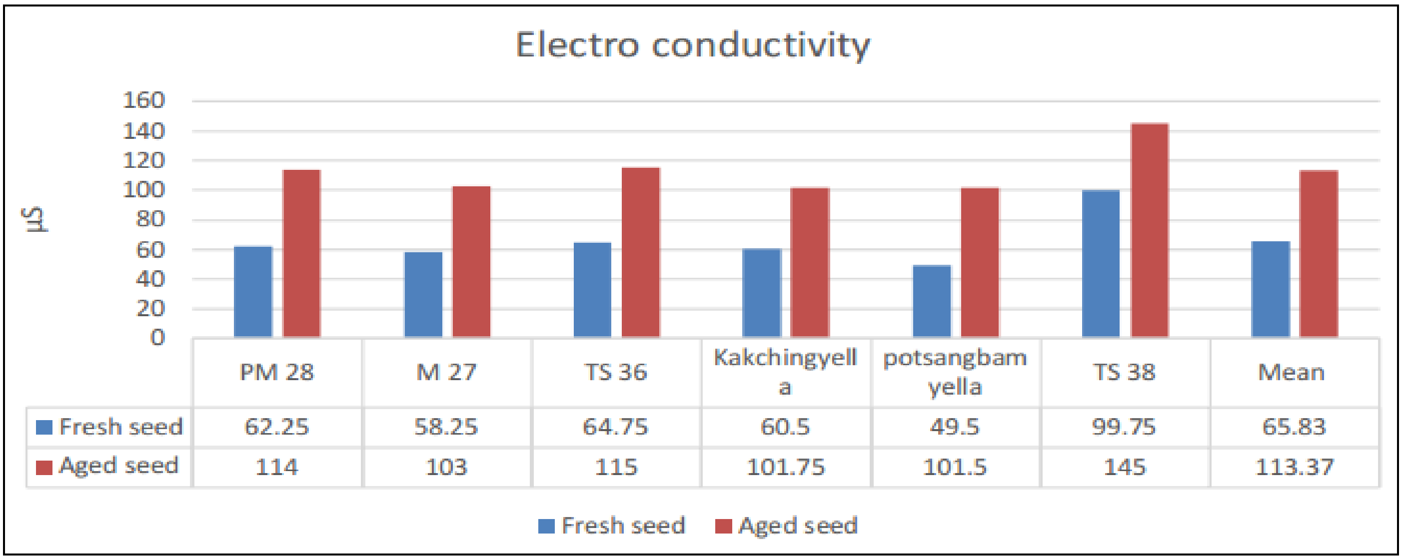

Fig 1 Effect of Ageing on Electrical Conductivity of Seeds in Different Varieties of Rapeseed and Mustard

Plate 1 Highlights the EC Testing Method, Under scoring its Role as a Practical Tool in Monitoring Seed Membrane Integrity and Predicting Nutrient Loss