



Study on seed dormancy status and dormancy-breaking methods in sunflower hybrid COH 3 and parental lines

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Abstract

Seed dormancy in sunflower is a major constraint affecting timely sowing, uniform crop establishment and continuity in seed supply systems. The present investigation was conducted during 2023 at the Department of Seed Science and Technology, Tamil Nadu Agricultural University, Coimbatore, to assess the dormancy status of sunflower hybrid COH 3 and its parental lines COSF 6A and IR 6 and also to identify the effective dormancy-breaking techniques. Freshly harvested seeds were evaluated at 5-day intervals using sand media until maximum germination was attained naturally. The hybrid COH 3 and female parent COSF 6A had a very weak dormancy, which exhibited the maximum germination (94 and 93 %) at 15 days after harvest (DAH), whereas IR 6 attained maximum germination (94 %) at 30 DAH, exhibiting a moderate dormancy. The seeds were subjected to different dormancy-breaking treatments at 5 DAH, viz., soaking in water, 2 % KNO₃, 50 ppm ethrel and dry heat treatment. After 12 hr of soaking the seeds in ambient laboratory conditions (28 ± 2 °C and 65 ± 5 % relative humidity), the seeds were shade-dried and 400 seeds from each treatment were subjected to a germination test in sand medium. Among the dormancy-breaking treatments, the seeds soaked in 50 ppm ethrel for 12 hr recorded the maximum germination percentage in sunflower hybrid COH 3 (93 %) and its parental lines COSF 6A (93 %) and IR 6 (91 %).

Keywords: germination; parental lines; seed dormancy; seed physiology; seed treatment; sunflower

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1. Introduction

Sunflower is one of the important oilseed crops grown throughout the world (1), for its edible oil (38–50 %), vitamins, minerals and dietary fibre that significantly contribute to human health (2). Seed dormancy at harvest is one of the major constraints limiting sunflower productivity (3). Seed dormancy is the property of a seed that prevents its germination under apparently favourable conditions (4). Sunflower seed dormancy is a complex phenomenon in which the embryo, seed coat and endosperm (5, 6), along with the phytohormones, play a major role in the imposition of seed dormancy, depending on the genotype (7), maternal environment (8) and post-harvest environments (9).

Among the various factors that regulate seed germination, the phytohormones abscisic acid (ABA) and gibberellic acid (GA) are considered to be the most important endogenous signals and the balance between ABA and GA is considered to be the decisive factor in determining seed dormancy or germination (10). Abscisic acid positively regulates dormancy induction

and maintenance, while GA promotes seed germination by negatively influencing each other's biosynthesis and signalling pathways (11, 12). Deficiency in ABA during seed development leads to loss of primary dormancy in mature seeds, whereas overexpression of ABA biosynthesis genes increases ABA accumulation and promotes seed dormancy (13). During seed maturation, ABA positively regulates reserve accumulation, inhibits embryo growth and induces desiccation tolerance and primary dormancy. Absciscic acid accumulated in seeds originates from synthesis in both maternal and zygotic tissues and transport from vegetative tissues; however, only ABA produced by zygotic tissues during late maturation stages has a predominant role in dormancy induction (14). Other phytohormones, such as jasmonates (JAs) and auxins, are involved in the regulation of seed dormancy and germination (15).

The genetic potential of any variety can be exploited only when high-quality seeds are used. Prolonged dormancy in cultivated species delays the immediate sowing of the seeds for commercial crop

production and also interferes with proper crop establishment. A balanced level of dormancy and germination is desirable in crop production, as excessive dormancy may result in uneven germination, whereas insufficient dormancy can cause premature germination leading to pre-harvest sprouting (16). This imposes major problem to the seed industry as it requires non-dormant seeds, particularly for counter season markets and to avoid discontinuity in the seed supply chain from breeder seed to certified seed. Further, non-uniformity in field emergence and crop stand due to dormancy will affect subsequent stages of crop growth, limiting yield and economic outcome (4).

Several techniques, starting from hydro priming, hormonal seed treatments and dry heat treatments, were used in sunflower to break dormancy. Ethrel promotes the release of seed dormancy in sunflower by inhibiting the inhibitory effects of ABA, enhancing the activity of protease enzymes and reducing the mechanical constraints imposed by embryonic tissues, thereby facilitating germination (17). Potassium nitrate (KNO_3) contributes to dormancy alleviation by functioning as a physiological signalling compound that enhances metabolic processes during germination. It promotes the generation of reactive oxygen species (ROS) at controlled levels, which improve seed vigour, modify membrane permeability and support early embryonic development, resulting in faster and more uniform germination (4, 18).

COH 3 is a high-yielding sunflower hybrid released in 2018 for cultivation in Tamil Nadu. It has a crop duration of 90–95 days and is well adapted to both rainfed and irrigated conditions. The hybrid records an average seed yield of 2214 kg ha^{-1} and possesses a high oil content of approximately 42 %, resulting in an oil yield of about 716 kg ha^{-1} . In addition, COH 3 exhibits moderate resistance to major diseases such as necrosis, leaf spot and powdery mildew (19). Understanding the mechanisms of dormancy and employing appropriate management practices are essential for ensuring a reliable supply of high-quality seeds for crop production.

2. Materials and Methods

The study was conducted during 2023 at the Department of Seed Science and Technology, Tamil Nadu Agricultural University (TNAU), Coimbatore. Freshly harvested breeder seeds of sunflower hybrid COH 3 and its parental lines (COSF 6A and IR 6) were collected from the Department of Oil Seeds, TNAU, Coimbatore, from the kharif season crop.

Dormancy duration

The seeds were shade-dried to 10 % moisture and stored under ambient laboratory conditions ($28 \pm 2^\circ\text{C}$ and $65 \pm 5\%$ RH) and were subjected to a standard germination test once every five days after harvest (DAH) until dormancy breaks naturally (when the seed germination percentage reaches its maximum) without giving any pre-germination treatment. Based on the

duration of dormancy observed in the present study, the entries were classified as very weak (0–15 days), weak (16–25 days), moderate (26–35 days), strong (36–45 days) and very strong (> 45 days) dormant seeds.

Germination test

The seeds were subjected to a germination test using sand media (20). Four replicates of 100 seeds were sown in the sand medium and kept in the germination room illuminated with fluorescent light, maintained at $25 \pm 2^\circ\text{C}$ and $95 \pm 5\%$ RH. After 10 days, the seedlings were evaluated and the normal seedlings were counted and expressed in percentage.

Dormancy breaking

The seeds of sunflower hybrid COH 3 and its parental lines COSF 6A and IR 6 were subjected to the following treatments 5 DAH. The treatments and their concentrations were selected based on previous studies / International Seed Testing Association (ISTA) technical report describing their effectiveness in breaking seed dormancy in sunflower.

Seed germination (%) =

$$\frac{\text{Number of normal seedlings}}{\text{Total number of seeds sown}} \times 100$$

Treatment details

T₀ - Control

T₁ - Soaking in water for 24 hr

T₂ - Soaking in 2 % KNO_3 for 12 hr

T₃ - Soaking in 50 ppm ethrel for 12 hr

T₄ - Dry heating at 50°C for 5 min

For soaking treatments, a 1 : 1 (w/v) seed-to-solution ratio was followed. After soaking, the seeds were shade-dried. For the dry heat treatment, the seeds were uniformly spread on a tray and incubated in a preheated hot air oven for the specified duration, followed by cooling to room temperature. The treated and untreated (control) seeds were then subjected to a standard germination test.

Statistical analysis

The experimental treatments were arranged in a completely randomised design (CRD) with four replications. Separation of means was based on Duncan's multiple range test (DMRT) with 0.05 probability assessed the significant differences between treatments. Data were subjected to analysis of variance (ANOVA) using SPSS for Windows (SPSS®, Version 22.0. Armonk, New York, USA). Percentage data were arcsine square-root transformed prior to ANOVA to stabilise the variance and the assumptions of normality and homogeneity of variance were assessed.



3. Results and Discussion

Dormancy status

Sunflower seeds exhibit dormancy immediately after harvest (21). The duration of this primary dormancy varies with genotype and maternal environmental conditions (8) and it extends up to several weeks or months (22) creating a huge challenge in the seed supply chain of the seed sector (23). According to Baskin and Baskin (24), sunflower seeds exhibit non deep physiological dormancy, which may arise from intrinsic embryo dormancy and/or coat-imposed dormancy (25).

In the present study, clear genotypic differences were observed among COH 3, COSF 6A and IR 6 in the rate and extent of dormancy, reflecting variation in underlying physiological and molecular mechanisms. The dormancy duration of sunflower hybrid COH 3 and its parental lines COSF 6A and IR 6 was computed as the period from harvest until its germination reached its maximum percentage and also based on the fresh ungerminated seeds (FUS) percentage. Fresh ungerminated seeds are seeds that remain firm and apparently viable at the end of a germination test but fail to produce seedlings (20). Sunflower hybrid COH 3 and COSF 6A reached the maximum germination of 94 and 93 % respectively, at 15 DAH from 71 and 66 % respectively, at 5 DAH. The FUS percentage was also reduced to 0–1 % at 15 DAH in both the lines from 24–25 % at 5 DAH (Tables 1 and 2). In contrast, the maximum germination percentage (94 %) in IR 6 was reached at 30 DAH and the FUS percentage also reduced from 38–0 % only at 30 DAH. Although the minimum germination percentage (70 %) was reached within 10 DAH, the presence of FUS up to 30 DAH in IR 6 led to it being characterised as a medium (26–35 days) dormant variety (Table 3). The results were also consistent with the study in sunflower hybrid KBSH 44, which recorded only 20 % germination at 7 DAH and reached maximum germination of 98.50 % at 60 DAH. Sunflower hybrids Sremac, Dusko, NS-H-111, Velja and Branko, along with the female line of hybrid NS-H-111 and the male lines of hybrids Sremac and Velja, exhibited little or no pronounced seed dormancy at 30 DAH. In contrast, the female lines of hybrids Sremac, Duško, Velja and Branko, as well as the male lines of hybrids Duško, NS-H-111 and Branko, showed a reduction in seed dormancy after 90 days of storage; however, dormancy was not completely eliminated (26).

Seeds of COH 3 and COSF 6A exhibited rapid dormancy loss, attaining high germination percentages (~94 and ~93 %, respectively) by 15 DAH, indicating weak primary dormancy. Such rapid dormancy release is characteristic of improved sunflower genotypes and parental lines with reduced dormancy constraints (21, 26). The early dormancy alleviation observed in COH 3 and COSF 6A might be associated with hormonal changes reported to occur during seed after-ripening, in which a decline in ABA levels and a corresponding increase in GA shift the hormonal balance toward

germination (18). In contrast, IR 6 exhibited delayed dormancy release up to 30 DAH, suggesting a moderate dormancy status (Table 4). This behaviour can be attributed to sustained ABA levels, slower ABA catabolism and delayed GA biosynthesis, resulting in a prolonged high ABA/GA ratio (Fig. 1). Additionally, delayed metabolic activation contributes to postponed germination in IR 6. In oilseed crops such as sunflower, germination depends on efficient lipid mobilisation and subsequent energy production through β -oxidation, glycolysis and the tricarboxylic acid (TCA) cycle. As depicted in Fig. 1, the rapid germination in COH 3 and COSF 6A suggests early activation of these metabolic pathways, whereas IR 6 likely exhibits delayed enzymatic activity involved in lipid breakdown and energy metabolism (27).

Reactive oxygen species (ROS) further modulate dormancy release by acting as signalling molecules during after-ripening. Controlled ROS accumulation promotes ABA degradation and enhances GA signalling, thereby facilitating germination (28). The faster dormancy loss observed in COH 3 and COSF 6A might therefore be associated with optimal ROS-mediated signalling, whereas IR 6 might exhibit reduced ROS production or enhanced antioxidant activity, leading to slower dormancy alleviation. These findings highlight that genotypic variation in sunflower dormancy is governed by an integrated network of hormonal regulation, gene expression dynamics, metabolic activation and ROS signalling, as summarised in Fig. 1A and 1B.

Overall, the results demonstrate that dormancy release in sunflower is a genotype dependent process, regulated by the rate of hormonal rebalancing, transcriptional control of key biosynthetic and signalling genes and metabolic readiness of the seed. COH 3 and COSF 6A might be characterised by rapid hormonal and metabolic transitions, enabling early germination, whereas IR 6 might exhibit delayed reprogramming, resulting in prolonged dormancy. These findings highlight the importance of selecting genotypes with optimal dormancy characteristics for improved seed performance and uniform field establishment. From a practical perspective, the extended dormancy in IR 6 may require post-harvest treatments such as extended after-ripening, ethrel application, or seed priming to achieve uniform germination. In contrast, COH 3 and COSF 6A are better suited for immediate sowing due to their minimal dormancy constraints.

Dormancy-breaking techniques

Sunflower hybrid COH 3 and its parental lines (COSF 6A and IR 6) exhibited a significant increase in germination percentage in response to dormancy breaking treatments such as ethylene, KNO_3 , dry heat and water soaking compared to the untreated control. These responses are well supported by established physiological mechanisms and previous studies.



Table 1. Status of seed dormancy in sunflower hybrid COH 3 lines

Treatments	Germination (%)	Abnormal seedlings (%)	Fresh ungerminated seeds (FUS) (%)	Dead seeds (%)
5 DAH	71 (57.42)	2	25	2
10 DAH	88 (69.73)	1	11	0
15 DAH	94 (75.82)	2	1	3
20 DAH	96 (78.46)	0	0	4
25 DAH	97 (80.03)	1	0	2
30 DAH	95 (77.08)	2	0	2
Mean	90 (71.57)	1	6	2
S. Ed	2.018	0.694	1.575	1.291
CD (P = 0.05)	4.398	NS	3.432	NS

Figures in parentheses are arc sine transformed values.

Table 2. Status of seed dormancy in sunflower COSF 6A

Treatments	Germination (%)	Abnormal seedlings (%)	Fresh ungerminated seeds (FUS) (%)	Dead seeds (%)
5 DAH	66 (54.33)	3	24	7
10 DAH	89 (70.63)	0	6	5
15 DAH	93 (74.66)	3	0	4
20 DAH	94 (75.82)	1	0	5
25 DAH	96 (78.46)	1	0	3
30 DAH	94 (75.82)	2	0	4
Mean	89 (70.63)	2	5	5
S. Ed	1.347	0.966	0.72	0.793
CD (P = 0.05)	2.935	2.153	1.569	1.729

Figures in parentheses are arc sine transformed values.

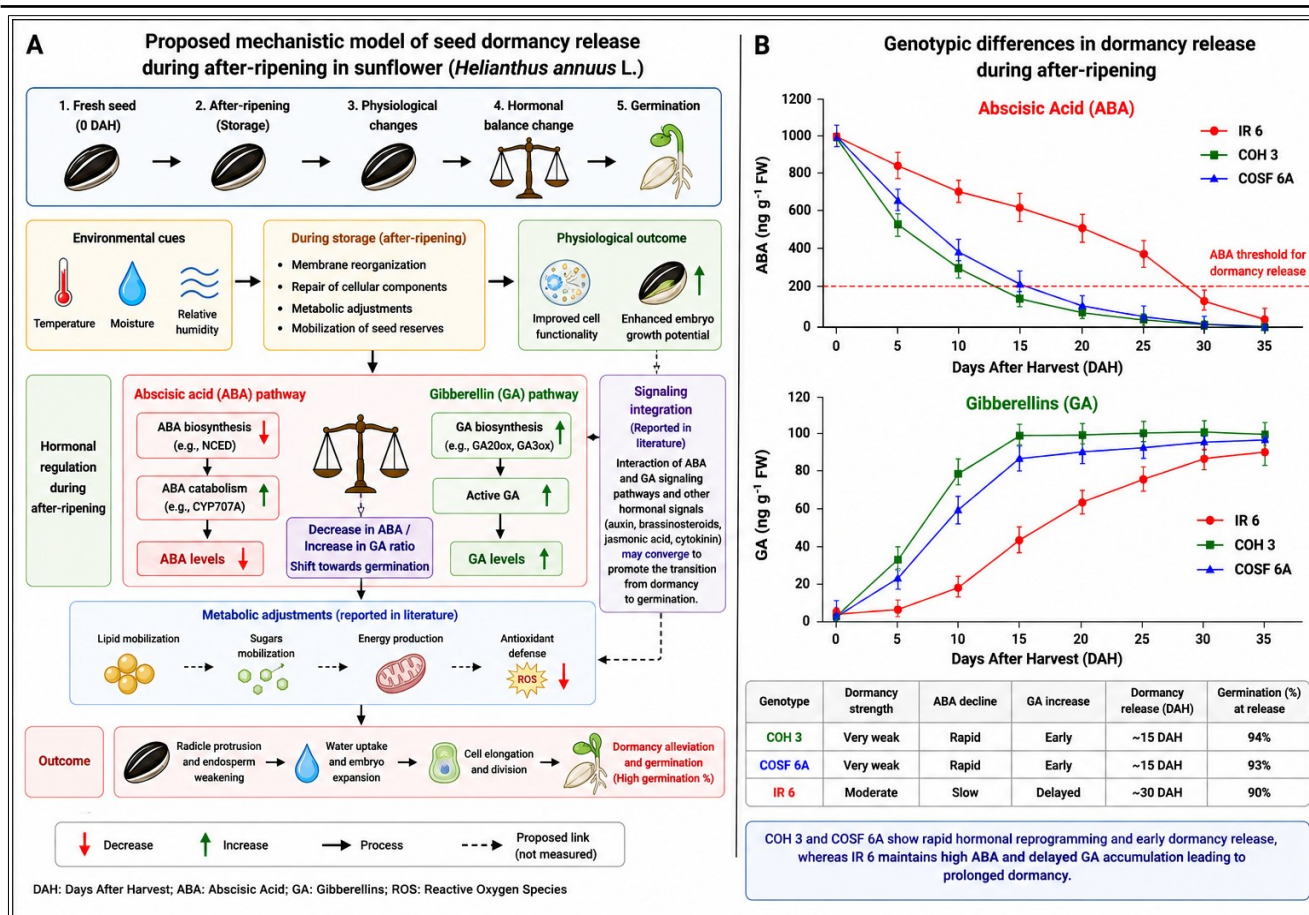
Table 3. Status of seed dormancy in sunflower IR 6

Treatments	Germination (%)	Abnormal seedlings (%)	Fresh ungerminated seeds (FUS) (%)	Dead seeds (%)
5 DAH	58 (49.60)	2	38	2
10 DAH	71 (57.42)	3	23	3
15 DAH	78 (62.03)	4	15	3
20 DAH	86 (68.03)	4	8	2
25 DAH	90 (71.57)	2	5	3
30 DAH	94 (75.82)	3	0	3
Mean	80	3	15	3
S. Ed	2.194	0.839	0.77	0.77
CD (P = 0.05)	4.781	1.828	1.677	NS

Figures in parentheses are arc sine transformed values.

Table 4. Effect of dormancy breaking treatments on physiological traits of sunflower hybrid COH 3, COSF 6A and IR 6 at 5 DAH

Treatments	COH 3				COSF 6A				IR 6			
	Germination (%)	Abnormal seedling (%)	FUS (%)	Dead seeds (%)	Germination (%)	Abnormal seedling (%)	FUS (%)	Dead seeds (%)	Germination (%)	Abnormal seedling (%)	FUS (%)	Dead seeds (%)
Control	73	3	21	3	69	5	22	4	55	6	35	4
Soaking in water for 24 hr	85	2	9	4	81	4	8	7	83	4	10	3
Soaking in 2 % KNO ₃ for 12 hr	87	4	5	4	82	3	6	9	85	4	5	6
Soaking in 50 ppm ethrel for 12 hr	93	2	2	3	93	3	0	4	91	3	3	3
Dry heating at 50 °C for 5 min	84	6	3	7	82	7	4	7	82	6	3	9
Mean	85	3	8	4	82	4	8	6	79	5	11	5
S. Ed	1.966	0.73	0.816	0.816	1.921	0.966	0.894	0.789	1.673	0.816	0.816	0.816
CD ($p = 0.05$)	4.0	2.0	2.0	2.0	4.0	2.0	2.0	2.0	4.0	2.0	2.0	2.0

**Fig. 1.** Proposed conceptual model and genotypic differences in seed dormancy release during after-ripening in sunflower.

Among the treatments, soaking in 50 ppm ethrel for 12 hr recorded maximum germination in COH 3, COSF 6A and IR 6 (93, 93 and 91 %, respectively), compared to the untreated control seeds (73, 69 and 55 %, respectively) (Table 1). Several growth regulators, including ethylene and ethylene releasing compounds, are commercially used to induce germination in sunflower seeds. The effectiveness of ethrel in breaking seed dormancy might be attributed to the release of ethylene, which has been reported to antagonise ABA signalling, promote endosperm weakening and facilitate radicle protrusion. Ethylene may also interact with GA and modulate the biosynthesis and signalling of other phytohormones, including JA, auxin and cytokinins, thereby contributing to dormancy alleviation (29, 30). In sunflower, dormant embryos at harvest require 40–50 $\mu\text{L L}^{-1}$ ethylene for germination at 15 °C, whereas only 3 $\mu\text{L L}^{-1}$ is required after 15 weeks of dry storage (31). Similarly, stratification of sunflower seeds with 25 ppm ethrel for one week at 4 °C improved germination in varieties such as PI413035, ex Kearney and NE (32). Ethephon treatment at 250 ppm effectively reduced innate dormancy and enhanced germination in freshly harvested sunflower seeds (33). These findings indicate that ethylene-mediated hormonal cross-talk plays a central role in overcoming sunflower seed dormancy.

Apart from ethylene, KNO_3 , dry heat treatment and water soaking also improved germination in COH 3 and its parental lines (Table 1). Potassium nitrate (KNO_3) is widely reported to stimulate germination by enhancing nitrate signalling pathways, promoting GA biosynthesis and reducing ABA sensitivity. It also improves oxygen availability and metabolic activation within seeds. Similar promotive effects of KNO_3 on dormancy release have been reported in sunflower and other oilseed crops (25). Seed treatment with KNO_3 increased germination in dormant sunflower seeds of varieties M-3272, NOVA and AGSUN 5383 following (34).

Dry heat treatment accelerates after-ripening by inducing non-enzymatic oxidative processes and controlled accumulation of ROS, which facilitate ABA degradation and dormancy alleviation. Controlled heat exposure has been shown to improve germination in dormant seeds by modifying membrane properties and activating metabolic pathways (24, 28). Similar findings were reported, which observed elevated hydrogen peroxide (H_2O_2) accumulation following dry heat treatment, likely due to increased seed permeability and enhanced oxygen uptake (35). The increased ROS production was suggested to play a key role in the release of physiological dormancy.

Water soaking (hydropriming) improves germination through seed hydration, which activates early metabolic processes including enzyme synthesis, reserve mobilisation, respiration and repair of cellular structures. Hydropriming also reduces the lag phase of germination and improves germination uniformity. Similar beneficial effects of hydropriming have been

widely reported in sunflower and several other crops (36).

Collectively, these dormancy-breaking treatments enhance germination through hormonal regulation, metabolic activation, ROS-mediated signalling and improved cellular readiness for germination. The results indicate that ethylene treatment was the most effective approach for overcoming dormancy in sunflower hybrid COH 3 and its parental lines.

4. Conclusion

The study indicated that the sunflower hybrid COH 3 and its cytoplasmic male sterile line COSF 6A were very weak (0–15 days) dormant varieties, whereas the restorer line IR 6 is a medium (26–35 days) dormant variety. The rapid dormancy release in COH 3 and COSF 6A might be due to weak physiological dormancy, whereas the delayed dormancy release observed in IR 6 might be associated with a higher abscisic acid (ABA) persistence and delayed metabolic activation. Among the seed treatment techniques, soaking in ethrel 50 ppm for 12 hr is effective in breaking the dormancy and may serve as a practical and economical method for commercial seed treatment. However, care should be taken to avoid prolonged soaking, as prolonged soaking may lead to pre-germination of the seeds. Genotypic variation in dormancy and differential sensitivity to dormancy-breaking treatments indicates distinct hormonal regulation and responsiveness rather than a uniform dormancy pattern in tested sunflower genotypes.

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Authors' contributions

RV conceptualised the study, conducted the research and prepared the original draft of this manuscript. KM and SK assisted in research work. DTS contributed for writing the article. VV and BV reviewed and edited the manuscript. All the authors have read and approved the final version of the manuscript.

Compliance with ethical standards

Conflict of interest

Authors do not have any conflict of interests to declare.

Ethical issues

None



Declaration of generative AI and AI-assisted technologies in the writing process

During the preparation of this work, the authors used ChatGPT in order to add a mechanistic layer of ABA/GA quantification, transcriptomic or metabolomic evidence. After using this tool, the authors reviewed and edited the content as needed and take full responsibility for the content of the publication.

References

- Adams RP, TeBeest AK. The effects of gibberellic acid (GA3), Ethrel, seed soaking and pre-treatment storage temperatures on seed germination of *Helianthus annuus* and *H. petiolaris*. *Phytologia*. 2016;98(3):213–8.
- Adeleke BS, Babalola OO. Oilseed crop sunflower (*Helianthus annuus*) as a source of food: Nutritional and health benefits. *Food Sci Nutr*. 2020;8(9):4666–84. <https://doi.org/10.1002/fsn3.1783>
- Ali F, Qanmber G, Li F, Wang Z. Updated role of ABA in seed maturation, dormancy, and germination. *J Adv Res*. 2022;35:199–214. <https://doi.org/10.1016/j.jare.2021.03.011>
- Allen E, Alvarez S. International rules for seed testing 2020. Bassersdorf: International Seed Testing Association; 2020.
- Andrade A, Riera N, Lindstrom L, Alemanno S, Alvarez D, Abdala G, et al. Pericarp anatomy and hormone profiles of cypselas in dormant and non-dormant inbred sunflower lines. *Plant Biol*. 2015;17(2):351–60. <https://doi.org/10.1111/plb.12244>
- Arata GJ, Riveira-Rubin MA, Batlla D, Rodríguez MV. Dormancy attributes in sunflower achenes (*Helianthus annuus* L.): I. Intraspecific variability. *Crop Sci*. 2021;61(6):4293–308. <https://doi.org/10.1002/csc2.20610>
- Baskin JM, Baskin CC. A classification system for seed dormancy. *Seed Sci Res*. 2004;14(1):1–16. <https://doi.org/10.1079/SSR2003150>
- Bodrone MP, Rodríguez MV, Arisnabarreta S, Batlla D. Maternal environment and dormancy in sunflower: the effect of temperature during fruit development. *Eur J Agron*. 2017;82:93–103. <https://doi.org/10.1016/j.eja.2016.10.007>
- Borghetti F, Noda FN, Sá CM. Possible involvement of proteasome activity in ethylene-induced germination of dormant sunflower embryos. *Braz J Plant Physiol*. 2002;14(2):125–31. <https://doi.org/10.1590/S1677-04202002000200007>
- Brunick RL. Seed dormancy in domesticated and wild sunflowers (*Helianthus annuus* L.): types, longevity and QTL discovery [dissertation]. Corvallis (OR): Oregon State University; 2007.
- Corbineau F, Côme D. Ethylene synthesis and sensitivity-an overview. In: Vendrell M, Klee H, Pech JC, Romojaro F, editors. *Biology and biotechnology of the plant hormone ethylene III*. Amsterdam: IOS Press; 2003. p. 216–22.
- Corbineau F, Rudnicki R, Côme D. Induction of secondary dormancy in sunflower seeds by high temperature. Possible involvement of ethylene biosynthesis. *Physiol Plant*. 1988;73(3):368–73. <https://doi.org/10.1111/j.1399-3054.1988.tb00612.x>
- Corbineau F, Xia Q, Bailly C, El-Maarouf-Bouteau H. Ethylene, a key factor in the regulation of seed dormancy. *Front Plant Sci*. 2014;5:539. <https://doi.org/10.3389/fpls.2014.00539>
- El-Maarouf-Bouteau H, Bailly C. Oxidative signalling in seed germination and dormancy. *Plant Signal Behav*. 2008;3(3):175–82. <https://doi.org/10.4161/psb.3.3.5539>
- Finch-Savage B. Seeds: Physiology of development, germination and dormancy - JD Bewley, KJ Bradford, HWM Hillhorst H. Nonogaki. 392 pp. Springer, New York–Heidelberg–Dordrecht–London 2013 978-1-4614-4692-7. *Seed Sci Res*. 2013;23(4):289. <https://doi.org/10.1017/S0960258513000287>
- Finch-Savage WE, Leubner-Metzger G. Seed dormancy and the control of germination. *New Phytol*. 2006;171(3):501–23. <https://doi.org/10.1111/j.1469-8137.2006.01787.x>
- Gubler F, Millar AA, Jacobsen JV. Dormancy release, ABA and pre-harvest sprouting. *Curr Opin Plant Biol*. 2005;8(2):183–7. <https://doi.org/10.1016/j.pbi.2005.01.011>
- Khan S, Choudhary S, Pandey A, Khan MK, Thomas G. Sunflower oil: Efficient oil source for human consumption. *Emerg Life Sci Res*. 2015;1:1–3.
- Kozaki A, Aoyanagi T. Molecular aspects of seed development controlled by gibberellins and abscisic acids. *Int J Mol Sci*. 2022;23(3):1876. <https://doi.org/10.3390/ijms23031876>
- Kucera B, Cohn MA, Leubner-Metzger G. Plant hormone interactions during seed dormancy release and germination. *Seed Sci Res*. 2005;15(4):281–307. <https://doi.org/10.1079/SSR2005218>
- Kumari CA, Singh BG. Ethephon adequacy in release of innate dormancy in sunflower. *J Res ANGRAU*. 2000;28(4):81–3.
- Maiti R, Vidyasagar P, Shahapur S, Ghosh S, Seiler G. Development and standardisation of a simple technique for breaking seed dormancy in sunflower (*Helianthus annuus* L.). *Helia*. 2006;29(45):117–26. <https://doi.org/10.2298/HEL0645117M>
- Manivannan N, Chandrakala R, Manonmani S, Viswanathan P, Ganesamurthy K, Dudhe MY, et al. Sunflower COH 3: A high yielding and high oil content sunflower hybrid for Tamil Nadu. *Electron J Plant Breed*. 2021;12(2):525–8. <https://doi.org/10.37992/2021.1202.074>
- Matilla A. Auxin: hormonal signal required for seed development and dormancy. *Plants*. 2020;9(6):705. <https://doi.org/10.3390/plants9060705>
- Nasreen S, Khan MA, Zia M, Ishaque M, Uddin S, Arshad M, et al. Response of sunflower to various pre-germination techniques for breaking seed dormancy. *Pak J Bot*. 2015;47(2):413–6.
- Nonogaki H. Seed dormancy and germination-emerging mechanisms and new hypotheses. *Front Plant Sci*. 2014;5:233. <https://doi.org/10.3389/fpls.2014.00233>
- Paparella S, Araújo S, Rossi G, Wijayasinghe M, Carbonera D, Balestrazzi A. Seed priming: state of the art and new perspectives. *Plant Cell Rep*. 2015;34(8):1281–93. <https://doi.org/10.1007/s00299-015-1784-y>
- Penfield S, Li Y, Gilday AD, Graham S, Graham IA. Arabidopsis ABA INSENSITIVE4 regulates lipid mobilisation in the embryo and reveals repression of seed germination by the endosperm. *Plant Cell*. 2006;18(8):1887–99. <https://doi.org/10.1105/tpc.106.041277>
- Rodríguez MV, Bodrone MP, Castellari MP, Batlla D. Effect of storage temperature on dormancy release of sunflower (*Helianthus annuus*) achenes. *Seed Sci Res*. 2018;28(2):101–11. <https://doi.org/10.1017/S0960258518000065>
- Rodríguez MV, Toorop PE, Benech-Arnold RL. Challenges facing seed banks and agriculture in relation to seed quality. In: Kermod AR, editor. *Seed dormancy: methods and*

- protocols. New York: Springer; 2011. p. 17–40. https://doi.org/10.1007/978-1-61779-231-1_2
31. Roselló PL, Vigliocco AE, Andrade AM, Riera NV, Calafat M, Molas ML, et al. Differential hormonal and gene expression dynamics in two inbred sunflower lines with contrasting dormancy level. *Plant Physiol Biochem.* 2016;102:133–40. <https://doi.org/10.1016/j.plaphy.2016.02.021>
 32. Seo M, Kanno Y, Frey A, North HM, Marion-Poll A. Dissection of *Arabidopsis* NCED9 promoter regulatory regions reveals a role for ABA synthesised in embryos in the regulation of GA-dependent seed germination. *Plant Sci.* 2016;246:91–7.
 33. Shu K, Liu XD, Xie Q, He ZH. Two faces of one seed: hormonal regulation of dormancy and germination. *Mol Plant.* 2016;9(1):34–45. <https://doi.org/10.1016/j.molp.2015.08.010>
 34. Vishal B, Kumar PP. Regulation of seed germination and abiotic stresses by gibberellins and abscisic acid. *Front Plant Sci.* 2018;9:838. <https://doi.org/10.3389/fpls.2018.00838>
 35. Visscher AM, Yeo M, Barreiro PG, Stuppy W, Frances AL, Di Sacco A, et al. Dry heat exposure increases hydrogen peroxide levels and breaks physiological seed coat-imposed dormancy in *Mesembryanthemum crystallinum* (Aizoaceae) seeds. *Environ Exp Bot.* 2018;155:272–80. <https://doi.org/10.1016/j.envexpbot.2018.07.009>
 36. Vujaković M, Radić V, Miklič V, Jovičić D, Balešević-Tubić S, Mrđa J, et al. Seed dormancy of hybrids and parent lines of sunflower (*Helianthus annuus* L.). *Helia.* 2012;35(56):111–8. <https://doi.org/10.2298/HEL1256111V>

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