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A REVIEW

Seed hardening

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Abstract : Pre sowing seed hardening with water and solutions of halide salts and growth regulating compounds to induce early germination, better root and seedling growth and increased yield has been employed by several workers. Seed hardening has been investigated by those concerned with problem of mitigating seed germination and seedling emergence under problematic field conditions. Hence, seed hardening is one of the physiological pre-sowing seed management practice given to seeds to resist drought or saline / sodic soils to boost up the yield and is also being practiced from time immemorial owing to the better performance among the agriculturists.

Key Words : Osmo hardening, Bio hardening, Chemical hardening, Seed quality characters

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INTRODUCTION

In India, nearly 70 per cent of cultivated land is rainfed, but accounts for about 42 per cent of the total quantity of produced food grains. Quality seeds play a major role, along with improved package of practices leading to enhanced productivity. The low productivity under rainfed condition is due to use of poor quality seeds, soil moisture deficit, low and erratic rainfall and improper crop management. The most common impediment faced by an Indian farmer is the failure of monsoon, which in its extreme manifestation is called drought. In some of the regions, erratic rainfall leads to drought during the vegetative phase upsetting the water balance of a plant and as a consequence, the physiological functions contributing to growth and yield are deranged. Safe guarding seeds during initial stage of germination will give a special impetus for the seed to overcome the moisture stress condition and develop into a vigorous plant. Though this largely depends on genetic make up of the variety, pre-sowing treatments like hardening are also practiced to challenge the ill effects of drought on emergence and growth of the crop.

Seed hardening :

Henckel (1964) was the first to describe seed hardening as "a simple method to alter the physiological and biochemical nature of the seed in order to induce the factors responsible for drought resistance". Seed hardening technique has come a long way since Henkel's time and modified to suit various needs as determined by environment.

Different physiological activities within the seed occur at different moisture levels and the last physiological activity in the germination process is the emergence of radicle (Vertuci and Leopold, 1984; Taylor, 1997). The initiation of radicle emergence requires high seed water content (upto 30%). By limiting seed water content, all the metabolic steps necessary for germination can occur without the irreversible act of radicle emergence. Prior to radicle emergence, the seed is considered desiccation tolerant, thus the hardened seed moisture content can be reduced by drying. After drying, hardened seeds can be stored for a short time prior to sowing.

Pre-sowing hardening is one of the best methods that results in modifying the physiological and biochemical nature of seed so as to get the characters that are favourable for drought resistance. Pre-sowing hardening is the result of extensive physiological reorganization induced by dehydration process.

It can be done with water / dilute chemical solutions / growth regulating compounds or using commonly available natural tonics like coconut water or milk. Hardening induces early germination, better root and seedling growth, reduces

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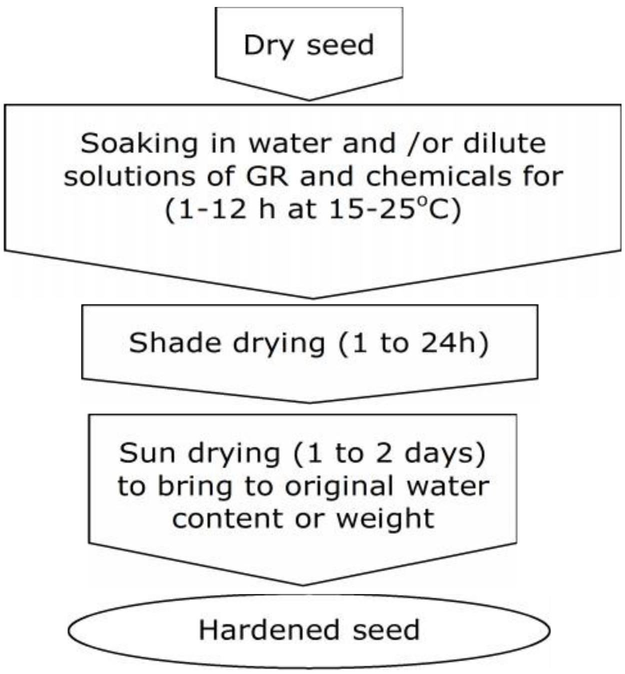
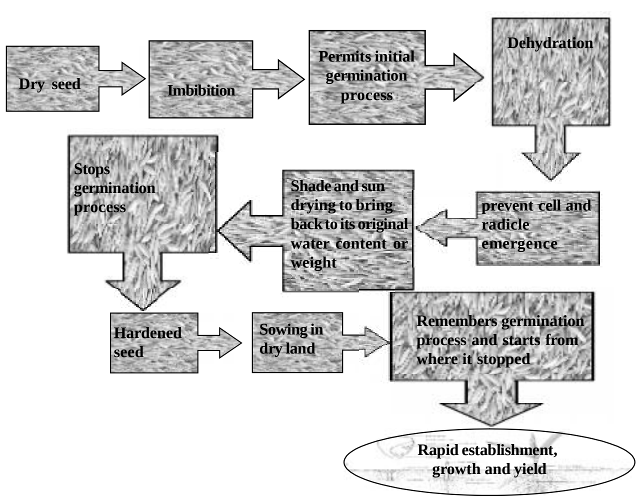
seedling mortality, increases crop population and enhances the yield potential of the crop varieties.

Steps in seed hardening



Principle

During hardening process, a number of physicochemical changes occur that modify the protoplasmic characters, increasing the embryo physiological activity and associated structures. Eventually leading to higher absorption of water, increase in the elasticity of cell and development of a stronger and efficient root system.



Mode of action

The basics for pre-sowing seed hardening, is the significant increase in hydrophilic property of protoplasmic colloids namely viscosity and elasticity; increased mitochondrial phosphorylation, reduction in solute leakage by improving cell membrane integrity, Resumption of rate of protein and RNA synthesis characterized in the first period of imbibition and shortening of the time of DNA replication in the second hydration period, stimulation of long lived mRNA under moisture stress conditions; simultaneous protein and proline content increase after hardening treatments and quenching of free radicals (Simon and Raja Harun, 1972). Pre-sowing treatments also initiate the formation of vital biomolecules, enhance mitochondrial activity and preserve cellular ultrastructres which would allow plants to resist adverse edapho-climatic conditions. The consequences of some of these cellular changes are claimed to include a more xeromorphic structure with higher rate of photosynthesis, lower rate of respiration, lower water deficit, the ability to retain a greater quantity of water and a more efficient root system with higher root-shoot ratio and less yield reduction when subjected again to drought as compared to non-hardened plants (May *et al.*, 1962).

Seed hardening will modify the physiological and biochemical nature of seeds, so as to get the characters that are favourable for drought tolerance. Although it varies from crop to crop, the principle remains same. When dry seeds are soaked in water/chemical solutions, the quiescent cells get hydrated and germination initiated. It also results in enhanced mitochondrial activity leading to the formation of high energy compounds and vital biomolecules. The latent embryo gets enlarged. When the imbibed seeds are dried again, triggered germination is halted. When such seeds are sown, reimbibition begins and the germination event resumes from where it previously ceased.

Beneficial effects of seed hardening includes accelerated rapid germination and growth rate of seedling, greater germination uniformity and increased germination per cent (Basra *et al.*, 2005). Increased germination rate and uniformity have been attributed to metabolic repair processes occurring during imbibitions (Bray,1995), buildup of germination enhancing metabolites (Basra *et al.*, 2005) and reduced imbibition lag time (Bradford, 1986), quick recovery of hardened plants from wilting than those from untreated plants, induction of resistance to salinity and drought situation, ability of seeds to with stand higher temperature for prolonged period, slight acceleration of flowering and capacity to compete more efficiently with weeds due to early emergence and finally resulting in higher yield.

Process :

The hardening resulting from pre-sowing treatments is due to a number of phyto-chemical changes within the cytoplasm including greater hydration of colloids, higher vicosity and elasticity of the protoplasm, increase in hydrophilic and decrease in lipophilic colloids, increase in the temperature required for protein coagulation and increase in bound water content. Root plays a major role as far as moisture extraction and nutrient absorption are concerned. Seed hardening with chemicals and mere water soaking were found to increase root growth even at the seedling stage. This will have a favourable influence on dry land situation prevailing under post monsoon season or conditions of early withdrawal. Increase in root dry weight helps in maintaining high moisture status of plant leaf and increase in productivity. The hardened plants develop a more extensive system, thus enabling them to survive better under drought conditions. It is possible that early radicle emergence and seedling treatment on planting in the field following seed hardening treatments simply give the plant a better start than non-hardened plants. By emerging early in the growing season, seedlings will be able to compete more efficiently with weeds. Further, the germination will be more synchronized which might ultimately lead in establishment of a uniform crop population (Basra *et al*., 2005). Thus, a pretreatment or hardened plant might survive adverse environmental stresses more easily because of its advanced state of development.

Basis of seed hardening :

Henckel (1964) enumerated the following as the basis of pre-sowing seed hardening.

Physiological reorganizations

– Significant increase in hydrophilic property of the protoplasmic colloids namely the viscosity and elasticity.
– Change in quality of proteins.
– Increase in osmotic potential.
– These overall changes leads to increase in water holding capacity of plants.

Metabolic changes :

– Increased respiration.
– High level of synthetic reaction even during drought; leaves of hardened plants have more starch.
– Increased phosphorylation activity of their mitochondria.
– Higher rate of photosynthesis because of increase in the bound water.
– Higher organic phosphorus and nucleoproteins.

Anatomical and morphological change :

– Hardened plants have a more xeromorphic morphology than unhardened ones.
– More extensive and denser network of veins and ribs.
– Epidermal and stomata cells are smaller.
– Number of stomata per unit leaf area is greater.
– Foliage area is increased.
– Faster recovery from atmospheric drought.
– Greater total and absorbing surface in the root system, as well as more number of primary roots.
– Leaves of hardened plants have more starch.

Method of seed hardening :

Seeds are soaked in water and allowed to absorb moisture up to 30-35 per cent of their weight either directly (soaking in water / solutions) or allowed to imbibe slowly (placed between moist fabric/sand) and kept in swollen condition for 1-12 h depending upon the crop / species at 25^0C (lower temperature of 15^0C is found more beneficial) and well aerated.

Then, the seeds are spread as a thin layer under shade for drying for 1 to 2 days. After shade drying, they are sun dried for 1 to 2 days to bring back to the original moisture content or weight. The hardened seeds are used for sowing. The treatment is repeated several times depending upon the kind and variety of crops. This can also be tried by using various concentrations using number of chemicals in sequence or in combination. High temperature treatment of seed can also be attempted for inducing resistance to drought.

Chemicals used for seed hardening :

In addition to water, the following chemicals are recommended (Table 1).

The concentration of chemical, duration of soaking and seed to solution ratio varies depending upon the crop species.

Seed hardening techniques recommended for crops :

Caution :

For seed hardening to be very effective, hard seeds / dormant seeds must not be included. Because, hard seeds will not imbibe while dormant seeds need treatments to alleviate dormancy. Hence, prior to seed hardening, seed lots must be tested for germination and measures taken to reduce dormancy inducing factors.

Advantages :

– Accelerate rapid germination and growth rate of seedling.
– Plants from the treated seeds recover quickly from wilting when compared to plants from untreated seeds.
– Flowering is slightly accelerated in treated plants.
– Induces resistance to drought and salinity.
– Seeds also withstand higher temperature (80-105^0C) for prolonged periods (24-48h) without loss of viability .
– By emerging early, seedlings will be able to compete more effectively with weeds.
– Treated plants are generally better in growth and yield.

Caution :

– Use wide mouth vessel for soaking seeds during hardening.
– Constant stirring during hardening (every 3-5hrs) is essential for effective hardening.

Table 1: Chemicals recommended for seed hardening

Chemicals	Role
Potassium nitrate	Involved in the physiological process of stomatal movement, osmo-regulation, cell wall and membrane permeability
Calcium chloride	Used to activate ATPase and amylase enzymes, participate in starch metabolism
Ammonium sulphate	Used as a constituents of amino acids like cystine, methionine, cystenine
Potassium chloride	Required for activation of enzyme process
Zinc sulphate	It induces the dehydrogenase, alcohol dehydrogenase and lactic dehydrogenase enzyme activity
Potassium di hydrogen phosphate	Used as a constituents of phospholipids, nucleotides and sugar phosphate
Growth regulators	
Growth regulators	Role
Gibberellic acid	Increases hydrolytic enzymes
CCC, Kinetin	Biosynthesis of tRNA and closely related to nucleic acid synthesis
Ascorbic acid	Involved in several oxidation and reduction reactions
Riboflavin	Participate in photo oxidation of IAA
Biotin	Involved in amino acid fatty acid metabolism.
Vitamin	
Vitamins	Role
Vit.K3	Involved in catalytic and regulating functions in cell metabolism.
Nicotinic acid	It interacts with IAA in auxin mediated process, involved in hydrogen transfer process
Pantothenic acid	Used as a component of many co enzymes
Adenine	Increases the rate of DNA replication, rate of RNA and protein biosynthesis.
Botanicals	
Leaf extracts	Role
Pongamia (*Millettia pinnata*)	Bio enhancement due to presence of synergistic plant metabolites
Prosopis (*Prosopis juliflora*)	Stimulatory effects caused by plant growth hormones
Moringa (*Moringa oleifera*)	Stimulatory effects caused by PGR
Pulse sprout extract	Induction of sugars and vitamins that promotes growth
Microbial enhancers	
Microbes / fungi	Role
Azosprillum	Weak source of IAA
Rhizobia	Plant growth hormones and induction of root nodulation
Azatobacter	Source of PGR
Trichoderma viridi	Fungal antagonist and PGR source

Table 2: Seed hardening techniques recommended for crops

Sr. No.	Crop	Salt	Method
	Cereals	General guidelines	The quantity of solution used is very less and hence seeds must be placed in wide mouth vessel / tray and stirred every hour for all the seeds to have access to solution thus promoting aeration, as seed hardening is metabolically active therapy.
1.	Paddy (SRI)	1 % Potassium chloride	40 g in 4 l of water. 4 kg seeds required for an acre are soaked for 16 hrs and then dried back to original moisture content under shade.
2.	Pearl millet	2 % Potassium chloride	42 g in 2 l of water. 3.2 kg seeds required for an acre are soaked for 16 hrs and then dried back to original moisture content under shade.
3.	Ragi	0.2 % Sodium chloride	8.4 g in 4.2 l of water. 6 kg seeds required for an acre are soaked for 16 hrs and then dried back to original moisture content under shade.
4.	Sorghum	2 % Potassium di hydrogen phosphate	120g of salt is dissolved in 6 l of water. 6 kg seeds required for an acre are soaked for 6 hrs and then dried back to original moisture content under shade
5.	Cotton	2 % Potassium chloride / Pungam leaf extract 1 %	78 g of salt is dissolved in 3.9 l of water and 6kg of seeds required per acre soaked for 10 hrs or 650g of fresh pungam leaf paste mixed with 6.5 l of water
	Pulses	General guidelines	Pulse seeds are imbibition sensitive. Water / solution must be used sparingly. Seeds need to be preimbibed by placing in between wet towel / gunny, moistened using water for 1 hr followed by direct soaking in solution.
6.	Redgram	100 ppm Zinc sulphate	300mg salt in 3 l of water for soaking 8 kg of seed/ac for 3 hrs with constant stirring and dried back to original moisture content.
7.	Black gram and Green gram	100 ppm Mangenese sulphate	300mg salt in 3 l of water and soak 8 kg of seed/ac for 3 hrs with constant stirring and dried back to original moisture content.
8.	Bengalgram	1 % Potassium di hydrogen phosphate	24 g in 2.4 l of water and 8 kg of seeds required per ac is soaked for 4 hrs followed by shade drying
9.	Sunflower	2 % Potassium chloride	Dissolve 60g of $ZnSO_4$ in 3 l of water and soak 6kg seeds for 16 hr followed by shade drying.
10.	Groundnut	0.5 % Calcium chloride	60 g of $CaCl_2$ in 1.2 l of water and soak 40kg seeds for 4 hr followed by shade drying

– Hardened seeds cannot be stored for more than 3 weeks. Hence, hardening should be practiced just prior to arrival of monsoon *i.e.* after the receipt of first showers. The hardened seeds must be stored in cool, dry place. Treatment using biofertilizers, bio-control agents can be done on the day of sowing.

Osmo hardening :

Osmo hardening is a technique wherein osmoticants are used for inducing drought hardiness. Osmoticants were the first chemicals tried for seed hardening as they were able to regulate water flow into the seed. Most of the osmoticants are halide salts at lower concentrations of 1-2 per cent. These salts when dissolved in water dissociate into ionic forms and enter into cells and get lodged in vacuoles. Increase in vacuolar concentration raises the osmotic potential of seed, making it negatively osmotic in comparison to water in soil, thus favouring the absorption of moisture from soil even at lower concentrations. This higher negative osmotic concentration is the key to seed hardening phenomenon.

Further, osmoticants proved to impart higher drought tolerance than other chemicals. Henckel (1964) reported that calcium chloride lead to redistribution of nutrient reserves resulting in the greater internodal length in crop. Calcium is most important element in plant during stress, drought condition, has ability to change stomatal movement (Schwartz, 1985; De Silva *et al.*, 1986 and reduces the water losses and maintains high water balance (Chari *et al.*, 1984). Similarly another halide, potassium has shown promise in several studies while sodium and aluminium have also been used, of course sparingly. In most cases the chloride salts have been found to be most effective in comparison sulphates, phosphates and hydroxides as the dissociation of chlorides is faster than other salts requiring low energy of dissociation. Chloride salts are also cheaper compared to other salts.

Elaborate experiments have been done and procedures for seed hardening have been brought to fore for farmers to practice seed hardening. In general, concentration is low (1-3%) and most of the research advocates the use of calcium chloride. The seed to solution ratio is another important criteria. Lower ratios are preferred for large seeds and higher ratios for smaller seeds. Chemicals have been used either individually or in combination with other salts and some times even hormones. The duration of soaking is another area of elaborate research and it varies with crop to crop. In general, seed imbibition studies are conducted prior to seed hardening to determine the soaking duration. The lag phase of imbibition is used as the duration for soaking beyond which, the seeds may start to germinate and get harmed. Benefits included shorter emergence time, increase in seedling dry weight, increase chlorophyll a, b contents, higher alpha amylase content, tiller number, duration of green leaf, sturdier root system, seed weight, yield and economics. The methods advocated for various crops are provided for easy understanding (Table 3).

Role of Osmo seed hardening in improving yield :

Studies by Farooq *et al*. (2006) in rice proved that mere water soaking reduced days for emergence while osmohardening using KCl or CaCl was found to reduce it even further. Higher tiller number was noticed in KCl with concomitant increase in thousand seed weight and kernel yield compared to control (Table 4). This study revealed that seed hardening technique promoted germination and yield. In addition to successful hydration during hardening these salts proved beneficial because of their role in enzyme activation, in particular of hydrolases. This is plausible as a positive correlation exists between seed vigour and field performance of rice (Du and Tuong, 2002). Resultant seeds also possessed higher protein content, longer kernels and higher water absorption which could indicate better cooking quality (Farooq *et al*., 2006) (Table 5).

The physiological basis for improved yield in rice was further elaborated by the experiments of Basra *et al*. (2005) who found that seed hardening improved the activity of alpha amylase activity which led to increase in reducing sugar concentration, thus speeding up the metabolic activity and increased yield. A closer look at the table will reveal the fact that increased soaking duration upto 24hrs improved the alpha amylase activity while prolonged soaking (48hr) was deleterious (Table 6). As the seed enters into log phase of imbibition, the higher metabolic rate needs more oxygen and prolonging the soaking duration, berefts the seed of oxygen, resulting in reduced effect of seed hardening. Further, seed hardening for 24 h resulted in higher germination, higher reducing and total sugars and α amylase activity. The enhanced activity of á amylase during pre-sowing treatments might be attributed to proper hydration during imbibitions that resulted in increased contents of total and reducing sugars and lower contents of non reducing sugars, the hydrolysis hydrolyzed the non reducing sugars in to reducing ones and complex starch to increased contents of total sugars. The benefit of increased starch hydrolysis by hydration treatments were not lost during redrying process, as evident by better rate and spread of germination. These results are in support with the findings of Lee and Kim (2000) reported increased α amylase activity that ultimately resulted in higher germination.

Osmohardening upon visible symptom of radicle emergence:

Several authors have advocated the use of seed hardening as it improves yield. Seed hardening involves soaking of seed in solutions for specified time and stopped prior to visible growth of embryonic axis. But experiments involving fingermillet (*Eleusine coracana*) seeds by soaking them in 0.5% $CaCl_2$ at 1: 1 ratio until viable expression of embryonic growth and then shade drying back to original

Table 3: List of crops and Osmo-hardening treatments tried along with their promontory effects (crop wise chronological order)

Sr.No	Crop	Osmo Chemicals used for seed hardening and their concentration	Effect on crop	Authors
1.	Upland rice	KCl and $CaCl_2$ 12 h	Maximum germination and seedling vigour	Nagaraj (1996)
2.	Rice	$CaCl_2$ 1%	Recorded significantly more grain yield and also increase in plant height, dry matter accumulation, grain number per ear head and 1000-grain weight as compared to that of untreated control	Ananda and Reddy (2002)
3.	Rice	$CaCl_2$ 1%	Successfully be integrated for vigour enhancement in coarse rice and performed better than control	Farooq *et al.* (2006)
4.	Rice	KCl 1% for 12 h and coating with Polykote® @ 3 g kg^{-1}.	Seeds significantly increased the seed germination, shoot and root length, dry matter production, vigour index and α-amylase, field emergence, chlorophyll content, protein content, and proline content over control	Susmitha (2006)
5.	Wheat	Seeds treated with KCl and distilled water	More plant height, enhanced tiller production, number of green leaves, leaf area and shoot dry weight significantly as compared to the control.	Misra and Dwivedi (1980)
6.	Wheat	$CaCl_2$ 2 %	Higher yield by 19 per cent as compared to control (untreated)	Ameregouda *et al.* (1994)
7.	Wheat	$CaCl_2$ or $AlCl_3$	Higher proline content under salt stress condition than unsoaked seed (control).	Migahid and Sadek (1994)
8.	Wheat	$CaCl_2$ 2%	Significant improvement in chlorophyll "a" and chlorophyll "b" as compared to that of untreated seeds.	Narendra *et al.* (2000)
9.	Wheat	$CaCl_2$ -2.5%	significantly higher number of effective tillers per plant or per meter row length, ear head length, number of spikelets per ear head, number of grains per ear head and eventually the yield .	Ugale and Mungse 2001
10.	Sorghum	$CaCl_2$ -2% at 1:1 (seed:solution) for four hours	Increased drought resistance and also increased the grain yield by 10 per cent over that of control.	Patil (1987)
11.	Sorghum	$CaCl_2$ -0.4 % and 0.2 % CCC	Increased the germination percentage, vigour index and root shoot ratio.	Rangaswamy *et al.* (1993)
12.	Sorghum	$CaCl_2$ -0.4 % and CCC -0.2%	Increased root length, root spread, grain and stover yield	Nirmala *et al.* (1994).
13.	Maize	$CaCl_2$ -2% at 1:3 (seed:solution) ratio	Recorded significantly higher plant height, LAI and total dry matter at different growth stages in maize as compared to untreated control.	Kulkarni and Eshanna (1988)
14.	Maize	$CaCl_2$ -0.3 % and 0.1 % $ZnSO_4$ either individually or in combination	The increased germination rate, seedling vigour, seedling fresh weight, seedling height and root length	Fasui *et al.* (1996)
15.	Pearl millet	KCl - 2 % or NaCl - 3 % at 1: 1 ratio for 6 hours followed by 5 hours shade drying.	Improved germination and final yield	Kadiri and Hussaini (1999)
16.	Ragi	$CaCl_2$ -1 %	Improved the seedling growth characters	Viswanath *et al* . (1972)
17.	Ragi	$CaCl_2$ -2.5 %	Recorded increased tillering, plant height, root length and DMP resulting in enhanced yield.	(Karivaratharaju and Ramakrishna, 1985).
18.	Ragi	NaCl -1.5%	Increased dry matter	(Karivaradaraju and Ramakrishnan (1985a)
19.	Ragi	$CaCl_2$ - 0.25% or 2.5% KCl (1%).	Increased the yield compared to control	Avjit Sen and Misra (1987)
20.	Ragi	KCl -1 %	Better germination and seedling vigour	Punithvathi (1997)
21.	Ragi	$CaCl_2$ -0.25 %, KH_2PO_4 -100 ppm and Na_2HPO_4 -100 ppm	Increased the plant height, LAI, LAD and dry matter accumulation at different growth stages	Maitra *et al.* (1998)
22.	Ragi	KCl -1 % + $CaCl_2$ -1%	Increased the grain yield	Kalarani *et al.* (2001)
23.	Chickpea	$CaCl_2$ -2 %	Increased morpho-physiological traits	Manjunath and Dhanoji (2011)
24.	Groundnut	$CaCl_2$ -1%	Improved the field emergence and yield components	Jujjuri venkata Rao (1988).
25.	Groundnut	$CaCl_2$ -1 %	Increased germination and yield attributes	Arjunan and Srinivasan (1989)
26.	Groundnut	Ca $(OH)_2$ -0.15 % and $CaCl_2$ -1.5 %	Improved the emergence index	Sandhya and Gopal Singh (1994)
27.	Groundnut	$CaCl_2$ -0.25 %	Induced the drought resistance	Pandey and Sinha (1999)
28.	Sunflower	Zinc Sulphate -1 % 6 h	Improved seed quality parameters.	Shaffee Ahamed (1997)
29.	Cotton	CaOH -2 and 4 % and KCl -1 %	Improved the germination and vigour	SenthilKumar (1993)
30.	Cotton	KCl -2 %	Better productivity of quality seed	Nirmala (2002)

Table 4: Effect of seed hardening on germination and yield in direct seeded coarse rice (Farooq *et al*., 2006)

Treatments	Days to 50% emergence	Tillers (No.m^{-2})	Branches/ panicle	1000 kernel weight (g)	Kernel yield (t .ha^{-1})
Hardening using water	4.39	713.3	24.0	17.00	3.03
Osmo hardening (KCl)	4.00	738.5	22.0	19.00	3.23
Osmo hardening ($CaCl_2$)	4.30	716.0	24.3	16.33	3.11
Control	5.35	623.3	21.2	16.33	2.71

Table 5: Effect of seed hardening on kernel quality of direct seeded fine rice (Farooq *et al*., 2006)

Treatments	Number of kernels per panicle	1000 kernel weight (g)	Kernel yield (t/ha)	Kernel protein (%)	Kernel amylase (%)	Kernel length (mm)	Kernel water absorption ratio
Control	81.00	14.67	2.11	7.62	28.50	6.11	3.99
Traditional soaking	81.33	14.33	2.01	7.60	28.74	6.24	4.12
Osmo hardening (KCl)	86.33	15.67	2.76	8.00	26.17	6.31	4.35
Osmo hardening ($CaCl_2$)	84.00	17.00	2.96	8.16	25.61	6.34	4.46

Table 6 : Effect of pre-sowing seed treatments on the biochemical changes in the fine rice seeds (Basra *et al*., 2005)

Treatments	α amylase activity (unit)	Total sugar (mg/g)	Reducing sugars (mg/g)	Non reducing sugars (mg/g)
Control	1.71	8.42	5.25	3.17
Traditional soaking	7.17	14.76	12.84	1.92
Seed hardening 18 h	4.58	12.18	10.16	2.01
Seed hardening 24 h	9.76	16.30	14.65	1.65
Osmo hardening 24 h	4.49	12.01	12.00	2.05
Osmo hardening 48 h	10.3	7.51	4.61	2.89

moisture content was tried. It was found that seed soaked with KCl + $CaCl_2$ solution recorded a yield increase of 19.6 per cent in var. CO-13, 17.5 per cent in var. PR-202 and 13.9 per cent in var. Indaf 9 over the control. The yield increase was due to maintenance of higher LAI. Osmo hardening of fingermillet resulted in shorter emergence time which may be crucial in rainfed situations, wherein the moisture received through rain may dry out if there is a gap in continuity of rainfall. Similarly a technique of using dried hardened pre germinated groundnut seed has been developed (Ponnuswamy, 2005).This technology has been adopted for seed lot with lower germination (60-70 per cent). The kernels are soaked in 0.5 % $CaCl_2$ solution at 1:1/2 ratio for 6 h and kept in dark in between moist gunny bags for 14-16 h. This leads to radicle emergence found in 30-40 per cent of seeds, the radicle emerged kernels are hand picked and air dried under shade. The ungerminated seeds are again kept under moist condition by covering with the same moist gunny bag for another two to three hours the process of separation of sprouted (viable) seeds are repeated. The hand picked sprouted kernels should be air dried under shade by spreading over dry gunny bags for three to four hours and can be sown immediately or within one to two days after treatment. The seeds hardened with $CaCl_2$ recorded higher germination and maintaining higher plant population, pod and seed yield (Ponnuswamy, 2005; Paramasivam, 2005).

Chemical hardening :

Most of the seed hardening studies earlier involved the use of chlorides of calcium and potassium. Later, experiments proved that other than salts, organic acids, enzymes, hormones, vitamins could be used. Halide salts impart physiological resistance to seeds under drought or saline conditions. Calcium and potassium chlorides alone or in combination, and phosphates of potassium have proved to beneficial in several occasions. Similarly heavy metal salts of boron, molybdenum, manganese, zinc have also proved appropriate for some crops.

However, they alone are insufficient to impart the ability to withstand enimical conditions. Hormones would be essential to speed up the metabolic processes involved and thereby impart drought hardiness. Mild hormonal concentrations of IAA, NAA, GA, CCC, MH have also been tried successfully. Several experiments have led to the conclusion that hormones and vitamin impart higher seed setting ability (Sunflower – Karivaratharaju *et al*., 1974), increased net assimilation rate and relative growth rate (pearlmillet – Kamala Thirumalaiswamy and Sakharam Rao, 1977); early flowering and ear emergence (maize – Asthana and Srivastava, 1978) to name a few. Similarly organic acids like citric, ascorbic, succinic acids have been tried. A brief review of seed hardening treatments using salts other than Ca or K have been summarized (Table 5). The list is not

Table 7: List of crops and chemical hardening treatments tried along with their promontory effects (crop wise chronological order)

Sr. No.	Crop	Osmo chemicals used for seed hardening and their concentration	Effect on crop	Authors
1.	Rice	Seeds treated with KNO_3 and Na_2HPO_4 (10^{-3} to10^{-5} M)	Maximum augmentation of seed quality attributes and yield parameters with disodium hydrogen phosphate	Geetha (1992)
2.	Rice	Seed hardening with water for 24 h	Higher germination percentage, higher reducing and total sugars and α amlylase activity	Basra *et al*. (2005)
3.	Wheat	Soaking of seed with Cycocel	Decreased the shoot growth and leaf area per plant progressively with increase in concentration by 10, 40 and 80 ppm, but the radical growth was increased considerably.	De *et al.* (1982)
4.	Wheat	Cycocel (500 ppm) applied as seed treatment	Decreased plant height and delayed flowering and maturation by 4 to 5 days as compared to control.	Dighe *et al.* (1983)
5.	Wheat	Seed treatment with Cycocel - 0.1% and KH_2PO_4 - 5%	Increased yield and nutrient uptake of late sown wheat	Bhatia and Rathore (1988)
6.	Wheat	Seed hardening with 10^{-5}M GA_3, kinetin or IAA or 10^{-4} cycocel	Increased number of leaves per plant, root, stem and total dry matter, RGR, NAR and LWR in wheat as compared to control.	Singh *et al.* (1991).
7.	Wheat	Seed hardening with 1.0% muriate of potash	Increased the grain yield (32 %) over control in Assam hill zone	Paul *et al.* (1998).
8.	Sorghum	Seed hardening of with water for 12 hours	Improved total dry matter and leaf area of plants.	Henkel (1961).
9.	Sorghum	Pre-sowing seed soaking in 1% KH_2PO_4 solution for 12 hours	Influenced plant growth, uptake of nutrients, 1000 grain weight and grain yield	Gopalakrishnan (1965).
10.	Sorghum	Seeds soaked in 1% solution of KNO_3 and KH_2PO_4. stated that overnight	The increase in sugar content would stimulate drought resistance through increased osmotic pressure and water uptake	Balasubramanian (1976).
11.	Sorghum	Soaking of seeds in water for 12 hrs	Hastened the flowering period by 96.83 days as against 100 days for control.	Singh *et al.* (1984)
12.	Sorghum	Soaking of seeds in 1 x 10^{-5} molar abscissic acid (ABA)	Increased the grain yield of water stressed plants	Traware and Sullivan, (1988)
13.	Sorghum	2 % KH_2PO_4	Enhanced field emergence, and growth parameters	Selvaraju (1992)
14.	Sorghum	The pre-sowing seed hardening treatments with 100 ppm of $CaCl_2$, KNO_3, ascorbic acid, pyridoxinehydrochloride, IAA and GA	Increased chlorophyll content	Kadiri and Hussaini (1999).
15.	Sorghum	Pre-sowing seed treatment with water, mineral solutions *viz.*, $CaCl_2$, $ZnSO_4$, $CoSO_4$, K_2SO_4,$CuSO_4$,$NaMoO_4$, H_3BO_3 and $MnSO_4$ or growth regulators *viz.*, ascorbic acid, kinetin, benzyl adenine, gibberellic acid and cycocel alone and in combination	Speed up germination process and increased the rate of germination, seedling vigour, resistance to water and salinity stress and finally the crop yield	Kulkarni and Chittapur (2003)
16.	Sorghum	Seed hardening with 2 % KH_2PO_4 followed by pelleting with DAP	Recorded higher seed yield and other growth parameters	Geetha and Selvakumari (2008).
17.	Pearl millet	Seed treatment with distilled water, CCC 5 ppm and kinetin 5 ppm	Slightly increased net assimilation rate (NAR), relative growth rate (RGR) and leaf area	Kamala Thirumalaiswamy and Sakharam Rao (1977)

Table 7 : Contd…………..

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18.	Pearl millet	KH_2PO_4 2 %	Improved grain yield	Menaka (2003)
19.	Pearl millet	The seed invigourated with 2 % KH_2 PO_4	improved seed germination seedling dry weight, field stand and seed yield	Bharathi *et al.* (2004).
20.	Ragi	Pre-sowing seed hardening	increased early germination, vigorous seedlings production and yield	Krishna Sastry *et al.* (1969).
21.	Ragi	KH_2PO_4 dibasic 20 %	Improved the grain and straw yield	Narayanan (1981)
22.	Ragi	Seed soaked in 100 ppm Na_2HPO_4	Improvement in plant height, tillering, LAl, LAD, CGR, DMP and yield	Maitra *et al.*(1997).
23.	Ragi	Brassinolide 0.1 ppm	Increased yield	Vigneshwari (2002)
24.	Maize	Ascorbic acid and Salicylic acid	Hastened the flowering and ear emergence	Asthana and Srivastava (1978)
25.	Maize	Seeds soaked in 20 ppm GA_3 for 30 min	Improved some germination traits, but could not affect grain yield	Subedi and Ma (2005).
26.	Black gram	Impregnated with succinic acid, cobalt nitrate, zinc sulphate, ascorbic acid, sodium molylbdate, potassium chloride, potassium sulphate, manganese sulphate and IBA.	Among the chemicals ascorbic acid would enable the plants to reach 50 % flowering phase early and produce more of large sized seeds	Vijayakumar (1982).
27.	Blackgram	Seeds hardened with succinic acid 20 ppm, cobalt nitrate 1 %, ascorbic acid 20 ppm, sodium molylbdate 100 ppm, zinc sulphate 100 ppm, potassium chloride 100 ppm, potassium sulphate 100 ppm, manganese sulphate 100ppm and IBA 200 ppm using 1/3 rd volume of seed to solution ratio	Increased the initial quality and yield	Vanangamudi and Karivaratharaju (1986)
28.	Blackgram and Cowpea	Sodium dihydrogen phosphate, potassium dihydrogen phosphate (10^{-4} M)	Increased yield of 15.3 to 18.0 % and 7.2 to 10.9 % in cowpea and blackgram, respectively.	Sujatha (1994)
29.	Blackgram	Seeds hardened with 100 ppm $ZnSO_4$ for 3 h	recorded higher germination, seedling vigour, total chlorophyll content, dehydrogenase and α-amylase activity under laboratory condition	Kavitha (2005).
30.	Blackgram	Moist sand conditioning with KH_2PO_4 or NaH_2 PO_4 followed by drying	It was effective against ageing	Sujatha *et al*. 2005).
31.	Blackgram	Seed hardening with KCl	improved the seed germination and other quality parameters compared to control	Srimathi and Sujatha (2006)
32.	Blackgram	Soaking the seeds in 0.5% KNO_3 for 4 h duration	Seed germination and seedling vigour of blackgram cv.VBN3 seed could be improved	Surulirajan (2007).
33.	Greengram	Seeds fortified with succinic acid, cobalt nitrate, ascorbic acid, sodium molylbdate, zinc sulphate, potassium chloride, potassium sulphate, manganese sulphate and IBA.	manganese sulphate was found to promote the growth of resulting crop and yield good quality seeds associated with good storability	Mubarakbasha, (1982).
34.	Greengram	Seeds given the invigoration treatment (hydration dehydration treatment)	increased the DMP and seed yield as compared to the control	Dharmalingam and Basu (1989).
35.	Greengram	Pre-sowing seed treatment with 0.75 % cytozyme for 4 h	Enhanced germination. root length, shoot length and vigour index	Mugunthan (1986).

Table 7 : Contd……….

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36.	Greengram	$MnSO_4$ 10 ppm	Improved the seed quality characters	Subbian *et al*. (1987)
37.	Greengram	Water soaking	Quickening the germination process and enhanced yield attributing characters	Dharmalingam and Basu (1989)
38.	Greengram	Na_2HPO_4 50 ppm and succinic acid 20 ppm	Improved the seed yield	Sabir-Ahamed (1999)
39.	Greengram	$MnSO_4$ 100 ppm	Increased seed quality characters	Shenbaganathan (2002)
40.	Red gram	Seeds hardened with succinic acid 20 ppm, cobalt nitrate 1 %, ascorbic acid 20 ppm, sodium molylbdate 100 ppm, zinc sulphate 100 ppm, potassium chloride 100 ppm, potassium sulphate 100 ppm, manganese sulphate 100ppm and IBA 200 ppm using 1/3 rd volume of seed to solution ratio	Beneficial effects produced by zinc sulphate on field emergence, growth and production of quality seeds as well as storability	Rajendran (1982).
41.	Redgram	Treating the seeds in molybdenum (100 mg kg-l of seed in one litre of water)	Increased the hundred seed weight but the differences in the number as well as weight of pods and seed yield were not expressive due to treatment	Karivaratharaju and Ramakrishnan (1985a).
42.	Redgram	Ammonium molybdate	improvement in yield nodulation	Xia *et al*.(1989)
43.	Redgram	Sodium molybdate	Improvement in yield and nodulation	Khan and Hedge (1989)
44.	Red gram	Pre-sowing soaking with calcium chloride at 0.4% and cycoel at 0.2%	Improved germination, vigour index and root shoot ratio	Rangaswamy *et al.* (1993).
45.	Redgram	Ferrous sulphate 1 %	Yield improvement	Renugadevi *et al.* (2001)
46.	Cowpea and Blackgram	seeds fortified with $ZnSO_4$ + $MnSO_4$ + Na_2MO_4	Registered the maximum rate of germination, field emergence, root and shoot length, dry matter production and vigour index	Vijaya (1996)
47.	Soybean	Water soaking	Quickening the germination process and enhanced yield attributing characters	Gopal singh (1995)
48.	Soybean	IAA+ NAA 10 ppm 6 h	Increased seed quality parameters	Nair and Deogirikar (2011)
49.	Chickpea	Water soaking	Enhanced seed quality characters and enzyme activity	Singh and Kumar (1992)
50.	Sunflower	KNO_3 500 ppm	Alleviate the water stress on germinability	Kathiresan *et al*. (1984)
51.	Sunflower	$ZnSO_4$ 1 % for 6 h	Improved seed quality parameters	Shaffee Ahamed (1997)
52.	Sunflower	MH,TIBA, NAA for 3 h	Improved germination and seedling vigour	Tamil Selvan (1997)
53.	Sunflower	Seed hydration for 24 h followed by drying	Increased yield	Khan *et al.* (2003)
54.	Groundnut	Low vigour seeds hydrated for 16 h followed by air drying	Higher speed of emergence, field emergence, better crop establishment and increased pod yield	Dhedhi *et al.* (2007)
55.	Cotton	CCC 1000 ppm for 6 h	Improved the vigour of the seedlings ad efficient root system	Pothiraj and Sankaran (1984)
56.	Cotton	KCl or CCC 100 ppm	Increased DMP was observed	Thandapani and Subbarayalu (1986)
57.	Cotton	Soaking in succinic acid 100 ppm	Proved superior in quality characters.	Sundarambal (1995).

exhaustive and has been provided as an indication of scientific works carriedout.

Seed hardening with 0.1 ppm brassinolide for 6 h excelled others in improving germination, dry matter, vigour index, á-amylase activity, chlorophyll content and laboratory condition in bajra. In field study, seeds hardened with 0.1 ppm brassinoloide gave higher percentage of field emergence, no. of protective tillers, weight of the ear head and also grain yield compared to other treatments. However, a comparison of seed hardening with organic acids and mild hormones along with potassium chloride revealed the fact that potassium chloride topped the list in providing statistically higher yield (Menaka and Vanangamudi, 2008) (Table 8).

The above may not be true always, as crop response differs for seed hardening. In sunflower highest yield was attributed to seed hardening with 1-2 per cent zinc sulphate (12 hr soaking) compared to other salts (Muthuvel *et al*., 1983). This was noticed in both seasons and trend continued among oil yield with 2 per cent concentration scoring higher over 1 per cent (Table 9).

Seed hardening studies in horticultural crops :

Vegetable crop seeds have also been subjected to seed hardening. Horticultural crops seeds are of high value, low seed rate and possess low germination due to morphological or physiological barriers. Improving the crop stand becomes the prime motive of a vegetable farmer and direct sowing is mostly avoided with preference for nursery. Direct sowing becomes important for large scale farming as labour becomes dearer and uneconomical. This has prompted the horticultural scientists to tred into the realm of seed hardening. However, the chemicals used are not merely salts of halides but heavy metals like molybdenum, boron along with growth promoting hormones. Use of rare elements *viz*., molybdenum and boron could be justified for their positive role in improving hormonal / enzymatic performance as most of them or co-factors for enzymes. Several plant enhancements *viz*., improved germination, germination rate, increased yield, improved fruit quality have been attributed to seed hardening treatments. But most of the research point towards improved germination and germination rate (Table 10).

Biohardening :

Biohardening is a novel concept that is being currently developed and researched. Biohardening involves use of biological products or organisms. Biological products may be of plant or animal origin. Plant parts or products can be used either fresh or dried. Animal products like diluted urine or panchagavya, milk can also be used for hardening. Beneficial microbes like *Azotobacter*, *Azosprillum*, rhizobia, *Pseudomonas* and fungal antagonists like *Trichoderma vridi* can be used as presowing seed hardening treatments. Even dilute solutions of seaweed extract was found to impart vigour to hardened seeds. Biohardening is simple and uses materials available with farmer and is economical and ecofriendly.

Experiments using ground fresh plant parts have been carriedout and such organic products from botanical sources are easily available to the farmer, they are cheap alternative to

Table 8: Effect of seed hardening on yield attributing characters in bajra (Menaka and Vanangamudi, 2008)

Treatments	Field emergence (%)	Number of protective of tillers	Weight of ear head (g)	Grain yield kg/ha
Control	78	4.0	42.5	2140
KCl 2 %	92	6.2	45.3	2518
Brassinolide 0.1 ppm	77	5.3	44.5	2413
Salicylic acid 200 ppm	75	5.1	44.3	2317
Mean	80	5.4	44.2	2349
C.D. (p=0.05)	0.931	0.890	0.703	86.204

Table 9: Effect of seed hardening in micro nutrients of sunflower (Muthuvel *et al*., 1983)

Treatments	*Kharif* 1982		Summer 1982	
	Seed yield (kg/ha)	Oil yield (kg/ha)	Seed yield (kg/ha)	Oil yield (kg/ha)
Water soaking	1054	446	1252	552
0.5 % $ZnSO_4$	1079	446	1280	572
1.0 % $ZnSO_4$	1181	471	1411	633
2.0 % $ZnSO_4$	1195	488	1531	673
0.5 % $MnSO_4$	1032	418	1237	559
1.0 % $MnSO_4$	1160	482	1307	578
2.0 % $MnSO_4$	1100	432	1314	597
0.5 % $NaMoO_4$	1144	462	1311	602
C.D. (p=0.05)	27.4	25.0	102	56

chemical methods. Examples of plant products used are - garlic (*Allium sativum* (L.) extract, coconut (*Cocos nucifera* (L.)) water, leaf extracts of prosopis (*Prosopis juliflora* (Sw.) DC.), moringa (*Moringa oleifera* (Lam.), pungam (*Millettia pinnata* (L.) Panigrahi) and Neem (*Azadirachta indica* L.). The extracts can be used alone or in combination. The research is still in its infancy. A gist of experiments tried for various crops using bio-hardening techniques and their effect has been provided in Table 11.

The beneficial effects of biological products could be attributed to the presence of plant hormones that stimulate

Table 10: Research in horticultural crop seed hardening (chronological order)

Sr. No.	Crop	Chemical used for seed hardening and their concentration	Effect on crop	Authors
1.	Onion	$MnSO_4$ 0.05,0.1 and 0.5 % for 12 h	Increased germination	Ozerov and Ozerov (1960)
2.	Tomato	0.05-2 % KH_2PO_4 and KNO3	Higher germination rate	Ellis (1963)
3.	Tomato	2 % KH_2PO_4 and KNO_3 2 %	Increased germination rate and percentage	Woodstock (1969)
4.	Carrot	KH_2PO_4	Increased field emergence	Hegarty (1970)
5.	Sugarbeet	0.05 % KNO_3, 0.01 % boron and 0.03 % $ZnSO_4$ for 24 h	Increased yield and sugar content	Namedov (1971)
6.	Carrot	Soaking in boron, manganese, cobalt and molybdenum	Increased yield	Alekseeva and Rasskezaov (1976)
7.	Tomato	0.2 % copper sulphate and 0.03 % boric acid	Increased fruit maturation and fruit yield	Kargopolova (1976)
8.	Tomato	1-1.5 % KNO_3	Increase yield	Dimov *et al.* (1978)
9.	Cauliflower	Molybdenum for 30 min	Improved the field emergence	Motta De and Leon (1978)
10.	Fenugreek	Ammonium sulphate, manganese sulphate and boric acid @ 0.1 to 1 % for 1 h	Increased germination and seedling growth	Saraswathamma and Jayachandra (1979)
11.	Papaya	Mono and di sodium phosphate and EDTA for 12 h	Improved germination	Veeraraghavatham *et al* . (1980)
12.	Faba bean	Sodium molybdate	Improvement in yield nodulation	Iliev *et al*., (1989)
13.	Ash gourd	KNO_3 1 % 12 h	Enhanced the speed of germination and seed quality characters	Renugadevi (1992)
14.	Papaya	Presoaking in GA_3 100 ppm for 16 h	Improved germination and seedling vigour	Anantha Kalaiselvi Selvi (1995)
15.	Cassava	Soaking the seeds in potassium nitrate (0.5 %) for 24 h	Enhanced germination and seedling vigour	Napoleon (1995)
16.	Carrot	Soaking the seeds in water for 3 days and drying and pyridoxine 0.5 % for 12 h	Enhanced speed of germination and vigour	Sundaralingam (1995)
17.	Carrot	$FeSO_4$ 0.2 % for 2 h	Increased germination and seedling growth	Ramesh (1996)
18.	Carrot	GA_3 and ethrel	Increased germination and field emergence	Bevilaqua *et al*., (1998)
19.	Amaranthus	Ethrel 200 ppm for 12 h	Increased germination	Menaka *et al*. (2008)
20.	Ash gourd	KNO_3 1 % 6h	Enhanced the speed of germination and seed quality characters	Sakthivel (2003)
21.	Cluster bean	GA_3 200 ppm	Improved the seed quality characters	Renugadevi (2004)
22.	China aster	$ZnSO_4$ 0.25 % for 2 h	Improved germination	Selvakumari *et al*.(2007)
23.	Petunia	GA_3 100 ppm or moringa leaf extract or KH_2PO_4 2 % for 16 h	Improved the germination and emergence	Natarajan (2003)

Table 11 : List of crops and bio-hardening treatments tried along with their promontory effects

Sr. No.	Crop	Botanicals used for seed hardening and their concentration	Effect on crop	Authors
1.	Rice	Hardening with leaf extracts of 1 % prosopis + acacia and prosopis + pungam	Higher germination and seedling vigour	Nagaraj (1996)
2.	Rice	Seeds soaked in 10% cow dung extract for 12 h	Registered more germination, root and shoot length compared with untreated seeds	Kamalam Joseph and Rajappa Nair (1989)
3.	Rice	Seed treatment with cow urine.	Beneficial effect on germination, growth components *viz.*, plant height, number of leaves, leaf area and yield components like number of grains, tiller number, grain weight and yield of crops	Kamalam Joseph and Rajappan Nair (1989)
4.	Rice	Seeds treated with 2.5% neem kernel extract	Resulted in more vigorous seedlings than untreated seeds	Kareem *et al*. (1989)
5.	Rice	seed treatment with cow dung extract	Increased the plant height, dry matter production and yield of paddy under rainfed condition as compared to untreated seeds	Salakinkop *et al.* (1996)
6.	Rice	Seed biofortification with *Azospirillum*	Increased certain physiological traits *viz.*, amylase activity, speed of germination, seedling length and seedling dry weight in low and high vigour seeds.	Ramamoorthy *et al.* (2000)
7.	Rice	*Pseudomonas fluorescens* @10 g kg^{-1} seedlings.	Increased per cent germination by 26.3 –52.6 % and there was similar increase in root length, shoot length and fresh weight of seedlings	Mishra and Sinha (2000)
8.	Rice	Seeds soaked in 0.5 % sargassum seaweed extract followed by drying.	Effective only in stored seeds enhancing the speed of germination, seedling length, dry matter production, dehydrogenase activity	Ramamoorthy *et al*. (2005)
9.	Rice	Panchagavya	Maximum seed quality parameters	Vijayan (2005)
10.	Hybrid Rice	Panchagavya	Maximum speed of germination and percentage	Sundaralingam (2005)
11.	Sorghum	Seeds hardened with aqueous solution of botanicals	Seed quality parameters and yield attributes significantly better than control	Jegathambal (1996)
12.	Sorghum	Seed hardening with calotropis leaf extract 2%	Higher seed germination (76%) and vigour index (969.1) of were recorded	Devarani and Rangasamy (1998)
13.	Maize	*Azospirillum* inoculation	Improved the physiological status by ameliorating the harmful effects of water short fall during the flowering period which will help in increase in grain production	Casanovas *et al.* (2003)
14.	Finger millet	Prosopis leaf extract (1%) seed hardening and pelleting using potassium di hydrogen ortho phosphate and DAP (1%)	Improve germination and yield	Vigneswari *et al.* (2005)
15.	Blackgram, Sunflower and Maize	Chicory leaf extract 20 %	Increased seed quality parameters	Vanitha (2005)
16.	Blackgram	Panchagavya 4 % 4 h	Improved germination and seedling characters	Manimekalai (2006)
17.	Blackgram	0.5 % KNO_3 + 2% moringa leaf extract	Increased germination	Surulirajan (2007)
18.	Blackgram	Sargassum seaweed 0.75 % as seed treatment	Aged seeds exhibited higher activity of free radical scavenging enzyme catalase, lower amounts of leachate amino acids, sugar and lipid per oxidation and also enhancement in germination and dry matter production	Ramamoorthy and Sujatha (2007)
19.	Cowpea and Bhendi	Seed hardening with prosopis leaf extract	Increased the field emergence and yield potential	Sasikala (1997)

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20.	Cowpea	Seeds soaked in 0.5 and 0.75 % in sargassum (seaweed extract)	Better performance could be observed on speed of germination, seedling and dry matter production and the deterioration was minimum in treated seeds	Ramamoorthy *et al*.(2006).
21.	Cowpea	Occimum 10% chicory 20% calotropis 15%	Increased seed quality parameters , growth and yield attributes	Sujatha and Ramamoorthy (2008)
22.	Cluster bean	Arappu 2 % leaf extract	Improved the seed quality characters	Renugadevi (2004)
23.	Bengal gram	Vermi wash and cow urine	Improved the seed quality parameters	Deshpande *et al*. (2008)
24.	Sesamum	Tamarind leaf extract 2%	Increased seed quality parameters	Suma (2005)
25.	Sunflower	Panchakavya 2 % 6 h	Improved seed quality parameters	Nguyen Thai Thinh (2006)
26.	Cotton	Seed hardening with prosopis 0.5% and pungam leaf extract 1.0%	Registered increase in field emergence, DMP and plant height	Rathinavel and Dharmalingam (1999).
27.	Bitter gourd	Panchagavya 3 % 9 h	Maximum germination and vigour	Thirusendura selvi (2003)
28.	Brinjal	Arappu (*Albizia amara*), Acacia (A. *nilotica*), Neem (A. *indica*), Notchi (*Vitex negundo*) and Pungam (M. *pinnata*)	Improved the germination and physiological potential	Viswanatha Reddy (1995)

the growth of embryo. Research by Kamalam Joseph and Nair (1989) revealed the effect of cow dung extract (10%) over germination and vigour of rice seeds which was 6% higher then control while nitric acid was inhibitory. Cowdung contains ammonia while cow urine contains plant growth hormones that could have attributed towards the invogration (Table 12).

A comparison of botanicals and animal products for seed hardening extolled the virtues of calotrophis leaf extract (2%) and cowdung extract (15%) in sorghum (Devarani and Rangasamy, 1998). However, the research also brought out the role of botanical products which in all cases were beneficial for sorghum seed germination while among the animal product, excreta from cow either as urine or dung was alone superior when compared to goat (Table 13).

Table 12 : Effect of treatments on germination percentage and vigour index in rice (Kamalam Joseph and Nair,1989)

Treatments	Germination (%)	Vigour index
Dry (control)	70.12	383
Water	75.99	526
Cow’s urine 5 %	73.67	465
Cow’s urine 10 %	76.40	413
Cow dung extract 10 %	77.57	693
N/10 nitric acid	66.60	377
C.D.(P=0.05)	-	101.44

Table 13: Seed hardening on germination and vigour index of sorghum (Devarani and Rangasamy, 1998)

Seed hardening	Germination (%)	Vigour index
Control	63	587.3
Water	65	697.2
Goat urine 15%	66	708.4
Cow dung extract 15%	76	895.0
Garlic extract 2%	70	775.1
Calotropis leaf extract 2%	76	969.1
Cow urine 5%	58	548.2
Morinda leaf extract 2%	70	765.0
KH_2PO_4	70	761.2
C.D. 5 %	2.8	37.3

Comparison of traditional seed hardening with osmoticants and leaf extracts were experimented by Palanisamy and Punithavathi (1998) in fingermillet who revealed the synergistic effect of pelleting with botanicals and chemical seed hardening (Table 14). Seeds hardened with KCl 1% followed by pelleting with pungam leaf power (60 g/kg of seed) recorded higher germination (93.0%), root length (9.5 cm), shoot length (8.3 cm), dry matter production (4.3 mg/ seedling), vigour index (1664) and field emergence (80.0%) in finger millet.

Economcis of seed hardening :

Research in seed hardening would be followed by farmers only when the ecnomcis workout in their favour. Shivamurthy and Patil (2009) summarized the economic benefits accruing out of seed hardening. Comparing seed hardening using chemicals and simle hardening with water and cow urine, they concluded that seed hardening with cow urine recorded significantly higher returns (Rs.9471/ha) and B.C ratio (1:48) over seed hardening with water and dry seed treatment. However, seed hardening with cow urine was at par with that of seed hardening with $CaCl_2$ (Table 15).

Conclusion :

The pre-sowing seed hardening with inorganic minerals, growth regulators and osmoticants will be much useful in improving the productivity of crop plants under both garden and dry land situation. Seed hardening are now being practiced in many parts of the world to reduce germination time, synchronize germination, improve germination rate and produce better seedling stands (Bradford *et al*., 1990; Khan, 1992 and Lee and Kim, 2000). Hardened seeds usually would exhibit rapid germination when absorb water under field conditions (Ashraf and Foolad, 2005). Seed hardening techniques were adopted to improve the drought tolerant characters in pearl millet (Ramachandran and Rao, 1975). Pre-sowing seed hardening enables the plant to resist soil moisture stress more efficiently causing rapid embryo enlargement, improving seedling vigour and effecting the productivity of crops (Chatterjee *et al*., 1985).

Mobilization of nutrients towards the panicles might have resulted in increased normal kernels because of uniform distribution of photo assimilates within the kernels. Improved kernel proteins seem to be the direct result of improved root proliferation, which might had resulted in higher seedling nutrient up take. This enhanced nitrogen availability might have contributed towards the improved kernel proteins. Improved kernel length from hardened seeds might be the result of improved assimilation rate that resulted in improved photo assimilation and its translocation and portioning towards the kernels. Improved kernel proteins and kernel length might be the reasons of improved kernel water absorption ratio as indicated by positive correlation between kernel proteins and kernel water absorption ratio. Proteins are hygroscopic nature, which results in enhanced water up take. These results support the findings of Thakuria and Choudhary (1995) who reported the improved kernel quality of direct seeded rice seeds hardened with salts of potassium. Improved kernel quality had been observed in direct seeded rice osmo hardened with KCl and $CaCl_2$ under flooded conditions (Zheng *et al*., 2002).

It can be concluded that, there is considerable evidence to show that drought resistance of plants can be increased by subjecting seeds to a soaking and drying before sowing. Seed

Table 14: Seed hardening on seedling characters of finger millet (Palanisamy and Punithavathi, 1998)

Treatments	Germination (%)	Root length (cm)	Shoot length (cm)	DMP (mg/seedling)	Vigour index
Control	82.0	7.4	5.6	2.3	1074
Water	87.0	7.3	5.8	2.0	1149
KCl - l %	86.0	8.2	6.2	2.6	1240
$CaC1_2$ -1 %	82.0	7.6	6.1	2.3	1125
KCl -0.5 % + $CaCI_2$ -0.5 %	82.0	7.7	6.0	2.3	1137
KCl -l% + Pungam leaf powder pelleting	93.0	9.5	8.3	4.3	1664
$CaCl_2$ - 1 % + Pungam leaf powder pelleting	90.0	9.1	7.7	3.6	1521
C.D. (5%)	-	0.28	0.21	1.25	53.8

Table 15 : Effect of seed hardening on bio-chemical parameters of wheat under rainfed conditions (Shivamurthy and Patil, 2009)

Treatments	Plant height (cm)	Straw yield (kg/ha)	Protein content (%)	β Carotene (ppm)	Total Chlorophyll (mg/g fresh wt)	Net return (Rs/ha	B.C ratio
Seed hardening with $CaCl_2$	72.94	3261	12.21	5.28	2.53	9039	1.41
Seed hardening with cow urine	74.12	3388	12.17	5.27	2.43	9471	1.48
Seed hardening with water	68.60	3063	11.89	5.11	2.22	7927	1.24
Control	66.90	2893	11.71	5.03	2.15	6924	1.08

hardening improved the early, uniform emergence and seed quality parameters and increased yield parameters. To achieve uniformity and synchrony of growth of plant under drought or salt stress condition, seed hardening can be adopted as a regular practice to boost the yield of rainfed crops. Among several chemicals tried calcium chloride seems to be the favourite of most researchers. However, simple on farm, no cost or low cost techniques like hydration-dehydration with water or cow urine provides all the enhancements as received from salt induced hardening treatements.

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