



AGRI MAGAZINE

(International E-Magazine for Agricultural Articles)

Volume: 03, Issue: 10 (October, 2026)

Available online at <http://www.agrimagazine.in>

© Agri Magazine, ISSN: 3048-8656

Use of HSP on Protecting the Cellular Structure of Seed

*Monika Priyadarshini Swain, Arpita Priyadarsini, N Rusali and Soubhagya Behera

Department of Seed Science and Technology, College of Agriculture, OUAT,
Bhubaneswar, Odisha-751003, India

*Corresponding Author's email: monikaswain0712@gmail.com

During maturation drying, long-term storage, and subsequent rehydration, seeds experience severe cellular stress. Heat shock proteins (HSPs), especially small heat shock proteins (sHSPs), are vital for safeguarding seed cellular structures throughout this drying–storage–rehydration cycle. HSPs avert irreversible protein clumping, stabilize membranes, support cytoplasmic vitrification, and help defend against oxidative stress. Additional HSP categories, such as HSP70, HSP90, HSP100/ClpB, and chaperonins, aid in protein refolding and recovery when seeds rehydrate. HSPs also work together with late embryogenesis abundant (LEA) proteins and soluble sugars as a unified protective mechanism. Their buildup during seed maturation is governed by abscisic acid (ABA) and maturation-related transcription factors, including ABI3, FUS3, and LEC1. Variations in HSP levels correlate with seed ageing, germination, vigour, priming. Thus, HSPs response, and longevity. hold significant potential in seed storage, gene bank conservation, seed invigoration, and breeding aimed at improved stress tolerance and storability.

Keywords: Heat shock proteins, small HSPs, seed longevity, desiccation tolerance, seed vigour, seed storage, LEA proteins, seed priming.

Introduction

Heat shock proteins (HSPs) act as molecular chaperones that protect cells from stress by helping proteins fold correctly and preventing damaged proteins from clumping together. Orthodox seeds stand out among plant tissues for their ability to withstand extreme water loss, often drying from roughly 80–90% water content at early maturity to under 10% at physiological maturity, and then staying viable in this nearly anhydrobiotic state for months, years, or even centuries. This shift is metabolically severe: as water is lost, macromolecular crowding rises sharply, membranes undergo phase changes, and proteins face a high risk of unfolding, misfolding, and irreversible clumping. A seed that fails to shield its proteome and membranes during drying, storage, and later imbibition simply will not survive to germinate. Heat shock proteins (HSPs), a broad superfamily of molecular chaperones originally identified through their response to high temperature, are now recognized as essential, always-present parts of the seed's protective system—not just stress-induced emergency responders. In seeds, HSPs work together with late embryogenesis abundant (LEA) proteins, non-reducing sugars (sucrose, oligosaccharides), and antioxidant systems to maintain cellular structure throughout the maturation- -drying-storage-imbibition cycle.

Need of Seed Protection

Late-seed maturation and desiccation imposes multiple stresses on cells:

1. The loss of the hydrated layers around proteins and membranes that normally promote native conformation.
2. Higher macromolecular crowding which increases the chance of non-specific, aggregation-prone protein–protein interactions.

3. Transition from fluid lamellar phase to gel or non-bilayer (hexagonal) phases with the removal of water and leakage on rehydration due to loss of compartmentalisation.
4. Oxidative stress resulting from production of reactive oxygen species (ROS) as a normal part of electron transport and metabolism, but under low water potential leading to its breakdown.
5. Cytoplasmic vitrification – the cytoplasm turns into a glassy, extremely viscous state – a protection in orthodox seeds, but one that requires the correct folding of proteins and the correct type of sugar to form a stable glass that is not damaging.
6. Any protein that denatures or starts aggregating under these circumstances can nucleate further aggregation and membranes that cannot reorganise properly on partial rehydration will leak solutes, ATP, and ions, typical indication of desiccation damage and loss of seed vigour. At each of these, an HSP steps in.

Classes of Heat Shock Proteins

Small HSPs

HSP100/ClpB

HSP70

HSP90

Chaperonins (HSP60/HSP10, CCT/TRiC)

1.Small HSPs (sHSPs, 15-42 kDa): These are most abundant in dry mature seeds. They inhibit protein aggregation and are found in cytosol and in organelles like mitochondria, plastids, ER and peroxisomes.

2.HSP70: ATP-dependent chaperones which bind and refold damaged or unfolded proteins, or target them for degradation.

3.Proteins: Aid in the folding of proteins and participate in hormone signaling, maturation and protein stability.

4.ATP-dependent disaggregases: HSP100/ClpB, which dissociate protein aggregates and promote recovery during rehydration and germination of seeds.

Chaperonins (HSP60/HSP10 & CCT/TRiC): ATP-dependent machine that furnishes a safe place for correct folding, particularly in mitochondria and plastids.

Mechanisms of structural protection

- Chaperone activity of HSPs: sHSPs bind partially unfolded proteins without ATP, stopping them from aggregating during seed drying. Immediately following imbibition, HSP70/HSP100 refold or degrade such proteins.
- Membrane stabilization: Organelle specific sHSPs stabilize organelle membranes during drying and rehydration which provide protection against leakage and maintain membrane integrity.
- Cytoplasmic vitrification: sHSPs maintain solubility of proteins and help to stabilize the protective glass matrix that forms with sugars and LEA proteins.
- Antioxidant function: Mitochondrial and plastidial sHSPs are involved in minimizing the ROS-mediated oxidative damage during the process of desiccation.
- Interactions with LEA proteins: the co-operating proteins in seed desiccation tolerance are LEA proteins and sHSPs. LEA proteins protect macromolecules and ions and sHSPs prevent protein unfolding and aggregation.

Effect of HSP on the quality, vigour and longevity of seed

1.Storage and longevity: sHSP is reduced as the seeds age, and is correlated with reduced germination in long stored lots; HSP/LEA profiles can be considered as one biochemical indicator of seed lot deterioration, in addition to the traditional vigour test.

2.Over expression of specific seed sHSPs (e.g., rice OsHSP18.2) has been seen to enhance germination percentage and establishment of seedlings under abiotic stress, demonstrating a causal — not just correlative — relationship between seed performance and expression of specific seed sHSPs.

3. The change in HSP and LEA protein profile in commercial seed priming (controlled partial hydration and re-drying) is one of the suggested mechanisms of priming that leads to more rapid, uniform germination.

4. Conservation in the Gene Bank: of interest for the molecular marker is HSP/LEA status as a molecular marker for prioritising the regeneration of ageing accessions in seed banks, which is linked to HSP-mediated protection, in long term dry storage survival.

5. Breeding and biotechnology: HSPs are used as an easily tractable target to enhance stress-tolerant germination and storability in crops stored under poor post-harvest storage conditions or under heat/drought stress establishment.

Development and hormonal Regulation

Seed HSP expression is not only stress-induced, but genetically programmed:

1. Maturation transcription factors (MTFs) ABI3, FUS3, and LEC1 are essential for the normal accumulation of sHSPs, with a reduction of sHSPs in mutants, and a loss of desiccation tolerance in several mutants, directly linking sHSP expression to seed quality outcomes.
2. Signalling by abscisic acid (ABA) is upstream of much of this regulation, and links the expression of HSPs to the broader maturation/dormancy programme, which is already a subject of study in seed scientists for its role in the release of dormancy and germination.
3. Further increase in HSP levels may be possible via classical heat shock transcription factors (HSFs) that bind to heat shock elements if seed maturation occurs when temperatures are higher in the field; maternal environment during seed fill can thus leave a molecular “signature” to influence the performance of subsequent seed lots.
4. It reaches a high level during mid-to-late maturation, remains high in the quiescent dry seed and then drops very rapidly upon germination because desiccation tolerance is no longer needed for the emerging seedling.

Conclusion

Mature drying, dry storage and rehydration pose an extraordinary challenge to seed's proteostatic and membrane stability. A large part of the answer lies in the heat shock proteins, particularly the small HSPs, but also HSP70, HSP90, HSP100/ClpB and chaperonins, which act as ATP independent and ATP dependent chaperones to prevent and reverse protein aggregation, stabilise membrane through phase transitions, assist in cytoplasmic vitrification, and cooperate with LEA proteins and soluble sugars in a broader protective network. They are developmentally programmed through the ABA/LAFL maturation pathway and overlaid with the classical heat-stress regulation pathway, the HSFs. Due to this, the status of HSP is not strictly an academic question but is of very practical importance as a criterion for seed vigour, storage life and stress resistance and is therefore a current research objective in both basic seed biology and applied seed technology/breeding.

References

- Hoekstra, F.A., Golovina, E.A. & Buitink, J. (2001) *Trends in Plant Science* **6**(9): 431-438 - mechanisms of plant desiccation tolerance.
- Kalemba, E.M. & Pukacka, S. (2008) *Environmental and Experimental Botany* **63**:274-280 - LEA and sHSP changes during beech seed storage.
- Kaur, H. et al. (2015) *Frontiers in Plant Science* **6**:713 - OsHSP18.2 and seed vigour/longevity.
- Kotak, S., Vierling, E., Bäumlein, H. & von Koskull-Döring, P. (2007) *Plant Cell* - transcriptional cascade regulating HSPs during Arabidopsis seed development.
- Smolikova, G. et al. (2020) *International Journal of Molecular Sciences* **22**(1): 101 - desiccation tolerance as the basis of long-term seed viability.
- Waters, E., Lee, G. & Vierling, E. (1996) *Journal of Experimental Botany* **47**: 325 - 338 - evolution, structure and function of plant sHSPs.
- Wehmeyer, N. & Vierling, E. (2000) *Plant Physiology* **122**(4): 1099 - 1108.