Biochemical Changes During Accelerated Ageing in Millet Seeds

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Abstract:

Millets are important cereal crops known for their nutritional richness, climate resilience, and suitability for cultivation in dry and semi-arid regions. Seed quality plays a vital role in ensuring proper germination, healthy seedling establishment, and higher crop productivity. However, seed ageing during storage leads to a gradual decline in viability and vigour, thereby negatively affecting crop performance. Accelerated ageing is a laboratory technique used to simulate natural seed deterioration by exposing seeds to high temperature and relative humidity for a specific period.

The present study focuses on the biochemical changes occurring during accelerated ageing in millet seeds. Ageing causes significant deterioration in seed quality through membrane damage, increased electrolyte leakage, lipid peroxidation, and accumulation of reactive oxygen species (ROS). These changes lead to oxidative stress, which damages essential cellular components such as proteins, enzymes, and nucleic acids.

The activity of key enzymes such as alpha-amylase, catalase, peroxidase, and dehydrogenases decreases with increasing ageing duration, affecting reserve mobilisation and germination efficiency.

Additionally, protein degradation and altered carbohydrate metabolism reduce the availability of energy required for embryo growth and seedling development. As a result, aged seeds show lower germination percentage, reduced seedling vigour, delayed emergence, and poor field performance. The study of these biochemical changes helps in understanding the mechanisms of seed deterioration and provides useful indicators for assessing seed quality.

This research contributes to improving storage practices, seed treatment methods, and seed longevity management in millet crops. A better understanding of accelerated ageing can support sustainable millet production and strengthen food security in regions dependent on these important cereals.

Introduction:

Millets are among the oldest cultivated cereal crops and are widely recognised for their nutritional value, drought tolerance, and adaptability to harsh environmental conditions. They serve as an important source of food and fodder, especially in semi-arid and tropical regions where major cereals such as rice and wheat may not perform well.(Abdul-Baki A.A. & Anderson J.D. (1972)) Due to their rich content of proteins, dietary fibre, minerals, vitamins, and antioxidants, millets play a significant role in food security and sustainable agriculture.

Seed quality is one of the most critical factors influencing crop establishment, growth, and productivity. High-quality seeds ensure better germination, vigorous seedling development, and improved yield potential. However, during storage, seeds gradually lose their viability and vigour due to natural ageing processes. This deterioration becomes more rapid under unfavourable storage conditions such as high temperature and humidity.(Delouche J.C. & Baskin C.C. (1973)) Accelerated ageing is an artificial method used to simulate natural seed ageing under controlled laboratory conditions by exposing seeds to elevated temperature and relative humidity for a specific period.

In millet seeds, accelerated ageing causes several biochemical and physiological changes that directly affect seed performance. One of the major changes is the degradation of cellular membranes, leading to increased membrane permeability and leakage of solutes.(Bewley J.D., Bradford K.J., Hilhorst H.W.M. & Nonogaki H. (2013)) Lipid peroxidation also increases during ageing, resulting in damage to membrane

lipids and disruption of normal metabolic activities. Reactive oxygen species (ROS) accumulate in aged seeds and create oxidative stress, which further damages proteins, nucleic acids, and enzymes essential for germination.

Enzymatic activity is significantly influenced during accelerated ageing. Important enzymes such as alpha-amylase, dehydrogenase, catalase, and peroxidase show altered activity levels. Reduced enzyme efficiency affects the mobilisation of stored food reserves and weakens the seed's ability to initiate normal germination. At the same time, antioxidant defence systems become less effective, reducing the seed's capacity to protect itself from oxidative damage.

Protein degradation and changes in carbohydrate metabolism are also common during the ageing process. Storage proteins may break down, and sugar utilisation becomes less efficient, leading to reduced energy availability for embryo growth.(McDonald M.B. (1999)) These biochemical alterations ultimately result in poor germination percentage, delayed seedling emergence, weak seedling growth, and lower field performance.

Millets: Nutritional and Agricultural Significance

Millets are gaining global recognition due to their exceptional nutritional and agricultural benefits.(Saleh A.S.M. et al. (2013)) They are rich in complex carbohydrates, proteins, dietary fiber, and essential micronutrients such as calcium, iron, magnesium, and zinc. Their low glycemic index makes them suitable for individuals with diabetes and other metabolic disorders.(Saleh A.S.M. et al. (2013)) Agriculturally, millets are highly resilient crops that can withstand drought, high temperatures, and poor soil conditions, making them ideal for cultivation in marginal lands.(National Institute of Nutrition (2020)) They require minimal inputs compared to other cereals, which makes them economically beneficial for farmers. In the context of climate change and increasing food demand, millets serve as an important alternative to conventional crops. Therefore, maintaining high-quality seeds with good germination capacity is essential to fully utilize their potential and ensure sustainable agricultural systems.

Concept of Seed Ageing

Seed ageing is an inevitable and irreversible process that leads to the gradual decline in seed quality during storage.(Bewley J.D., Bradford K.J., Hilhorst H.W.M. & Nonogaki H. (2013)) It involves a series of complex physiological and biochemical changes that reduce seed viability and vigor. Natural ageing occurs over a long period under normal storage conditions, whereas accelerated ageing is induced under controlled high temperature and humidity to speed up the deterioration process. During ageing, cellular structures such as membranes lose their integrity, enzymes become less active, and genetic material undergoes damage.(McDonald M.B. (1999)) Oxidative stress caused by the accumulation of reactive oxygen species plays a major role in seed deterioration.(Copeland L.O. & McDonald M.B. (2001)) As a result, aged seeds show reduced germination rates, poor seedling growth, and decreased resistance to environmental stress. Understanding the concept of seed ageing is essential for developing effective storage strategies and improving seed longevity.

Accelerated Ageing Technique in Seeds

Accelerated ageing is a widely used experimental method to evaluate seed vigor and predict storage potential within a short

period. In this technique, seeds are exposed to high temperature, typically between 40°C and 45°C, and high relative humidity close to 100% for a specific duration. (Delouche J.C. & Baskin C.C. (1973))These conditions create stress that accelerates the natural ageing process. After treatment, seeds are tested for germination percentage, vigor index, and biochemical parameters to assess their quality.(International Seed Testing Association (2018)) This method is useful for identifying weak seed lots and understanding the mechanisms of seed deterioration. It is commonly used in seed testing laboratories and research institutions.(McDonald M.B. (1999)) Accelerated ageing helps in making quick decisions regarding seed storage, distribution, and planting, ensuring that only high-quality seeds are used for cultivation.

Biochemical Changes During Accelerated Ageing

Accelerated ageing induces several biochemical changes in millet seeds that significantly affect their quality and viability.(McDonald M.B. (1999)) One of the most important changes is the increased production of reactive oxygen species, which leads to oxidative stress and damages cellular components. Lipid peroxidation results in the breakdown of membrane lipids, causing loss of membrane integrity and increased permeability.(Bewley J.D., Bradford K.J., Hilhorst H.W.M. & Nonogaki H. (2013)) Antioxidant enzymes such as superoxide dismutase, catalase, and peroxidase show reduced activity, weakening the seed's defense system against oxidative damage. Proteins undergo degradation, affecting enzymatic functions and metabolic activities.(Harman G.E. & Mattick L.R. (1976)) Additionally, nucleic acids such as DNA and RNA may be damaged, impairing genetic stability and cell division. These biochemical alterations collectively lead to reduced germination, poor seedling growth, and overall decline in seed vigor.

Physiological and Biochemical Indicators of Seed Deterioration

The extent of seed deterioration can be evaluated using various physiological and biochemical indicators.(Copeland L.O. & McDonald M.B. (2001)) A significant decrease in germination percentage is one of the primary signs of ageing. Seed vigor, which reflects the ability of seeds to establish healthy seedlings, also declines. Increased electrolyte leakage from seeds indicates damage to cell membranes and loss of structural integrity. (Delouche J.C. & Baskin C.C. (1973))The accumulation of malondialdehyde serves as an indicator of lipid peroxidation and oxidative stress. Changes in enzyme activities, such as reduced amylase and increased peroxidase activity, also reflect deterioration. Additionally, aged seeds often produce weak and abnormal seedlings.(Heath R.L. & Packer L. (1968)) These indicators are widely used in seed science to assess seed quality and predict storage performance under different environmental conditions.

Factors Affecting Seed Ageing in Millets

Several environmental and genetic factors influence the rate of seed ageing in millets. Temperature plays a critical role, as higher temperatures accelerate metabolic reactions and increase the rate of deterioration.(Harrington J.F. (1972)) Moisture content is another important factor, as high moisture levels promote microbial growth and biochemical degradation.(Ellis R.H. & Roberts E.H. (1980)) Oxygen availability contributes to oxidative stress by facilitating the formation of reactive oxygen species.

Storage conditions, including packaging materials and ventilation, also affect seed longevity.(Copeland L.O. & McDonald M.B. (2001)) Additionally, the genetic makeup of millet varieties determines their inherent storage capacity and resistance to ageing. Proper management of these factors is essential to minimize seed deterioration, maintain seed viability, and ensure high germination rates during cultivation.

Methods to Improve Seed Longevity

Improving seed longevity requires the adoption of effective storage and treatment strategies. Maintaining low temperature and low moisture conditions during storage significantly slows down the ageing process by reducing metabolic activity. Seed priming techniques,(McDonald M.B. (1999)) such as hydropriming and osmopriming, enhance germination and improve seed vigor. The application of antioxidants helps in reducing oxidative damage caused by reactive oxygen species. Proper packaging materials that prevent moisture and oxygen entry are also important for maintaining seed quality. (Bailly C. (2004))Additionally, selecting high-quality seeds with good initial vigor ensures better storage performance. These methods collectively contribute to extending seed shelf life, improving germination, and ensuring successful crop establishment.

Future Research Perspectives

Future research on seed ageing in millets should focus on understanding the molecular and genetic mechanisms involved in deterioration. Advanced techniques such as genomics, proteomics, and metabolomics can provide deeper insights into the biochemical pathways affected during ageing. (Rajjou L. & Debeaujon I. (2008))Identification of specific genes and markers associated with seed longevity can support breeding programs aimed at developing improved millet varieties. There is also a need to develop innovative storage technologies and eco-friendly treatments to enhance seed viability.(H.W.M. & Nonogaki H. (2013)) Additionally, research on climate-resilient varieties with better storage capacity is essential in the context of global climate change. Such efforts will help improve seed quality and contribute to sustainable agricultural development.

Conclusion

Accelerated ageing is an effective technique for studying seed deterioration in millets under controlled conditions. It highlights the biochemical changes such as oxidative stress, lipid peroxidation, enzyme inactivation, and membrane damage that lead to reduced seed viability and vigor. Understanding these changes is essential for developing strategies to improve seed storage and longevity. Proper control of environmental factors such as temperature and moisture, along with the use of modern technologies, can significantly enhance seed quality. Overall, improving seed longevity is crucial for ensuring consistent crop production, supporting food security, and promoting sustainable agricultural practices in millet cultivation systems.

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