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Islavath Suresh Naik
Department of Seed Science and Technology, University of Agricultural Sciences, Dharwad, Karnataka, India

VK Deshpande
Department of Seed Science and Technology, University of Agricultural Sciences, Dharwad, Karnataka, India

Corresponding Author
Islavath Suresh Naik
Department of Seed Science and Technology, University of Agricultural Sciences, Dharwad, Karnataka, India

Seed coat dormancy: An overview in legumes

Islavath Suresh Naik and VK Deshpande

Abstract
Most of the food species belongs to the family Leguminosae. The resting condition of many seeds, especially those of different farm and garden crops, is maintained only as long as the seeds are in dry storage. Immediately after the suitable conditions occurs the seed is activated making the arrangements within and starts germinating. In case of most legumes the seed coat dormancy is prevailing to stop the seed to do its activity although the favourable conditions prevail for germination. Seed coat is a natural occurring barrier and is the character of seed that helps to postpone the germination. Physical factors and physiological factors and more likely in legumes leading to dormancy. This is sometimes bane and is reduced by the scarification mainly in legumes.

Keywords: seed coat dormancy, barrier, physical, physiological, bane

Introduction

Legumes belong to the family Leguminosae, (also known as Fabaceae) which consists of four subfamilies *viz*. Papilionoideae, Caesalpinoideae, Mimosoideae, and Swartzioideae. Legumes are among the three largest families of flowering plants. The flowering plants of greatest importance to world agriculture belong to the orders Gramineae (cereals and grasses) and Leguminosae (legumes or the bean family). The Leguminosae consist of about 750 genera and 19,000 species of herbs, shrubs, trees, and climbers. This large family is divided into four subfamilies—the Mimosoideae, Caesalpinoideae, Swartzioideae, and Papilionoideae. The Swartzioideae is a small subfamily of about 80 species and relatively unimportant economically. There are different types of dormancy's present like physical dormancy, physiological dormancy, morphological dormancy, among that morphological dormancy which due to the seed coat thickness is more in case of Leguminosae family. Numerous studies have examined the effect of moisture and temperature on seed germination for species with physical dormancy (e.g. Mareno-Casasola *et al*., 1994; McDonald, 2002) [28, 29]. However, factors required for dormancy release and for germination are often confounded (Thompson and Ooi, 2013) [53]. For example, a positive correlation under wet conditions between temperature and germination rate could be the result of greater dormancy release, better germinating conditions for species that are already non-dormant, or both. Nonetheless, dormancy release is commonly found to be positively correlated with temperature and with moisture availability, and their interaction (Baskin and Baskin, 1998; van Klinken and Flack, 2005; Hu *et al*., 2009; Jayasuriya *et al*., 2009) [3, 55, 23]. Hard-coatedness is usually caused by impermeability of the seed coat or some of its layers to water or to gases, though both mechanical and chemical inhibition of germination mayaiso be factors in dormancy. In some cases, e.g. avocado, Persea gratissima (EGGERS 1942) [15] and tung, Aleurites fordii (SHARPE and MERRILL 1942) [44], germination is promoted by removal of the seed coat but the nature of this effect is unknown. Impermeable coats are characteristic of certain species and even of certain families of plants. The family Leguminosae is the one of the most commonly known to possess seeds with impermeable coats, but certain members of other families (Gramineae, Malvaceae, Oannaceae, Geraniaceae, Ohenopodiaceae, Oonvallariaceae, Oonvulvulaceae, Solanaceae, and others) also produce such seeds. Riggio-Bevilacqua *et al.* (1985) [37] attributed the inhibition of water uptake to the combination effect of the imperviousness of the hilum and the impermeability of a non-cellular lipid layer found between the inner surface of the integument and the endosperm. High hard seed content in a seed lot can cause delayed or decreased seedling emergence.

Legume Seed Coat (Testa) Development and Structure

The angiosperm seed develops from the fertilized ovule and depending on the stage of development is usually composed of (1) the embryo, arising by fertilization of the egg cell by one of the pollen tube nuclei; (2) the nutritive tissue of the endosperm, generated by the fusion of two polar nuclei of the embryo sac with the other sperm nucleus; and (3) a protective seed coat (testa), derived from the inner/outer or both ovular integuments (Bradford and Nonogaki, 2009) [7].

The seed coat tissue components

The origin of the seed coat can be traced back to the L1 sporophyte layer of the ovule primordium (Schneitz *et al.*, 1997) [43] with an emerging network of regulatory pathways coordinating growth of the inner and/or outer integuments surrounding the ovule (Skinner *et al.*, 2004; Galbiati *et al.*, 2013; Kurdyukov *et al.*, 2014) [46, 17, 24]. The number of ovule integuments varies depending on the species; legumes have two integuments (bitegmic ovules). The inner integument largely vanishes during development (Esau, 1965) [16] while the outer one produces several distinct cell layers and establishes the "typical" seed coat structure. The chalazal region is an important part of the testa where connections of the vascular tissues of the maternal funiculus terminate. Current seed identification criteria are based upon morphological characteristics including seed size, general shape, surface shape, color, hilum length and width. These are often used in taxonomical classifications (Lestern and Gunn, 1981; Chernoff *et al.*, 1992; Güneş, 2013) [25, 10, 19] and archeobotany (Zohary *et al.*, 2012) [61]. Legume seed characters support the concept of one family (Fabaceae) as advocated already by De Candolle (1825) [14]. Although the seed coats of different species vary greatly in structure and composition, they undergo similar phases of development in relation to the embryo and endosperm (Butler, 1988) [5]. Weber *et al.*, 2005 stated that embryo and seed coat is developed first followed by the development of embryo.Seeds with physical dormancy cannot become physically dormant again once the testa is compromised and there is sufficient moisture for imbibition (Baskin and Baskin, 2004; van Klinken *et al*., 2008) [4, 57]

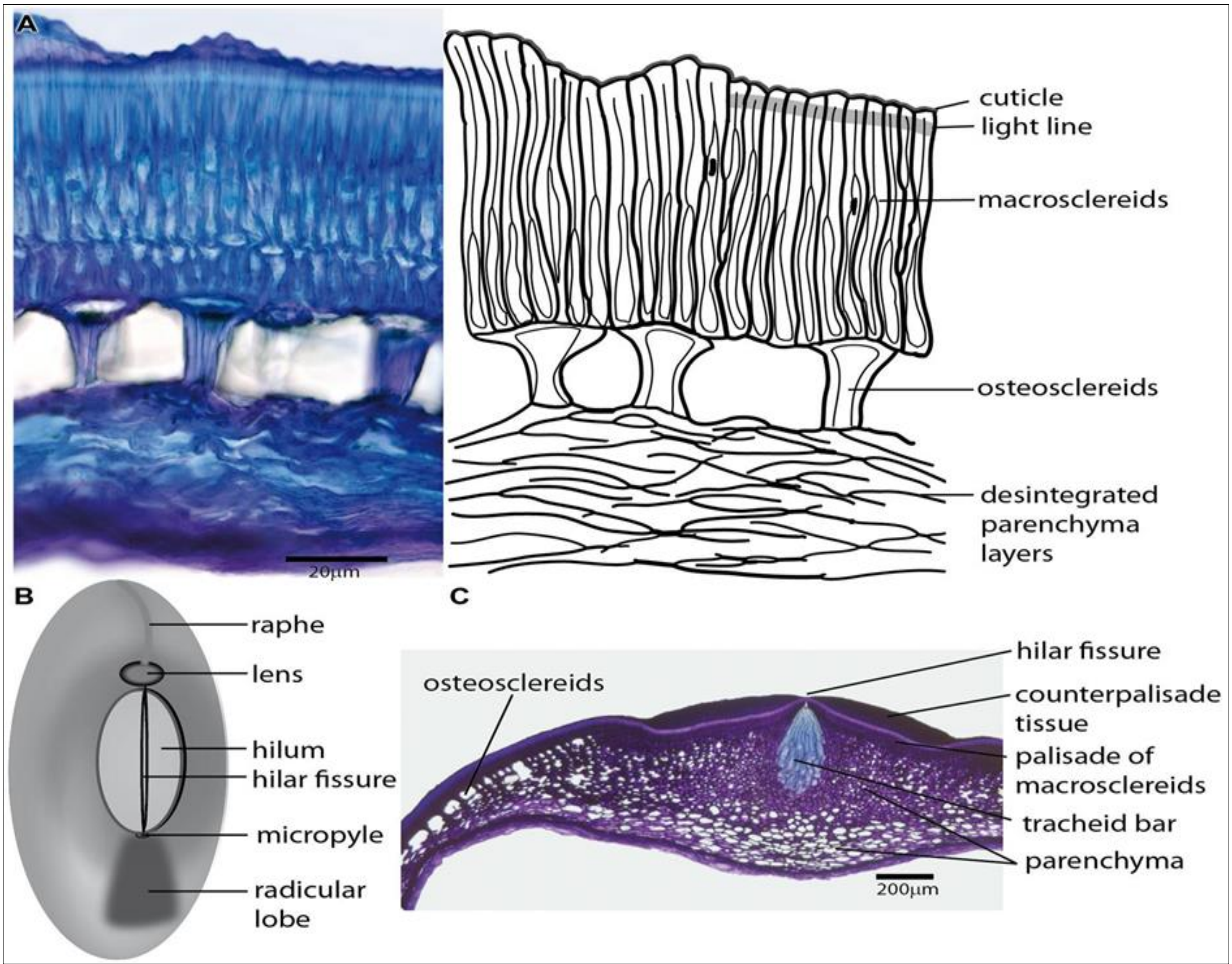

Fig 1: The arrangement of Leguminosae seed coat share rather common structural features. (A) Transversal section of the seed coat of wild Pisum sativum subsp. elatius (left), with a schematic drawing (right); epidermal cells differentiate into macrosclereids, which are characterized by a cuticle-covered surface. The outer parts of the macrosclereids (sclereid caps) are frequently separated by a region of the cell wall (light line) with specific features, resulting in different optical and staining properties. The central part of the testa differentiates into osteosclereids with a specific shape caused by thickened secondary cell wall. The innermost layers of parechymatous cells frequently die during differentiation and only disintegrated fragments are left. (B) Generalized scheme of the seed coat morphology commonly found in Fabaceae seeds showing the most important structural features, including the hilum, lens differentiated on the raphe and micropylar pore. (C) Transversal section of a Pisum sativum seed coat in the area of the hilum. The macrosclereids of the hilar scar are covered with counter palisade tissue with a central fissure above the tracheid bar, which is surrounded by star-shaped parenchyma interconnected to intercellular spaces of a layer of osteosclereids.

Role of seed coat in enhancing seed dormancy

Seed coat is the outermost layer of the seed which is called as testa (the protective layer) provides the protection to the seed from the damage. As the seed coat thickness increases the seed may become dormant although the favourable conditions prevent for seed germination. This thickness not only make the seed dormant but also protect the seed from external factors that cause damage. The thickness of seed coat is due to the formation of secondary cell walls in due of time from the primary cell walls leading to the thickened layer and makes the seed coat strong and hard, thus making the seed dormant. Pfeiffer (1934) [33], working with *Symphoricarpos racemosus* (a species with dormant embryos), showed that the softening and disintegration of the seed coats is caused by decomposition of wall substances by fungi. If the seeds are kept under conditions favourable for this process (moist storage and optimal temperatures) but are maintained free from fungi the coats remain unchanged. The hardness and impermeability of the seed coat, as an inhibited factor in seed germination, has been studied in several species of the family Leguminosae (Demel 1996; Sacheti and Al-Rawahy 1998; Sy *et al*. 2001; Orozco-Almanza *et al*. 2003; Pipinis *et al*. 2005) [11, 42, 31, 34].

Seed dormancy

A dormant seed does not have the capacity to germinate in a specified period of time under any combination of normal physical environmental factors that are otherwise favourable for its germination, i.e. after the seed becomes non-dormant. A completely non-dormant seed has the capacity to germinate over the widest range of normal environmental factors. Dormancy is useful to sustain unfavorable conditions, and for the dispersal, spread and distribution. Plants are vulnerable to the hazards of drought and extremes of heat and cold. In the non-growing condition, the seed moisture content is low and the cell protoplasm is protected from damage, owing to its low metabolic rate. Seeds of many plants do not germinate even if conditions are favorable, they are dormant (Finch savage and leubner Metzger, 2006; Baksin and Baskin, 2014) [23]. Dormancy and germination are two crucial seed traits that are often considered key components in plant life history strategies (Rees, 1997) [38]. Germination of many seeds is retarded only by impermeable coats which hinder the admission of water. If these coats are not subjected to pre-treatment, germination can be erratic and prolonged, sometimes extending over a period of many years (Anonymous, 1965) [1]. The seed coat confers physical dormancy through tightly packed palisade cells impregnated with water repellent substances (Baskin and Baskin, 1998; Jayasuriya *et al.*, 2009) [3, 23]. Physical dormancy which is the main reason for the hindering of germination and less dispersal. In many of the legume species the main reason for the dormancy is the seed coat which is thick and leads to the hinderance of growth after imbibition.

Breaking of dormancy

Scarification

Scarification means weakening, opening, or otherwise altering the coat of a seed to encourage germination. Scarification is often done mechanically, thermally, and chemically. The seeds of many plant species are often impervious to water and gases, thus preventing or delaying germination. Scarification, regardless of type, works by speeding up the natural processes which normally make seed coats permeable to water and air. Seed scarification, a physical damage to break the hard seed coat without lowering the quality of seeds, has been studied for more than a century (Dixon, 1901; Harrington, 1916; Stewart, 1926; Rincker, 1954; Rolston, 1978; Stanwood, 1980; Rutar *et al*., 2001; Zeng *et al*., 2005; Dittus and Muir, 2010) [13, 21, 40, 48, 60, 12, 50].

Mechanical scarification

For mechanical scarification, many researchers have used mechanical scarifiers (Carleton *et al*., 1971; Townsend and McGinnis, 1972; Miklas *et al*., 1987; Singh *et al*., 1991; Patane and Gresta, 2006; Dittus and Muir, 2010) [12, 32] or sandpapers to rub seeds manually (Baes *et al*., 2002; Uzun and Aydin, 2004; Patane and Gresta, 2006; Can *et al*., 2009) [55, 32]. The seeds are rubbed towards the rough surface until the thick seed coat is loosened or decreased in number of layers. The seed coat ruptures immediately after the seed is rubbed over the sand paper or rough surface. Mechanical scarifiers are used to scarify the seeds when they are in huge quantity. When the seeds are passed in to the scarifier the seeds are rubbed over the rough surface in the machine and seed coat is loosened. An RPM of 50-60 is adjusted in the scarifier and the seeds are subjected to scarification.

Heat scarification

Heat scarification has been one of the most popular methods because it is simple and easy to use. Two main heating devices used in heat scarification *viz*. oven (Harrington, 1916; Staker, 1925; Stewart, 1926; Lute, 1927; Rincker, 1954; Rutar *et al*., 2001) [21, 40, 49, 50, 27] and hot water bath (Uzun and Aydin, 2004; Patane and Gresta, 2006; Can *et al*., 2009) [55, 32]. Efficacy of heat scarification varies significantly depending on heating devices, duration and temperatures. Heat scarification using the dry heat in oven seems to be effective on hard seed reduction and germination improvement when appropriate duration and temperature are used (Harrington, 1916; Staker, 1925; Stewart, 1926; Lute, 1927; Rincker, 1954; Tomer and Maguire, 1989; Rutar *et al*., 2001) [21, 40, 49, 50, 27]. Various temperatures (below 40 °C to over 100 °C) and treatment times (one min to 21 h) were used in different studies and variable results were reported.

Acid scarification

In mechanical scarification, they may be shaken with some abrasive material such as sand or be scratched with a knife. In chemical scarification, seeds are dipped into strong sulfuric acid, organic solvents such as acetone or alcohol, or even boiling water. Frequently seed coats are permeable to water yet block entrance of oxygen; this applies, for example, to the upper of the two seeds normally found in each burr of the cocklebur plant. The lower seed germinates readily under a favourable moisture and temperature regime, but the upper one fails to do so unless the seed coat is punctured or removed or the intact seed is placed under very high oxygen concentrations. A paper was published by the New Zealand Journal of Experimental Agriculture and stated that the seeds they examined in their study germinated only 30% under the preferred conditions, yet when they were treated chemically with concentrated sulphuric acid or mechanically scarified, the germination rate increased to more than 80%. win pe *et al.*, 1975, Liu *et al.* (1981) also recommended scarification with concentrated sulfuric acid for 30-90 min to break the hard coat of C. canadensis seeds. After scarification, the seed of *C. siliqua* strum requires a period of cold moist stratification in order to remove endosperm dormancy (Rascio *et al*. 1998) [36]. Gebre and Karam (2004) [18] considered the most effective and necessary treatment for germination of imbibed *C. siliquastrum* seeds to be moist stratification at 4 °C for 16 weeks.

Freeze-thaw scarification

Mechanism behind the reduction of hard seededness by a freeze-thaw scarification is to make tiny scars on hard seed coat and make seed coat brittle to enhance germination (Busse, 1930; Pritchard *et al*., 1988; Stout, 1990; Hall *et al*., 1993) [6, 35]. A force that produces scars on seed surface through this technique is depending on the size, shape, water content of seedstreatment intensity and durations (Candolle, 1922; Steinbauer, 1926; Busse, 1930) [14, 6]. Methods for cooling in freeze-thaw scarification include freezer (Midgley, 1926; Shibata and Hatakeyama, 1995) [30, 45]; carbon dioxide (CO_2) snow, dry ice, liquid air (Busse, 1930 [6]; ultra-low freezer (Stout, 1990) [51]; acetone (Rutar *et al*., 2001); liquid Nitrogen (Brant *et al*., 1971; Stanwood, 1980; Pritchard *et al*., 1988; Acharya *et al*., 1993; Patane and Gresta, 2006) [1, 48, 32, 35].When the seeds are subjected to low temperatures followed by warmer temperature then the seed coat dormancy is decreased. Temperatures maintained here are in the range of -5 to -15 ^{0}C and followed by room temperature breaks the dormancy.

Conclusion

Seed coat which acts as a barrier in the process of germination in the Leguminosae family species by not making the radicle to emerge out of the seed due to presence of thick layer of seed coat during the favourable conditions were removed by the rupture of thick seed coat by following the different methods to overcome seed coat induced dormancy. Acid treatment and rubbing the seed over the hard-rough surface for a period of time and cold stratification for the specified time leads to breaking of seed coat dormancy.

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References

1. Acharya SN, Kokko EG, Fraser J. Storage duration and freeze-thaw effects on germination and emergence of cicer milkvetch (*Astragalus cicer*) seeds. J Seed Technol 1993;17:1-13.
2. Anonymous. A continuation of the Bulletin of Popular Information of the Arnold Arboretum. Harvard University, 1965, 25.
3. Baskin JM, Baskin CC. Seeds: Ecology, biogeography, and evolution of dormancy and germination. San Diego, Academic Press, 1998.
4. Baskin JM, Baskin CC. A classification system for seed dormancy. Seed Science Research 2004;14:1-16.
5. Butler EA. “The SEM and seed identification, with particular reference to the Vicieae,” in Scanning Electron Microscopy in Archeology, ed. S. L. Olsen (Oxford: BAR International Series) 1988;452:215-224.
6. Busse WF. Effect of low temperatures on germination of impermeable seeds. Bot. Gazette 1930;89:169-179.
7. Bradford K, Nonogaki H. Seed Development, Dormancy and Germination. Annual Plant Reviews, Oxford: Blackwell 2009, 27.
8. Can E, Celiktas N, Hatipoglu R, Avci S. Breaking seed dormancy of some annual *Medicago* and *Trifolium* species of different treatments. Turk. J Crops 2009;14:72-78.
9. Candolle HT. Seed vitality experiments. Am. J. Bot 1922;9:266-269.
10. Chernoff M, Plitmann U, Kislev ME. Seed characters and testa texture in species of Vicieae: their taxonomic significance. Isr. J. Bot 1992;41:167-186.
11. Demel T. Germination ecology of twelve indigenous and eight exotic multipurpose leguminous species from Ethiopia. Forest Ecology and Management 1996;80:209-223.
12. Dittus DA, Muir JP. Breaking germination dormancy of texas native perennial herbaceous legumes. Native Plants 2010;11:5-10.
13. Dixon HH. Vitality of seeds. Nature 1901;64:256-257.
14. De Candolle AP. Mémoires sur la Famille des Légumineuses. Paris: A. Belin, 1825.
15. Eggers ER. Effect of removal of the seed coat on avocado seed germination. Yearb. Calif. Avocado Ass 1924, 41-43.
16. Esau K. Plant Anatomy, 2nd Edn. New York: John Wiley 1965.
17. Galbiati F, Sinha Roy D, Simonini S, Cucinotta M, Ceccato L, Cuesta C *et al*. An integrative model of the control of ovule primordia formation. Plant J 2013;76:446-455.
18. Gebre GH, Karam NS. Germination of Cercis siliquastrum seeds in response to gibberellic acid and stratification. Seed Science and Technology 2004;32:255-260.
19. Güneş F. Seed characteristics and testa textures of *Pratensis*, *Orobon*, *Lathyrus*, *Orobastrum* and *Cicercula* sections from *Lathyrus* (Fabaceae) in Turkey. Plant Syst. Evol. 2013;299:1935-1953.
20. Hall JW, Stout DG, Brooke BM. Hard seed and field establishment of irrigated Alfalfa. Crop Sci 1993;33:1025-1028.
21. Harrington GT. Agricultural value of impermeable seeds. J Agric. Res 1916;6:761-796.
22. Hu XW, Wu YP, Wang YR. Different requirements for physical dormancy release in two populations of *Sophora alopecuroides* in relation to burial depth. Ecological Research 2009;24:1051-1056.
23. Jayasuriya KMGG, Baskin JM, Geneve RL, Baskin CC. A proposed mechanism for physical dormancy break in seeds of *Ipomoea lacunosa* (Convolvulaceae). Annals of Botany 2009;103:433-445.
24. Kurdyukov S, Song Y, Sheahan MB, Rose RJ. Transcriptional regulation of early embryo development in the model legume *Medicago truncatula*. Plant Cell Rep 2014.
25. Lersten NR, Gunn CR. Seed morphology and testa topography in *Cicer* (Fabaceae: Faboideae). Syst. Bot 1981;6:223-230.
26. Liu NY, Khatamian H, Fretz TA. Seed coat structure of three woody legume species after acid and physical treatments to increase seed germination. Journal of the American Society for Horticultural Science 1981;106:691-694.
27. Lute AM. Alfalfa seed made permeable by heat. Science 1927;65:166-166.

28. Mareno-Casasola P, Grime JP, Martinez ML. A comparative study of the effects of fluctuations in temperature and moisture supply on hard coat dormancy in seeds of coastal tropical legumes in Mexico. Journal of Tropical Ecology 1994;10:67-86.
29. McDonald CK. Germination responses to temperature in tropical and subtropical pasture legumes. 1. Constant temperatures. Australian Journal of Experimental Agriculture 2002;42:407-419.
30. Midgley AR. Effect of alternate freezing and thawing on the impermeability of alfalfa and dodder seeds. J Am. Soc. Agron 1926;18:1087-1098.
31. Orozco-Almanza MS, Leon-Garcia LP, Grether R, Garcia-Moya E. Germination of four species of the genus Mimosa (Leguminosae) in a semi-arid zone of Central Mexico. Journal of Arid Environments 2003;55:75-92.
32. Patane C, Gresta F. Germination of *Astragalus hamosus* and *Medicago orbicularis* as affected by seed-coat dormancy breaking techniques. J Arid Environ 2006;67:165-173.
33. Pfeiffer NE. Morphology of the seed of *Symphoricarpus racemosos* and the relation of fungal invasion of the coat to germination capacity. Contr. Boyce Thompson Inst 1934;6:103-122.
34. Pipinis E, Aslanidou M, Milios E, Gkioumousides C, Karakosta C. Germination study on three leguminous species *Calycotome villosa*, *Spartium junceum* and *Medicago arborea* (in Greek). Scientific Annals of the Department of Forestry and Natural Environment 2005;43:253-263.
35. Pritchard HW, Manger KR, Prendergast FG. Changes in *Trifolium arvense* seed quality following alternating temperature treatment using liquid nitrogen. Ann. Bot 1988;62:1-11.
36. Rascio N, Mariani P, Vecchia FD, Rocca NL, Profumo P, Gastaldo P. Effects of seedchilling or GA3 supply on dormancy breaking and plantlet growth in *Cercis siliquastrum* L. Plant Growth Regulation 1998;25:53-61.
37. Riggio-Bevilacqua L, Roti-Michelozzi G, Serrato-Valenti G. Barriers to water penetration in Cercis siliquastrum seeds. Seed Science and Technology 1985;13:175-182.
38. Rees M. Seed dormancy. In Plant ecology. (ed. M. Crawley), Blackwell Science, London 1997, 214-238.
39. Rolston MP. Water impermeable seed dormancy. Bot. Rev 1978;44:365-396.
40. Rincker CM. Effect of heat on impermeable seeds of alfalfa, sweet clover and red clover. Agron. J 1954;46:247-250.
41. Rutar R, Stjepanovic M, Popovic S, Bukvic Z, Pacek D. Effect of temperature on germination and hard alfalfa seed. CIHEAM 2001;2:137-139.
42. Sacheti U, Al-Rawahy SH. The effects of various pre-treatments on the germination of important leguminous shrub-tree species of the Sultanate of Oman. Seed Science and Technology 1998;26:691- 699.
43. Schneitz K, Hülskamp M, Kopczak SD, Pruitt RE. Dissection of sexual organ ontogenesis: A genetic analysis of ovule development in Arabidopsis thaliana. Development 1997;124:1367-1376.
44. Sharpe RH, Merrill S Jr. Effect of stratification and time of planting on germination of tung seed. Proc. Amer. Soc. horticult. Sci 1942;40:286-291.
45. Shibata T, andHatakeyama Y. Breaking of dormancy in the seeds of *Astragalus mongholicus* Bunge (*Leguminosae*). J Plant Physiol 1995;146:366-368.
46. Skinner DJ, Hill TA, Gasser CS. Regulation of ovule development. Plant Cell 2004;16:S32-S45.
47. Steinbauer GP. Differences in resistance to low temperatures shown by clover varieties. Plant Physiol 1926;1:281-286.
48. Stanwood PC. Tolerance of crop seeds to cooling and storage in liquid nitrogen (-196 °C). J Seed Technol 1980;5:26-31.
49. Staker EV. The effect of dry heat on alfalfa seed and its adulterants. J Am. Soc. Agron 1925;17:32-40.
50. Stewart G. Effect of colour of seed, of scarification and of dry heat on the germination of alfalfa seed and of some of its impurities. J Am. Soc. Agron 1926;18:743-760.
51. Stout DG. Effect of freeze-thaw cycles on hard-seededness of alfalfa. J Seed Technol 1990;14:47-55.
52. Sy A, Grouzis M, Danthu P. Seed germination of seven Sahelian legume species. Journal of Arid Environments 2001;49:875-882.
53. Thompson K, Ooi MKJ. Germination and dormancy breaking: two different things. Seed Science Research 2013;23:1.
54. Tomer R, Maguire JD. Hard seed studies in alfalfa. Seed Res 1989;17:29-31.
55. Uzun F, Aydin I.). Improving germination rate of *Medicago* and *Trifolium* species. Asian J Plant Sci 2004;3:714-717.
56. Van Klinken RD, Flack L. Wet heat as a mechanism for dormancy release and germination of seeds with physical dormancy. Weed Science 2005;53:663-669.
57. Van Klinken RD, Lukitsch B, Cook C. Interaction between seed dormancy-release mechanism, environment and seed bank strategy for a widely distributed perennial legume, *Parkinsonia aculeata* (Caesalpinaceae). Annals of Botany 2008;102:255-264.
58. Win Pe MJ, Hill Margot Johnston EH. Acid Treatment and mechanical scarification. New Zealand Journal of Experimental Agriculture 1975, 1.
59. Weber H, Borisjuk L, Wobus U. Molecular physiology of legume seed development. Annu. Rev. Plant Biol. 2005;56:253-279.
60. Zeng LW, Cocks PS, Kailis SG. Softening of impermeable seeds of six Mediterranean annual legumes on the soil surface and buried beneath the soil surface. Seed Sci. Technol 2005;33:551-561.
61. Zohary D, Hopf M, Weiss E. Domestication of Plants in the Old World, 4th Edn. Oxford: Oxford University Press 2012.