Agric. Rev., 25 (2) : 129 - 140, 2004

SEED HARDENING FOR FIELD CROPS - A REVIEW

A. Solaimalai and K. Subburamu

Krishi Vigyan Kendra
Tamil Nadu Agricultural University, Vriddhachalam - 606 001, India

ABSTRACT

Quality seeds along with other improved package of practices play a vital role in improving productivity of crops under rainfed condition. Seed hardening is a practice adopted to make crop plants resistant to soil moisture stress. NaCl, Na_2SO_4, KCl, $MgSO_4$, KH_2PO_4, K_2SO_4, $CaCl_2$, Na_2HPO_4, nitric acid, succinic acid, auxins, CCC, Jalshakthi, triazoles, cow's urine and cow dung extract are used as seed hardening chemicals. Hardening of seedling resulting from pre-sowing treatment is due to a number of physico-chemical changes within the cytoplasm. Pre-sowing seed hardening with different chemicals improve seed viability as well as vigour, root length, root shoot ratio and yield of rainfed crops. Research carried out on seed hardening is reviewed in this paper.

In India, nearly 70 % of cultivated land is rainfed and accounts about 42 % of the total quantity of food grains produced. 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. For enhancing productivity, quality seeds play a major role along with improved package of practices. Seed hardening is a practice adopted to alleviate the moisture stress or making the plant resistant to moisture stress. The inorganic salts like NaCl, Na_2SO_4, KCl, KH_2PO_4, $CaCl_2$ and $MgSO_4$; organic acids like succinic acid, CCC and auxins are used as pre-hardening agents.

As early as in 1964, Henckel developed these wetting and drying treatments of seeds for imparting resistance to drought and adverse conditions. The technique for pre-sowing drought hardening used by him is basically as follows: Seeds are allowed to take up a certain amount of water and then they are kept at 10-25^{0}C for several hours before drying in a steam of air. The best results are claimed for seeds subjected to 2 or 3 cycles of wetting and drying although for some species one cycle is sufficient. The timing of the initial imbibition period(s) is critical because as germination and growth proceed, the degree of "hardening" induced is claimed to become greater the more advanced in the embryo at the time of drying. The optimum stage of germination or early growth for imposing drying treatment must be a compromise between the two conflicting tendencies. As long as dehydration and desiccation have only a purely physical effect on the colloids of the embryo, its vitality is not affected. By contrast, biological dehydration involving the death of the radicle is irreversible. The temperature of the soaking and drying cycles and the rate of drying may all be important. The responses of plants following wetting and drying cycles at the seed stage are variable. Drought tolerance for 0.5 % KH_2PO_4, was observed in dryland crops (Vananagamudi and Kulandaivelu, 1989). 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 bio-molecules. 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 continues from where it is stopped previously. Beneficial effects of seed hardening includes accelerated rapid germination and growth rate of seedling, hardened plants recover much more quickly from wilting than those from untreated plants, induces resistance of salinity and to drought condition, seeds with stand higher temperature for prolonged period, flowering is slightly accelerated, compete more efficiently with weeds due to early emergence and results in more yield.

Process

The hardening resulting from pre-sowing treatments is due to a number of physico-chemical changes within the cytoplasm including greater hydration of colloids, higher viscosity 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. Pre-sowing treatments also initiate the formation of vital biomolecules, stimulate mitochondrial activity and preserve cellular ultrastructures which would allow plants to resist adverse edapho-climate 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). Root is the main plant part as far as moisture extraction and nutrient absorption are concerned. Seed hardening with chemicals and simple water were found to increase root growth even at the seedling stage. This will have a favourable influence on dryland and post monsoon season situations. 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 in a uniform crop population. Thus, a pretreatment or hardened plant might survive adverse environmental stresses more easily because of its advanced state of development.

It is quite possible that yield advantages due to seed hardening treatment would be apparent when the drought was not too severe and be obliterated by extreme moisture stress. Differences in response can also be expected in accordance to the phenological stage at which the stress occurred and the stress duration. Henkel and Kolotova (1934) described seed hardening technique to improve the drought tolerance. Excessive water loss could be prevented by seed hardening (Crafts *et al.*, 1949). The physiological induction as a cause of seed conditioning towards increased drought resistance in crop (Henkel, 1961). The seeds subjected to a cycle of wetting and drying which increased the resistance of plants to drought and heat (Petinov and Molokovsky, 1961). Seed hardening with water recorded high degree of tolerance to drought particularly at the seedling stage (Domanskii, 1959). Repeated cycle of soaking the seeds in water of dilute solutions such as 0.25 % calcium chloride and drying induced drought hardiness in plants (Henckel, 1961). The chemicals/ compound used for hardening are **(i) Use of hydrophilic polymers:** Use of water absorbing compounds particularly hydrophilic polymers for seed treatment to improve plant-water relationships is advocated. Jalshakti is such as hydrophilic polymer. It is a granular, organic super-absorbent, non-toxic, biodegradable having no adverse effects on crop and soil. **(ii) Seed treatment with CCC:** Chloremquat is a synthetic plant growth inhibitor and is highly specific to crops through foliar application in addition to seed treatment. **(iii) Use of triazoles for water stress:** Triazoles are a group of chemicals and is used as fungicides and plant growth regulators. The plant growth regulating effects include increases in leaf thickness, epicuticular wax, chloroplast size, photosynthetic pigments, nuclic acids, protein, stimulation of rooting, size of stomatal aperature and delay leaf sensecence (Fletcher and Hofstra, 1988).

Seed hardening for cereals

Rice: Pre soaking of seeds with 75 ppm NAA and IAA each and with one molar solution of KH_2PO_4 resulted in greater production of dry matter (Sinha, 1969). Soaking of seeds in GA 10 ppm solution for 12 hours increased seed germination rate and seedling height but decreased root growth (Wu and Peterson, 1979). Seeds soaked in 1% solution of $KMnO_4$ for 24 hours showed improved germination in direct sown flooded rice field (Reddy *et al.*, 1983). Seed hardening with water and different salt solutions increased the number of panicles/m^2 and grain yield (Kundu and Biswas, 1985). In upland rice, pre-sowing hardening of seeds with succinic acid (0.25%) registered more number of tillers (Karivaradaraju *et al.*, 1986). Soaking in 4% manganese sulphate solution recorded more number of productive tillers (Kannadasan *et al.*, 1986). Upland rice raised from the pre-hardened seeds with different salt solutions gave better root development, higher growth and yield (Singh and Chatterjee, 1985). Seeds treated under pressure for 5 - 14 minutes to increase water content to 28, 32 and 39% compared with 13% in the original seed registered decreased germination and delayed sprout emergence (Shoji and Hoshikawa, 1988). Soaking of seeds in 0.05 or 0.1% copper sulphate solution increased germination percentage, leaf area, photosynthesis, N and P uptake, number of grains panicle^{-1}, 1000 grain weight and yield and decreased spikelet sterility (Aleshin *et al.*, 1989). Seeds soaked in 10% cowdung extract for 12 hours registered more germination, root and shoot length compared with untreated seeds (Kamalam Joseph and Rajappa Nair, 1989). Cow's urine (5%), cowdung extract (10 %) and nitric acid (0.1 N) treatments resulted in higher root length and vigour index in paddy (Kamalam Joseph and Rajappa Nair, 1989). Seeds treated with 2.5% neem kernel extract gave more vigorous seedlings than untreated seeds (Kareem *et al.*, 1989). Dry seeds treated for 3 days with 0.5% hydrogen peroxide solution before sowing recorded more germination compared to control (Lai and Luo, 1989; Tan *et al.*, 1991). Seed treatment with triacontanol 100 ppm increased the grain yield in rice (Mahadevappa *et al.*, 1989). Soaking of seeds in magnetic water improved imbibition, vigour and germination rates (Tian *et al.*, 1989). Pre-soaking seed hardening in KH_2PO_4 gave increased grain yield. The pre-sowing treatment of seeds with 0.1% ammonium molybdate and 0.5% sodium molybdate increased number of panicles, panicle length and grain yield (TNAU, 1989). Pre-hardening of seeds with water, sodium dihydrogen phosphate (350 ppm), aluminum nitrate (200 ppm), KH_2PO_4 (2%), sodium chloride (3%) and growth regulators like kinetin, resistine, succinic acid, ascorbic acid (100 ppm) would increase drought tolerance (Vananagamudi and Kulandaivelu, 1989).

Seed treatment with 1% KH_2PO_4 increased the yield components and yield of rice (Guang, 1990). Increase in rice yield was observed due to 2% CCC seed treatement (Asgar *et al.*, 1990; Fuenzalida and Melflli, 1991). Seed hardening with 100 ppm succinic acid and 2% KH_2PO_4 significantly increased grain yield of dry sown rice (Jose mathew and Sankaran, 1993). An yield increase was observed due to seed hardening with KCl 4% in Assam (Paul, 1994). Seed hardening with 1% KCl solution and shade drying withstand drought (Karivaradaraju *et al.,* 1995). Seed treatment with CCC @ 500 ppm recorded highest yield (TNAU, 1995). Seed treatment with 1% KCl was found to be superior and recorded highest grain yield in semidry rice. (TNAU, 1998). Seed hardening with KCl gave higher stand of seedlings and 20% increase in CR 1009 rice yield (TNAU, 1989; TNAU, 1996; Thakuria and Sarma, 1995). Seed treatment with fresh biodigested slurry @ 50% + potassium dihydrogen phosphate 1% + penshibao @ 50 ml/ha resulted in higher germination percentage, root and shoot lengths and yield of rice (Kalyanasundaram *et al.,* 2002).

Maize: Soaking the seeds of maize in 0.1% salicyclic acid or 0.1% ascorbic acid for 24 hours enhanced germination but inhibited root and shoot growth (Asthana *et al.,* 1978). Pre-sowing seed treatment with growth regulators can be made to promote vegetative growth as well as to increase productivity (Eshanna and Kulkarni, 1990). Seed soaking in thiourea (500 ppm) tended to improve grain yield by 13.4 % over control (Sahu *et al.,* 1993).

Winter cereals

Wheat: Alternate soaking and drying in solutions of various chemicals *viz.,* sodium chloride, sodium sulphate, potassium nitrate, calcium chloride, ammonium sulphate and KCl accelerated germination and growth rate of seedling. The treated plants recovered more quickly from wilting than the untreated control (Chinoy, 1947). High degree of tolerance to drought was observed in barley when seeds were hardened in water (Domanskii, 1959). Plants raised from hardened seeds soaked in 7.5% monobasic potassium phosphate solution recovered from wilting much more quickly on rewatering than the plants from untreated seeds (Mehrotra *et al.,* 1968). Higher yield was obtained hardened with water soaking for 12 hours (Woodraff, 1969). Pre-soaking of seeds of wheat in 3% solution of sodium chloride and sodium sulphate registered considerable increase in yield with 1620 and 2326 kg/ha respectively as compared to 733 kg/ha by untreated control (Puntamkar *et al.,* 1971). Inducement of drought tolerance through pre-sowing seed hardening with potassium salts assumes prospect (Misra and Pal, 1978). Pre-soaking of seeds in 40 ppm succinic acid registered maximum growth parameters, grain and straw yields compared with unsoaked and water soaked seeds (Padole, 1979). Triazoles treated seeds produced plants with thicker roots with higher root to shoot ratio (Fletcher and Nath, 1984). CCC seed hardening increased the grain yield due to more number of grains/ear, test weight and the straw yield (Misra and Reddy, 1985). Total uptake of N, number of grains/ear and grain yield of wheat were enhanced by calcium chloride and it was significantly superior to sodium chloride, distilled water and control (Parwar and Kadam, 1981; Asgar *et al.,* 1986). Harvest index did not change much due to the use of different seed treatments (Mandal and Basu, 1987; Shinde and Bhalerao, 1991). Seed treatment with cycocel 0.1% and 5% KH_2PO_4 increased yield and nutrient uptake of late sown wheat (Bhati and Rathore, 1988). Triazoles increased epicuticular wax and reduced the length but increased the width and thickness of leaves, decreased stomatal aperture and length of trichomes (Gao *et al.,* 1988). Pre-sowing seed treatment with 1% KH_2PO_4 appeared to be best in maintaining seed viability and vigour (Paul and Choudhury, 1991). Anaerobic pre-treatment of seeds by soaking in deionized water twice their volume at 20^{0}C under fluorescent light for 12 hours improved germination rate and root dry weight

(Ascherman *et al.*, 1992). Seeds soaked in 0.5 or 1.0 or 2.0% KCl or KH_2PO_4 or K_2SO_4 for 18 hours registered higher germination, root and shoot length and seedling vigour (Paul and Choudhury, 1993). Hardened seed (18 hours seed soaking once in 1.0% KH_2PO_4 solution) proved better than normal seed (Das and Choudhury, 1996). Rainfed crop suffers from moisture stress, as it has to depend on conserved soil moisture carried over from the post monsoon and occasional showers. Pre-sowing seed hardening with K salts is one of the methods of increasing yield of wheat (Misra and Dwivedi, 1980). Higher yield attributes and yield were recorded with pre-sowing seed treatment with K salts under moisture stress condition (Paul *et al.*, 1993). Seed hardening with 1.0% murate of potash was found to be effective in increasing the grain yield (32 %) of rainfed wheat over control in the hills zone of Assam (Paul *et al.*, 1998). Seed hardening with water recorded higher grain yield compared to dry seeds (Paul and Choudhury, 1991).

Barely: Seed hardening with water resulted higher degree of tolerance to drought at the seedling stage (Martyanova, 1961). Seed treatment with triadimefon and triadimenol delayed the leaf senescence (Forster *et al.*, 1980).

Seed hardening for millets

Sorghum: Increased resistance to water loss was observed due to pre-sowing water soaking of seeds (Jacoby and Oppenheimer, 1962). Pre-soaking of sorghum seeds in water for 10 hours increased the germination by 26% and hastened the seedling emergence by a day (Lyles and Fanning, 1964). Seed hardening with water resulted in reduced plant height, dry matter accumulation, leaf area index and root-shoot ratio compared with seed hardening with CCC and calcium chloride. Pre-sowing seed soaking in 1% KH_2PO_4 solution for 12 hours favourably influenced plant growth, uptake of nutrients, 1000 grain weight and grain yield (Gopalakrishnan, 1965). Seed hardening of sorghum with water for 12 hours improved total dry matter and leaf area of plants. The magnitude of increase in yield over the control was 20 % when the duration of water soaking was increased to 24 hours (Henkel, 1961). Seed hardening with 1% resistin resulted in enhanced root growth and increased drought resistance (AICRPDA, 1970). Sorghum seeds soaked in water significantly increased the grain size and weight over unsoaked control (Chinnaveeraraju, 1970). However, soaking twice in water reduced grain yield due to poor germination and uneven field stand (Corleto and Saqui, 1975). Seeds soaked in 1% solution of KNO_3 and KH_2PO_4 contained more sugar and KH_2PO_4 exerting the greatest effect. The increase in sugar content would stimulate drought resistance through increased osmotic pressure and water uptake (Balasubramanian, 1976).

Table 1. Seed hardening on germination and vigour index of sorghum

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
CD (5%)	2.8	37.3

(Devarani and Rangasamy, 1998)

Higher seed germination (76%) and vigour index (969.1) of sorghum were recorded under seed hardening with calotropis leaf extract 2% (Devarani and Rangasamy, 1998) (Table 1). Seed hardening with $CaCl_2$ (0.4 %) and cycocel (0.2%) increased root length, root spread, grain and stover yield of rainfed sorghum (Rangasamy *et al.*, 1994). Seeds hardened with aqueous solution of botanicals performed significantly better than control (Jagathambal, 1996). Seedlings from hardened sorghum seeds recorded higher shoot length and total dry matter production than dry seeds (Nirmala *et al.*, 1994). Over night soaking of seeds of sorghum in 1% $CaCl_2$ solution is recommended to induce drought tolerance (Kulkarni *et al.*, 2002).

The benefits of water soaking was observed when sorghum seeds pre-soaked in water for 24 hours (Corleto *et al.*, 1977). Improved drought tolerance and increased seed production following better and quicker seedling emergence were observed due to seed hydration (Corleto and Mallik, 1980). Seed treatment with KH_2PO_4 increased the plant height, LAI, DMP and uptake of N, P and K and consequently enhanced the grain yield (Periathambi, 1980). Seeds were soaked in cow's urine to induce drought tolerance of seeds. Increased yield was obtained due to soaking of seeds with CCC 2% (Ramachandran and Narayanan, 1985). Seed hardening with 2% CCC recorded higher yield of rainfed sorghum (Rangasamy, 1986). Jalshakti seed coating @ 1 - 4% increased grain yield (Kulkarni, 1987). Soaking of seeds in 1 x 10^{-5} m abscissic acid (ABA) increased the grain yield of water stressed plants (Trawre and Sullivan, 1988). Seeds soaked in water, 0.5% KH_2PO_4 or 1% sodium chloride exhibited accelerated emergence and increased root as well as shoot length (Vanangamudi and Kulandaivelu, 1989). Soaking in 100 ppm GA or ascorbic acid for 12 hours enhanced grain yield and harvest index (Shinde and Bhalerao, 1991). Pre-sowing soaking with calcium chloride at 0.4% and cycocel at 0.2% improved germination, vigour index and root shoot ratio (Rangasamy *et al.*, 1993). The beneficial effects of water soaking and chemical treatments in inducing growth and yield might be attributed to leaching out of toxic metabolites from the seed and to antifungal and anticatabolic effects of the treatment (Basu, 1994).

Pearl millet: Seed treatment with 0.09% solution of succinic acid for 3 hours before sowing was found to promote germination and growth besides increasing survival (Manohar and Mathur, 1966). Seed treatment with CCC recorded maximum germination, more effective root growth and leaf area due to increased uptake of nutrients compared to control in pearlmillet (Ramachandran, 1972; Karivaratharaju, 1973). Over night soaking of seeds of pearl millet in 1% $CaCl_2$ solution is recommended to induce drought tolerance (Kulkarni *et al.*, 2002). Soak the seeds in either 2% KCl or 3 % NaCl at 1:1 ratio for 6 hours followed by 5 hours shade drying improve the germination and final yield. Jalshakti at 1 and 2% seed treatment did not influence the plant height, leaf area, DMP at flowering and maturity, yield components and yield (TNAU, 1987). Seeds were soaked in 100 ppm cycocel or 0.15% succinic acid or 1% sodium chloride resulted higher percentage of germination, root shoot ratio and vigour index (Shumugasundaram and Kannaiyan, 1989). Seed hardening techniques were adopted to improve the drought tolerant characters in pearl millet (Ramachandran, 1975).

Finger millet: Pre-sowing treatment of seeds in 2% tri-basic potassium phosphate solution recorded an increased grain and straw yield (Narayanan, 1951; Rajendran, 1969). Soak the seeds in 0.5% $CaCl_2$ at 1:1 ratio until viable expression of embryonic growth and then shade dry original moisture content. Seeds soaked in water significantly increased plant height, number of tillers, shoot weight and grain yield (Dawson, 1965). Over night soaking of seeds of finger millet in 1% $CaCl_2$ solution is recommended to induce drought tolerance (Kulkarni *et al.*, 2002). Pre-sowing seed hardening increased early germination, vigorous seedlings production and yield (Krishna Sastry *et al.*, 1969). Seed hardening with calcium chloride, ascorbic acid and benzyladenine recorded better germination capacity and more vigorous seedling growth (Viswanath *et al.*, 1972). Seed hardening with 2.5% calcium chloride recorded increased tillering, plant height, root length and DMP resulting in enhanced yield (Karivaratharaju and Ramakrishnan, 1985). Dry matter production was increased due to the effect of pre-sowing hardening with 1.5% sodium chloride (Karivaradaraju and Ramakrishnan, 1985a). Pre-sowing seed hardening with CCC (100 ppm) increased the plant height, LAI and DMP productive tillers, 1000 grain weight and grain yield (Kannaiyan, 1987). Seed soaked in 100 ppm Na_2HPO_4 caused remarkable improvement in plant height, tillering, LAI, LAD, CGR, DMP and yield (Maitra *et al.*, 1998).

Table 2. Seed hardening on seedling characters of finger millet

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 1%	86.0	8.2	6.2	2.6	1240
$CaCl_2$ 1%	82.0	7.6	6.1	2.3	1125
KCl 0.5% + $CaCl_2$ 0.5 %	82.0	7.7	6.0	2.3	1137
KCl 1% + 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
CD (5%)	—	0.28	0.21	1.25	53.8

(Palanisamy and Punithavathi, 1998)

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 (Palanisamy and Punithavathi, 1998) (Table 2).

Seed hardening for pulses

Green gram: Green gram seeds given the invigoration treatment (hydration - dehydration treatment) increased the DMP and seed yield as compared to the control (Dharmlingam and Basu, 1984).

Cowpea: Pre-sowing soaking with calcium chloride at 0.4% and cycoel at 0.2% improved germination, vigour index and root shoot ratio (Rangasamy *et al.*, 1993).

Red gram: Treating the seeds in molybdenum (100 mg kg^{-1} 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). Pre-sowing soaking with calcium chloride at 0.4% and cycoel at 0.2% improved germination, vigour index and root shoot ratio (Rangasamy *et al.*, 1993).

Chickpea: Pre-soaking of seeds in 1%

KH_2PO_4 solution for 4 hours gave a grain yield of 69 3kg/ha compared to unsoaked seeds (604 kg/ha) (TNAU, 1983). Seed coating with jalshakthiat 1% increased the grain yield by 32% (Kulkarni, 1987).

Bean: Triazoles conferred drought tolerance on plants with a reduction of the leaf area, increase in diffusive resistance of the leaves, reduction in transpiration and increase in root water potential (Asare *et al.*, 1986).

Seed hardening for oilseeds

Groundnut: Seed hardening of groundnut kernel with 1% calcium chloride had given significantly increased pod yield through increased germination, higher dry matter accumulation and more number of mature pods/plant (Arjunan and Srinivasan, 1989). Pre-sowing soaking with calcium chloride at 0.4% and cycoel at 0.2% improved germination, vigour index and root shoot ratio (Rangasamy *et al.*, 1993). Seed soaking and drying has also been shown to be of advantage in extending viability of seeds in groundnut (Kulkarni *et al.*, 2002).

Sesame: Pre-sowing seed treatment increased yield attributes and yield under moisture condition (Chatterjee *et al.*, 1985). Seed hardening with 2% potassium dihydrogen phosphate significantly increased plant height (132.7 cm), root length (13.7 cm), branches/plant (5.5), capsules/plant (64.2) and seed yield (718 kg/ha) which gave 49.9% higher seed yield over control (Venkatakrishnan, 1998).

Sunflower: Seeds soaked in water for 12 hours registered better germination and early emergence of seedlings over the control (Nageswara Rao *et al.*, 1978). Hardening with water soaking for 12 hours improved leaf water content and thereby enhanced the yield (Ahmed and Baig, 1974).

Mustard: Pre-sowing seed treatment with growth regulators can be made to promote vegetative growth as well as to increase productivity (Prasad, 1991). Under limited soil moisture encouraging results in term of germination, vigour and drought tolerance was obtained by treating the seeds of Indian mustard (Ghosh *et al.*, 1986).

Table 3. Seed soaking on yield of Indian mustard

Seed treatment	Plant height (m)	Branches/ plant	Siliquae/ plant	1000 seed weight (g)	Seed yield (q/ha)
Dry seeds	1.40	4.5	139	3.12	538
Water soaked	1.45	4.7	157	3.32	654
KCl 1.0%	1.50	4.7	175	3.49	700
KH_2PO_4 1.0%	1.54	4.9	199	3.64	793
Na_2HPO_4 0.25%	1.51	4.8	195	3.33	756
Na_2HPO_4 5×10^{-4}	1.53	4.8	206	3.63	679
CD (5%)	NS	NS	NS	NS	139

(Paul *et al.*, 1999)

Where toria and Indian mustard are grown under moisture stress condition as rainfed crops, the soaking of seeds in 1.0% KH_2PO_4, 0.25 % Na_2HPO_4 and 1.0% KCl may be recommended for getting higher yield (Paul *et al.*, 1999) (Table 3). Seed treatments with 0.25% $NaHPO_4$ and 1.0% KCl showed significantly better yield over dry and water soaked seeds in toria (Paul *et al.*, 1995).

Safflower: Seed soaking for 12 hours was found beneficial and registered higher grain yield of 11.65 q/ha than control (9.10 q/ha) in rainfed condition (Bastia *et al.*, 1999).

Seed hardening for cotton

Soaking the seeds in water for 6 to 12 hours and drying the seeds in shade to its original moisture condition had profound effect on germination and preventing chilling injury (Thomas and Christiansen, 1971). Seed cotton yield was increased due to increased number of bolls and short internodes when cotton seed was soaked in CCC before sowing (Ahmed and Baig, 1974). Increased germination and emergence of cotton seedlings were observed due to 6 hours water soaking at 30°C (Cole and Christiansen, 1975). Soaking of seeds for 24 hours in 50 and 100 ppm of CCC, malic hydrazides (MH), diaminozides and AMO - 1618 revealed that higher yield with diaminozide soaking at 50 ppm. The effects of other compounds were highly variable (Antably, 1976). Shorter internode, smaller leaf area, significant increases in number of bolls $plant^{-1}$ and seed cotton yield were recorded when seed was soaked in CCC (1000 ppm) and yield was reduced with higher concentration of CCC (2000 ppm). Increased seed cotton yield was obtained by soaking seeds in 200 to 400 ppm of CCC (Singh, 1976). Seed cotton yield was significantly increased by pre-sowing seed treatment with 0.01% succinic acid (Tripathy *et al.*,, 1976). Soaking seeds for 24 hours in CCC under saline condition resulted an increased in seed cotton yield (Gabr and Ashkar, 1977).

Germination was 93% for water soaked seeds compared to 66% for the control. Water soaking improved the seedling vigour as measured by mean root length and dry matter (Dharmalingam and Basu, 1978). Varalakshmi cotton seeds soaked in water for 12 hours recorded 70% emergence of seedlings on 4th day compared to only 12% for the unsoaked control (Madhusudhana Roa *et al.*, 1978). CCC seed treatment increased boll number, boll weight and seed cotton yield and decreased plant height (Gidnavar, 1979). An yield increase of 25% in seed cotton yield was obtain when the seeds were treated with CCC (1000 ppm) for 6 hours compared to untreated dry seed (Pothiraj, 1982). In black cotton soils of Coimbatore (T.N), the problem of erratic emergence and the resultant loss of population associated with dry seeding could be reduced by soaking the delinted cotton seeds in 1000 ppm CCC and sowing at a depth of 5 cm. This practice gave 20 - 30% increased yield (TNAU, 1983). Seed hardening with 500 ppm CCC in cotton recorded higher monetary return (TNAU, 1986). Cotton seeds hardened with succinic acid, sodium salt or alpha phenyl butric acid recorded higher plant height (Devolta and Chowdappan, 1997; Kariev, 1981). Pre-sowing treatment with nutrient solutions improved germination and seedling growth (Salwau *et al.*, 1991; Ragah *et al.*, 1991). Increased DMP was observed due to hardening with chemical or growth regulators (KCl or CCC) (Thandapani and Subharayalu, 1986; Dharmalingam *et al.*, 1988). Seed hardening with prosopis 0.5% and pungam leaf extract 1.0% registered increase in field emergence (9 %), DMP (26.1%), plant height (23.2%) over control (Rathinavel and Dharmalingam, 1999).

REFERENCES

Ahmed, M.I. and Baig, N.A. (1974). *Pakistan J. Sci.*, **26**(1-6): 23-28.

AICRPDA (1970). Annual report, All India Coordinated Research Project for Dry land Agriculture, Agricultural Research Station, Kovilpatti, T.N., P: 63-66.

Aleshin, E.P. *et al.* (1989). *Vestnik Sel's Khohoe Yaistevernai*, **7**: 107-111.

Antably, H.M.M.E. (1976). *Acta Agronomica*, **25**: 134-141.

Arjunan, A. and Srinivasan, P.S. (1989). *Madras Agric. J.*, **76**: 523-524.

Asare, N.K. *et al.* (1986). *Pl. Cell Physiol.*, **27**: 383-390.

Ascherman, C. *et al.* (1992). *Seed Sci. Technol.*, **20**: 435-440.

Asgar, J. *et al.* (1990). *J. Agric. Res. Pakistan*, **24**: 305-312.

Asthana, J.S. *et al.* (1978). *Indian J. Pl. Physiol.*, **21**: 150-155.

Balasubramanian, S. (1976). *Indian J. Agric. Sci.*, **48**: 346-347.

Bastia, D.K. *et al.* (1999). *Indian J. Agron.*, **44**: 621-623.
Basu, R.N. (1994). *Seed Sci. Technol.*, **22**: 107-126.
Bhati, D.S. and Rathore, S.S. (1988). *Madras Agric. J.*, **75**(9-10): 363-364.
Chatterjee, B.N. *et al.* (1985). *Indian J. Agric. Sci.*, **55**: 262-264.
Chinnaveeraraju, P. (1970). M.Sc (Ag) Thesis, Tamil Nadu Agricultural Univeristy, Coimbatore.
Chinoy, J.J. (1947). *Indian Fmg.*, **8**(2): 72-74.
Cole, D.F. and Christiansen, M.N. (1975). *Crop Sci.*, **15**: 410-412.
Corleto, A. and Mallik, A. (1980). *In:* Proc. XIII International Grassland Congress, Leipzig, Vol: 2, P: 729-734.
Corleto, A. and Saqui, M. (1975). *Agrochemica*, **19**: 147-159.
Corleto, A. *et al.* (1977). *Rivista di Agronomia*, **11**(3): 178-181.
Crafts, A.S. *et al.* (1949). *In:* Physiology of Plants, Chronica Botanica Co., Mass. P: 205.
Das, J.C. and Choudhury, A.K. (1996). *Indian J. Agron.*, **41**(3): 397-400.
Dawson, M.J. (1965). *Indian J. Pl. Physiol.*, **8**: 52-56.
Devarani, N. and Rangasamy, A. (1998). *Madras Agric. J.*, **85**(10-12): 674-675.
Devolta, A.D. and Chowdappan, S.R. (1997). *Madras Agric. J.*, **64**(6): 401-03.
Dharmalingam, C. and Basu, R.N. (1978). *Crop. Sci.*, **47**: 484-487.
Dharmalingam, C. and Basu, R.N. (1984). *Seeds and Farms*, **25**(5): 34-36.
Dharmalingam, C. *et al.* (1988). The Hindu, November 16, 1988.
Domanskii, R. (1951). *Fizol. Res.*, **6**: 354-355.
Eskanna, M.R. and Kulkarni, G.R. (1990). *Seed Res.*, **18**(1): 7-10.
Fletcher, R.A. and Hofstra, G. (1988). *In:* Sterol biosynthesis inhibitors, Ellis Horwood Ltd, London.
Fletcher, R.A. and Nath, V. (1984). *Physiol. Pl.*, **62**: 422-426.
Forster, H. *et al.* (1980). *Zpflanzenkr P'flanzernschutz*, **87**: 640-653.
Fuenzalida, P.J. and Melflli, J.I. (1991). *Agro-cinencia*, **4**(2): 99-107.
Gabr, A.I. and Ashkar, S.A.E. (1977). *Biologia Plantarum*, **19**: 391-393.
Gao, J. *et al.* (1988). *Can. J. Bot.*, **41**: 1178-1185.
Ghosh, R.K. *et al.* (1986). *Indian J. Agric. Sei.*, **56**(3): 182-186.
Gidnavar, V.S. (1979). *Colt. Dev.*, **9**(3): 15-17.
Gopalakrishnan, S. (1965). *In:* Advances in Agricultural Sciences. Madras Agricultural Students Union, Coimbatore, P: 76-77.
Guang, J.Z. (1990). *IRRN*, **15**(5): 7.
Hafees, A.T.A. (1969). *Field Crop Abstr.*, **24**: 4444
Henkel, P.A. (1961). *In:* Proc. Symp. on Plant Water relationship in Arid and Semi arid Conditions. UNESCO, Paris, P: 102-107.
Henkel, P.A. and Kolotova, S.S. (1934). *Madras Agric. J.*, **62**: 127-130.
Jacoby, B. and Oppenheimer, H.R. (1962). *Phyton.*, **19**: 109-113.
Jegathambal, R. (1966). Ph.D. Thesis, Tamil Nadu Agricultural University, Coimbatore.
Jose mathew and Sankaran, S. (1993). *Indian J. Agron.*, **38**: 295-298.
Kalyanasundaram, D. *et al.* (2002). *In:* Proc. National Seminar on Recent trends on the use of humic substances for sustainable agriculture, February 27-28, Annamalai University, Annalamalai Nagar, P: 48.
Kamalam Joseph and Rajappa Nair, N. (1989). *Seed Res.*, **17**: 188-190.
Kannadasan, M. *et al.* (1986). *Madras Agric. J.*, **72**: 256-258.
Kannaiyan, M. (1987). M.Sc (Ag) Thesis, Tamil Nadu Agricultural University, Coimbatore.
Kareem, A.A. *et al.* (1989). *J. Eco. Ent.*, **82**(4): 1219-1223.
Kariev, A. (1981). *Khlopkovodstvo*, **3**: 37-38.
Karivaratharaju, T.V. (1973). *Andhra Agric. J.*, **20**: 115-118.
Karivaratharaj, T.V. and Ramakrishnan, V. (1985). *Madras Agric. J.*, **72**: 249-255.
Karivaratharaju, T.V. and Ramakrishnan, V. (1985a). *Indian J. Pl. Physiol.*, **28**: 243-248.
Karivaratharaju, T.V. *et al.* (1986). *Madras Agric. J.*, **60**(9-12): 1266-1272.
Karivaratharaju, T.V. *et al.* (1995). Suggested Plans for Drought Management, Tamil Nadu Agricultural University, Coimbatore, P: 17-35.
Krishna Sastry, K.S. *et al.* (1969). *Mysore J. Agric. Sci.*, **11**: 47-49.
Kulkarni, M.G. (1987). Jalshakthi. National Chemical Laboratory, Pune, P: 1-21.
Kulkarni, S.S. *et al.* (2002). *Kisan World*, **29**(7): 37.
Kundu, C. and Biswas, S. (1985). *IRRN*, **10**(2):23.
Lai, T.B. and Luo, S.W. (1989). *Hereditas*, **11**(5): 12-16.

Lyles, L. and Fanning, C.D. (1964). *Agron. J.*, **56**: 518-520.
Madhusudhana Rao, D.V. *et al.* (1978). *Mysore J. Agric. Sci.*, **12**: 239-244.
Mahadevappa, M. *et al.* (1989). *IRRN*, **14**(2):26.
Maitra, *et al.* (1998). *Indian Agric.*, **42**(1): 37-43.
Mandal. A.K. and Basu, R.N. (1987). *Field Crop Res.*, **15**: 259-265.
Manohar, M.S. and Mathu, M.K. (1966). *Adv. Front. Pl. Sci.*, **17**: 133-148.
Martyanova, K.L. (1961). *Fiziol. Rast.*, **7**: 301-302.
Mehrotra, O.N. *et al.* (1968). *Indian J. Agron.*, **13**: 53-56.
Misra, N.M. and Dwivedi, D.P. (1980). *Indian J. Agron.*, **25**(2): 230-234.
Misra, N.M. and Pal, H. (1978). *Indian Potash J.*, **3**(3): 10-14.
Misra, N.M. and Reddy, M.G.R.K. (1985). *Andhra Agric. J.*, **32**: 32-33.
Nageswara Rao, B. *et al.* (1978). *Curr. Agric.*, **2**: 97-99.
Narayanan, T.R. (1951). *Madras Agric. J.*, **38**: 100-103.
Nirmala, M. *et al.* (1994). *Madras Agric. J.*, **81**: 695-696.
Padole, V.R. (1979). *J. Maharashtra Agric. Univ.*, **4**: 85-86.
Palanisamy, V. and Punithavathi, N. (1998). *Madras Agric. J.*, **85**(10-12): 583-585.
Parwar, H.K. and Kadam, R.M. (1981). *J. Maharashtra Agric. Univ.*, **6**: 75-76.
Paul, S.R. (1994). *J. Potassium Res.*, **10**(1): 91-93.
Paul, S.R. and Choudhury, A.K. (1991). *Ann. Agric. Res.*, **12**(4): 415-418.
Paul, S.R. and Choudhury, A.K. (1991). *Seeds and Farms*, **17**(1-2):12-15.
Paul, S.R. and Choudhury, A.K. (1993). *Ann. Agric. Res.*, **14**(3): 357-359.
Paul, S.R. *et al.* (1993). *J. Potassium Res.*, **9**(2): 160-165.
Paul, S.R. *et al.* (1995). *Ann. Agric. Res.*, **16**(1): 131-133.
Paul, S.R. *et al.* (1998). *J. Potassium Res.*, **15**(1-4): 54-58.
Paul, S.R. *et al.* (1999). *Indian J. Agron.*, **44**(2): 392-395.
Periathambi, C. (1980). M.Sc (Ag) Thesis. Tamil Nadu Agricultural University, Coimbatore.
Petinov, N.S. and Molokovsky, V.G. (1961). *In:* Proc. Symp. on Plant-water relationship in arid and semi arid conditions. UNESCO, Paris. P: 275-283.
Pothiraj, P. (1982). Ph.D. Thesis. Tamil Nadu Agricultural University, Coimbatore.
Prasad, M. (1991). *Indian J. Agron.*, **36**(4): 612-614.
Puntamkar, S.S. *et al.* (1971). *J. Agric. Sci.*, **41**: 717-718.
Ragah, M.T. *et al.* (1991). *Ann. Agric. Sci.*, **29**(4): 1345-1357.
Rajendran, R. (1969). M.Sc (Ag) Thesis, Tamil Nadu Agricultural University, Coimbatore.
Ramachandran, K. (1972). M.Sc (Ag) Thesis, Tamil Nadu Agricultural University, Coimbatore.
Ramachandran, K. (1975). *Madras Agric. J.*, **62**: 127-130.
Ramachandran, K. and Narayanan, A. (1985). *In:* Regional Workshop on Crop Production Constraints and Solutions, RRS, Paiyur, February 7, P:1-3.
Rangasamy, A. (1986). Ph.D Thesis, Tamil Nadu Agricultural University, Coimbatore.
Rangasamy, A. *et al.* (1993). *Madras Agric. J.*, **80**(9): 535-537.
Rangasamy, A. *et al.* (1994). *Madras Agric. J.*, **81**(2): 68-71.
Rathinavel, K. and Dharmalingam, C. (1991). *Madras Agric. J.*, **86**(1-3): 68-72.
Reddy, B.C. *et al.* (1983). *IRRN*, **8**(2): 18.
Sahu, M.P. *et al.* (1993). *J. Agron. Crop Sci.*, **171**(1): 65-69.
Salwau, M.N. *et al.* (1991). *Ann. Agric. Sci.*, **29**(4): 1299-1302.
Shanmugasundaram, V.S. ahd Kannaiyan, M. (1989). *J. Agron. Crop Sci.*, **163**(3): 174-176.
Shinde, S.S. and Bhalerao, R.K. (1991). *J. Maharashtra Agric. Univ.*, **16**(3): 447.
Shoji, K. and Hoshikawa, K. (1988). *Crop Sci. Soc. Japan*, **31**: 41-42.
Singh, A.I. and Chatterjee, B.N. (1985). *Indian J. Agron.*, **30**: 479-486.
Singh, K. (1976). *Indian J. Agric. Res.*, **10**: 205-206.
Sinha, R.N. (1969). *Madras Agric. J.*, **56**(1): 16-19.
Tan, Z.J. *et al.* (1991). *Chinese J. Rice Sci.*, **5**(1): 41-44.
Thakuria, R. and Sarma, N.N. (1995). *Indian J. Agron.*, **40**(2): 288-290.
Thandapani, V. and Subharayalu, M. (1986). *Madras J. Agric.*, **73**(12): 668-675.
Thomas, R.C. and Christiansen, M.N. (1971). *Crop Sci.*, **11**: 454-456.
Tian, W.X. *et al.* (1989). *J. Jilin Agric. Univ.*, **11**(4): 11-16.
TNAU, (1983). *In:* 12th Annual Report, Tamil Nadu Agricultural University, Coimbatore, P: 48.

TNAU (1986). *In:* Proc. Cotton Scientists Meet, Tamil Nadu Agricultural University, Coimbatore, August 18-19, P: 29.
TNAU (1987). Annual Report, Tamil Nadu Agricultural University, Coimbatore.
TNAU (1989). Water Management Research in Tamil Nadu, Water Technology Centre, Tamil Nadu Agricultural University, Coimbatore, P: 12-16.
TNAU (1995). *In:* Proc. Rice Scientists Meet, Tamil Nadu Rice Research Institute, Aduthurai, April 24-25, P: 53.
TNAU (1996). *In:* Activities and Achievements, Tamil Nadu Agricultural University, Coimbatore.
TNAU (1998). *In:* Proc. Rice Scientists Meet, Tamil Nadu Rice Research Institute, Aduthurai, April 30-May 1, P:63.
Trarore, M. and Sullivan, C.Y. (1988). *In:* Proc. of the International Cong. of Plant Physiology, New Delhi, Vol: 2, P: 15-20.
Tripathy, H.P. *et al.* (1976). *PAU J. Res.*, **13**: 242-243.
Vanangamudi, K. and Kulandaivelu, R. (1989). *Seed and Farm*, **15**(9-10): 33-34.
Venkatakrishnan, A.S. (1998). *Indian J. Agron.*, **43**(1): 154-157.
Viswanath, P.P. *et al.* (1972). *Mysore J. Agric. Sci.*, **6**: 24-28.
Woodraff, D.R. (1982). *Aust. J. Agric. Res.*, **20**: 13-24.
Wu, Y.L. and Peterson, M.L. (1979). *Botanical Bull. Academia Sinica*, **20**(1): 27-37.