Journal of Academia and Industrial Research (JAIR)
Volume 2, Issue 7 December 2013

ISSN: 2278-5213

RESEARCH ARTICLE

Effect of Seed Hardening and Film Coating on Crop Growth and Yield of Sorghum cv. CO (S) 28 under Neyveli Lignite Mine Spoil Condition

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Abstract

Sorghum cv. CO (S) 28 seeds were given hardening treatment with 2% KH_2PO_4, 2% KCl and 1% prosopis leaf extract and film coated with pink polykote @ 3 g kg^{-1} + carbendazim @ 2 g kg^{-1} + imidachloprid @ 1 mL in 5 mL of water + *Azospirillum* @ 40 g kg^{-1} of seed. The hardened and film coated seeds were evaluated initially both under laboratory and pot culture experiments for germination, vigour performance, crop growth, yield and yield attributing characters along with the untreated control. From the findings obtained from the hardening and film coating treatments, the best treatment was selected and coated using DAP @ 30 g kg^{-1} and micronutrient mixture @ 20 g kg^{-1} of seed. Again this treated seeds were evaluated both under laboratory and pot culture conditions along with the control. The results indicated that seeds hardened with 2% KH_2PO_4 and film coated with carbendazim @ 2 g kg^{-1} + imidachloprid @ 1 mL in 5 mL of water + 30 g DAP + 20 g micronutrient mixture + pink polykote @ 3 g kg^{-1} + *Azospirillum* @ 40 g kg^{-1} of seed recorded higher germination (98%), vigour index (3695), dehydrogenase activity (0.50 OD value), α-amylase activity (6.2 mm) and total seedling chlorophyll content (1.71 mg g^{-1}) under laboratory evaluation and the same treated seeds sown in enriched mine spoil (MS + RS + Sand + FYM @ 1:2:1:1) recorded higher emergence (96%), root length (23.1 cm) and root volume (3.8 cm^3) at vegetative stage, plant growth parameters, earhead length (26.5 cm), earhead weight (46.91 g $plant^{-1}$) and grain yield (12.98 g $plant^{-1}$) under pot culture evaluation than 2% KH_2PO_4 hardened and pink polykote @ 3 g kg^{-1} + carbendazim @ 2 g kg^{-1} + imidachlorpird @ 1 mL in 5 mL of water + *Azospirillium* @ 40 g kg^{-1} of seed film coated seeds and untreated seeds (control).

Keywords: Sorghum, hardening treatment, carbendazim, imidachloprid, vigour performance, crop growth.

Introduction

Mining is next to agriculture in world's economy, but mining and its allied works have wasted and ravaged the land surface, particularly the loss of top soil, which is an integral storage and exchange site for nutrients. Surface mining is spread over to about 5000 ha at Neyveli Lignite Corporation Limited (NLC), Neyveli. The mined soil of NLC is sandy clayey in texture, devoid of organic matter and other essential plant nutrients. Surface crusting, high bulk density, poor buffering capacity, lack of soil structure and inadequate soil microflora are the soil problems that restrict plant growth and productivity of the mine spoil over burdens. Due to unfavourable physical, chemical and biological properties and low nutrient status, the mine spoil does not support any plant growth in untreated condition. Therefore, it is an imperative need to reclaim mine spoil so as to effectively rehabilitate the environment. At present, crop production is ventured in mine spoil soils, which is subjected to high degree of uncertainty in productivity. It is imperative to evolve a suitable strategy for augmenting the productivity of such mine spoils. Reclamation and rehabilitation of the mine spoil can be made with selection of a suitable seed management technologies viz., seed hardening and film coating with organic and inorganic substances and soil amendment technique, which includes the addition of red earth, sand and farm yard manure. Seed hardening and film coating is the kingpin to increase the productivity by overcoming the moisture stress and nutrient deficiency for sustained production. Pre-sowing hardening of seeds is one of the methods, which result in modifying physiological and biochemical nature of seed so as to get the characters that are favourable for drought resistance (Henckel, 1964) and also it helps in imbibing enough quantity of water resulting in quick initiation of germination process (Kamalam, 1991).

Pre-sowing soaking of sorghum seeds in 0.5% KH_2PO_4 increased the seedling emergence and vigour when compared to untreated seeds (Vanangamudi and Kulandaivelu, 1989). Sorghum seeds hardened with prosopis leaf extract (2%) and combination of prosopis + pungam and prosopis + Acacia leaf extract (each 1%) recorded higher germination and seedling vigour (Jegathambal, 1996). Seed coating with nutrients is one of the methods that have been used to increase early plant growth. Seed coating apart from improving ballistic properties of seed such as protection and carrying of nodule bacteria, act as a carrier for nutrients and protective materials.

Seed coating materials were reported to improve the germination ability and to increase seedling emergence at changing soil moisture especially in the sub-optimal range (Mucke, 1987). John (2003) reported that maize seeds coated with 3 g polykote, 2 g carbendazim, 1 mL imidachloprid, 30 g DAP and 19.7 g micronutrient mixture per kg of seed recorded higher germination and seed yield over control. Keeping these in view, an experiment was under taken at the Department of Seed Science and Technology, Tamil Nadu Agricultural University, Coimbatore and Neyveli Lignite Corporation (NLC), Neyveli during 2003-2005 both under laboratory and pot culture condition to develop a suitable seed hardening and film coating technologies for enhancing the survival, establishment, growth and productivity of sorghum under NLC mine spoils manipulated with different soil enriching amendments.

Materials and methods

Collection of seeds: Seeds of Sorghum cv. CO (S) 28 obtained from Tamil Nadu Agricultural University, Coimbatore was cleaned and graded using 9/64" sieve. The processed seeds were soaked in different chemicals and botanicals in 1:0.6 ratio of seed to solution (v/v) for 6 h and subsequently shade dried to bring back its original moisture content to 12%. Then, the hardened seeds were film coated with pink polykote, carbendazim, imidachloprid and *Azospirillum* and shade dried for 24 h to bring back its original moisture content.

Experimental design:
Experiment I: Treatment details

T_1 – Dry seed (Control).
T_2 – Seed hardening with 2% KH_2PO_4 + coating with carbendazim @ 2 g kg^{-1} + imidachloprid @ 1 mL in 5 mL of water + *Azospirillum* @ 40 g kg^{-1} of seed.
T_3 – Seed hardening with 2% KCl + coating with carbendazim @ 2 g kg^{-1} + imidachloprid @ 1 mL in 5 mL of water + *Azospirillum* @ 40 g kg^{-1} of seed.
T_4 – Seed hardening with 1% prosopis leaf extract + coating with carbendazim @ 2 g kg^{-1} + imidachloprid @ 1 mL in 5 mL of water + *Azospirillum* @ 40 g kg^{-1} of seed.
T_5 – Seed film coating with pink polykote @ 3 g kg^{-1} seed + carbendazim @ 2 g kg^{-1} + imidachloprid @ 1 mL in 5 mL of water + *Azospirillum* @ 40 g kg^{-1} of seed.
T_6 – Seed hardening with 2% KH_2PO_4 followed by T_5.
T_7 – Seed hardening with 2% KCl followed by T_5.
T_8 – Seed hardening with 1% prosopis leaf extract followed by T_5.

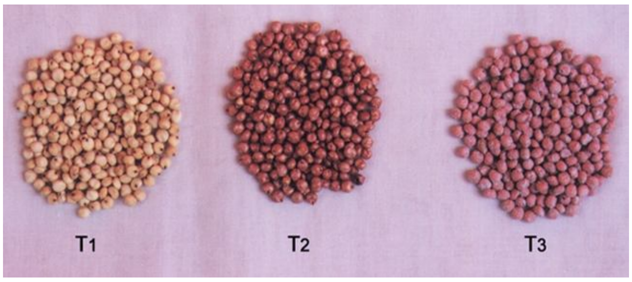
The hardened and film coated seeds were evaluated both under laboratory and pot culture experiments along with control. The pot culture experiment was conducted by adopting factorial completely randomized design with 3 replications (2 pots/replication) and pot size of height 29 cm; diameter 34 cm (25 kg capacity) using four types of mine spoil enriching amendments {(M1-Mine spoil alone (MS), M2-Red soil alone (RS), M3-MS + RS @ 1:1 and M4-MS + RS + Sand + FYM @ 1:2:1:1 (enriched spoil)} to evaluate the efficacy of seed hardening and film coating treatment on growth, establishment and productivity of sorghum under mine spoil condition. From the results and findings obtained from the hardening and film coating treatments, the best treatment was selected and coated using DAP and micronutrient mixture.

Experiment II: Treatment details

T_1 – Dry seed (Control).
T_2 – Seed hardening with 2% KH_2PO_4 + Seed film coating with pink polykote @ 3 g kg^{-1} + carbendazim @ 2 g kg^{-1} + imidachloprid @ 1 mL in 5 mL of water + *Azospirillum* @ 40 g kg^{-1} of seed.
T_3 – T_2 + Seed coating with 30 g DAP + 20 g micronutrient mixture.

Again this hardened and carbendazim + imidachloprid + DAP + micronutrient mixture + seed coating polymer + biofertilizer film coated seeds were evaluated both under laboratory and pot culture experiments along with the best performed hardening and carbendazim + imidachloprid + seed coating polymer + biofertilizer film coating treatment and untreated seeds (control) (Plate 1). The seed samples drawn from the above treatments were evaluated for the seed quality parameters viz., speed of germination (Maguire, 1962), germination (ISTA, 1999), root length, shoot length, dry matter production, vigour index (Abdul-Baki and Anderson, 1973), dehydrogenase activity (Kittock and Law, 1968), α-amylase activity (Simpson and Naylor, 1962) and total chlorophyll content (Yoshida *et al*., 1971) of seedlings under laboratory condition and days to initial emergence, emergence, root length and rot volume at vegetative stage, dry matter production, plant height, total chlorophyll content, days to first and 50% flowering, length of earhead, weight of earhead $plant^{-1}$ and grain yield $plant^{-1}$ under pot culture evaluation.

Plate 1. Hardened and film coated seeds.



Statistical analysis: The results were subjected to analysis of variance and tested for significance according to Panse and Sukhatme (1985). Percentage values were transformed into arcsine values prior to analysis.

Table 1. Effect of seed hardening and film coating treatments on physiological and biochemical parameters of sorghum cv. CO(S) 28 under laboratory conditions.

Treatments	Speed of germination	Germination (%)	Root length (cm)	Shoot length (cm)	Drymatter production (mg seedling^{-1})	Vigour index	Dehydrogenase activity (OD value)	α-amylase activity (mm)	Total chlorophyll (mg g^{-1})
T_1	39.14	86(68.06)	20.7	12.0	14.07	2812	0.26	4.0	1.25
T_2	45.10	96(78.52)	22.8	13.4	16.39	3475	0.42	5.4	1.53
T_3	41.36	98(82.66)	23.7	14.0	17.45	3695	0.50	6.2	1.71
Mean	41.87	93(76.45)	22.4	13.1	15.97	3327	0.39	5.2	1.50
SEd	0.02	1.39	0.19	0.17	0.03	35.22	0.008	0.08	0.01
CD (P=0.05)	S0.03**	2.93**	0.39**	0.35**	0.07**	74.01**	0.017**	0.16**	0.02**

(Figures in parentheses are arc sine transformed values).

Results and discussion

In this investigation, among the treatments, T_2 registered a high speed of germination (45.10) when compared to T_1 (39.14) and T_3 (41.36) (Plate 1). The high speed of germination in T_2 might be due to advancement in the physiology of germination during soaking (Kamalam, 1991; Punithavathi, 1997). Polymer due to its hydrophilic property helped the seeds to emerge at a faster rate in laboratory condition with the available moisture. The reduction in germination rate of T_3 might be due to the restriction imposed by the coating material, which causes slow absorption of moisture and so delayed germination. Unlike the speed of germination, T_3 recorded significantly higher germination (98%), which accounted for 12.0 and 2.0% higher over T_1 (86%) and T_2 (96%) respectively (Table 1). The probable reason for higher germination in T_3 might be due to greater hydration of colloids, higher viscosity and elasticity of protoplasm, increase in bound water content, lower water deficit (May *et al.,* 1962) and increased metabolic activity (Josepha and Nair, 1989). The improvement in germination by 1% KH_2Po_4 in wheat was reported by Paul and Choudhury (1993). The 'K' element being more permeable through seed coat might have promoted the germination (Kohli *et al.,* 1992). Similarly, the effect of the treatment T_3 was also much evident in growth of the seedling with 14.5 and 16.7% higher root and shoot growth, respectively over T_1 (Plate 2). Though, the performance of T_2 was slightly low with regard to seedling growth, its performance was also remarkable against untreated control (T_1) with 10.1 and 11.7% increase, respectively for the root and shoot length (Table 1). Potassium present in the chemicals improve oxidative phosphorylation, utilization of sugars along with pentose phosphate cycle, formation of $NADPH_2$ and ribose-5-phosphate, synthesis of mitochondria (Kursanov *et al.,* 1965) and the activity of ATPase enzyme (Okanenko and Bershteir, 1966). This beneficial effect of nutrients might be the reason for better seedling growth. It might also be due to enhanced metabolic activity and earliness in germination (Joseph and Nair, 1989). The higher dry matter production (17.45 mg seedling^{-1}) and vigour index (3695) was recorded by T_3, which were 24.0 and 31.4% increase over T_1 and 6.5 and 6.3% increase over T_2 respectively (Table 1). The increase in dry weight might be due to enhanced lipid utilization through glyoxalate cycle, a primitive pathway leading to faster growth and development of seedlings to reach autotrophic stage well in advance of others and enabling them to produce relatively more quantity of dry matter. The beneficial effect of nutrients and polymer might be the reason for increased dry matter production and vigour. Also, the *Azospirillum* added in the coating material stimulated the seedling growth and vigour index. The dehydrogenase (0.50 OD Value) and α-amylase activity (6.2 mm) was higher in the treatment T_3, which were 92.3 and 55.0% higher over T_1 and 19.0 and 14.8% higher over T_2, respectively (Table 1) (Plate 3). In the process of seed hardening, the quiescent cells get hydrated and this initiates the early process of germination i.e. seeds activated up to IInd phase of imbibition. In this IInd phase of imbibition, gibberellins were released from the scutellum and move through the endosperm of the aleurone layer. Then, they trigger the synthesis of hydrolytic enzymes including α-amylase and dehydrogenase.

Plate 2. Seedling growth.

Plate 3. α-amylase activity.

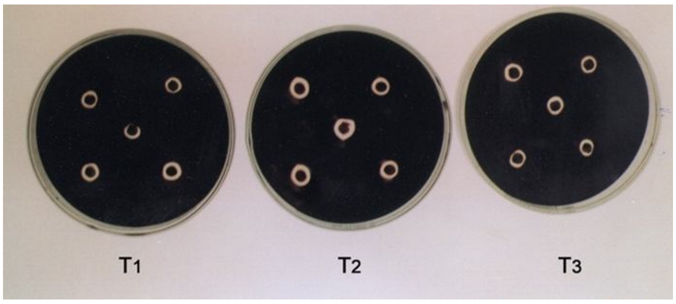


Table 2. Influence of seed hardening, film coating treatments and mine spoil enriching amendments on days to initial emergence, emergence, root length and root volume in sorghum cv. CO(S) 28 under pot culture experiment.

Treatments	Days to initial emergence					Emergence (%)					Root length at vegetative stage (cm)					Root volume at vegetative stage (cm^3)				
	M_1	M_2	M_3	M_4	Mean	M_1	M_2	M_3	M_4	Mean	M_1	M_2	M_3	M_4	Mean	M_1	M_2	M_3	M_4	Mean
T_1	6.2	5.0	5.6	4.8	5.4	82 (64.90)	88 (69.78)	85 (67.25)	90 (71.62)	86 (68.39)	12.5	18.4	15.1	19.7	16.4	1.2	2.4	1.9	3.2	2.2
T_2	4.1	3.5	3.9	3.4	3.7	86 (68.06)	93 (74.76)	90 (71.58)	94 (75.86)	91 (72.57)	14.5	20.5	16.9	22.5	18.6	1.7	2.9	2.4	3.6	2.7
T_3	6.4	5.3	5.7	5.1	5.6	90 (71.62)	94 (75.86)	93 (74.69)	96 (78.52)	93 (75.17)	15.4	21.5	18.3	23.1	19.6	1.9	3.1	2.6	3.8	2.9
Mean	5.6	4.6	5.1	4.4	4.9	86 (68.20)	92 (73.46)	89 (71.17)	93 (75.33)	90 (72.04)	14.1	20.1	16.8	21.8	18.2	1.6	2.8	2.3	3.5	2.6
		T	M	T x M			T	M	T x M			T	M	T x M			T	M	T x M	
SEd		0.06	0.07	0.12			0.63	0.73	1.27			0.18	0.21	0.36			0.05	0.06	0.10	
CD(P=0.05)		0.12**	0.14**	0.24**			1.31**	1.51**	NS			0.37**	0.43*8	NS			0.10**	0.12**	NS	

Zinc is one of the important components in micronutrient mixture, which is a constituent of several dehydrogenase enzymes and amino acids and might have attributed to the increased dehydrogenase activity (John, 2003). The total chlorophyll content of seedlings registered by T_3 (1.71 mg g^{-1}) and T_2 (1.53 mg g^{-1}) was 36.8 and 22.4% higher, respectively than T_1 (1.25 mg g^{-1}) (Table 1). Potassium promoted CO_2 fixation by direct activation of RuBP carboxylase, thereby favouring synth esis of chlorophyll (Peoples and Koch, 1979). Prasad and Mohammad (1987) suggested the possibility of stimulation for the production of phytochrome, which ultimately resulted in synthesis of chlorophyll by the additional supply of nutrients. Under pot culture experiments, among the soil amendments used, the emergence was earlier (4.4 d) in soil medium containing mine spoil + red soil + sand + farm yard manure @ 1:2:1:1 (enriched mine spoil) followed by red soil (4.6 d), whereas it was late in mine spoil (5.6 d) (Table 2).

The quick, early and increased emergence of seeds might be due to the addition of FYM reduced the compaction thereby reduced the bulk density and particle density, increased the percent pore space and permeability of the soil. The late emergence in mine spoils due to sub-soil compaction and surface crusting. High evaporation rates and temperature creates a continuous water deficit in mine spoil. Among the seed treatments, T_2 was faster in germination and it took minimum days (3.7 d) for initial emergence, which was 1.7 and 1.9 d earlier than T_1 (5.4 d) and T_3 (5.6 d), respectively (Table 2). The earlier emergence in T_2 might be due to the pre-sowing soaking of seed is one of the methods, which result in modifying physiological and biochemical nature of seed so as to get the characters that are favourable for drought resistance (Henckel, 1964) and also it helps in imbibing enough quantity of water resulting in quick initiation of germination process (Kamalam, 1991). Emergence percent was higher in enriched mine spoil (MS + RS + Sand + FYM @ 1:2:1:1) (93%), which was 7, 1 and 4% higher over mine spoil (86%), red soil (92%) and MS + RS @ 1:1 (89%), respectively (Table 2).

It is obvious from this investigation, that the mine spoils affected the seedling emergence. The higher reduction in germination could be ascribed to poor fertility status particularly the organic carbon, available nitrogen, phosphorus and exchangeable Ca and Mg contents. Addition of red soil, sand and organic amendments such as FYM to mine spoil improved the emergence percent. This result explain that releasing compaction improves germinability, which may be due to improvement in the porosity, infiltration, spoil texture and structure and reducing the flooding and other stress. The addition of biologically active organic N_2 to the mine spoil through the incorporation of FYM may be a possible attributed reason for the better germination. Among the seed treatments, T_3 recorded higher emergence (93%), which was 7 and 2% higher over T_1 (86%) and T_2 (91%), respectively (Table 2).

The improvement in emergence could also be ascribed to activation of cells, which results in the enhancement of mitochondrial activity leading to the formation of more high energy compounds and vital biomolecules, which were made available during the early phase of germination (Dharmalingam *et al.,* 1988). These initial changes culminate in enlargement of the latent embryo. The hardened seeds were dried back to its original moisture content; the triggered germination events were halted. When the seeds are sown, germination event begins from the point where it stopped previously. As a consequence, early emergence and establishment of seedling are achieved before the available soil moisture is depleted. The interaction effect revealed that the seeds of T_3 sown in enriched mine spoil (MS + RS + Sand + FYM @ 1:2:1:1) recorded the higher emergence of 96% when compared to other combinations (Table 2). The higher root length (21.8 cm) and root volume (3.5 cm^3) at vegetative stage was recorded in enriched mine spoil (MS + RS + Sand + FYM @ 1:2:1:1), which were 54.6 and 118.8% higher over mine spoil, 8.5 and 25.0% higher over red soil and 29.8 and 52.2% increase over MS+RS @ 1:1, respectively (Table 2). From the results of the study, it is inferred that mine spoil affected the root growth of the crops. If the water content reduces, the spoil has been observed to become hard.

Table 3. Influence of seed hardening, film coating treatments and mine spoil enriching amendments on days to first and 50% flowering in sorghum cv. CO(S) 28 under pot culture experiment.

Treatments	Days to first flowering					Days to 50% flowering				
	M_1	M_2	M_3	M_4	Mean	M_1	M_2	M_3	M_4	Mean
T_1	62	59	60	58	59.8	69	65	67	64	66.3
T_2	59	56	57	55	56.8	67	63	65	62	64.3
T_3	58	54	56	53	55.3	66	62	63	60	62.8
Mean	59.7	56.3	57.7	55.3	57.3	67.3	63.3	65.0	62.0	64.4
		T	M	T x M			T	M	T x M	
SEd		0.46	0.53	0.91			0.46	0.53	0.91	
CD(P=0.05)		0.93**	0.07	NS			0.94**	0.09**	NS	

Hardiness of the spoil declines if the spoil is maintained moist at field capacity. However, the hardiness is expected at some time of a day due to diurnal variation in temperature. Such hardening of spoil during spoil drying, not only exerts water stress but also compaction stress on plant roots, which consequently affects the root metabolism. However, the overall influence shows that root extension rather than shoot extension was preferentially affected in mine spoil. In compacted spoils, supply of O_2 to the plant roots is limited which in turn limits the absorption of N_2 and minerals by plant roots. This low N_2 absorption limits the vegetative growth. This compaction can be reduced by addition of sand, which would also enable increase in porosity. Red soil, sand, farm yard manure were mixed with mine spoil at 2:1:1 ratio as an agent to release compaction and also increase the nutrient status of mine spoil, which facilitate the root growth.

Among the seed treatments, T3 registered the highest root length (19.6 cm) and root volume (2.9 cm^3), which accounted for 19.5 and 31.8% increase over T_1 and 5.4 and 7.4% higher over T_2 (Table 2). The beneficial effect of nutrients and polymer present in the pelleting material might be the reason for better root growth and increased root volume. It might be also due to enhanced metabolic activity, earliness in emergence and increased uptake of nutrients by microorganisms associated plants and their synergistic effect. The microorganisms that are used as biofertilizers stimulate the plant growth by providing necessary nutrients by their colonization at the rhizosphere or by their symbiotic association. The association may also regulate the physiological processes in the ecosystems by involving in the decomposition of organic matter, fixation of atmospheric nitrogen, secretion of growth promoting substances, increasing the availability of mineral nutrients and protecting the plants from pathogen (Jakobsen *et al.,* 1994). Thus, the rhizosphere effect through microbial activity modifies the plant itself by producing the plant growth substances and increasing the availability of elements to the root zone (Newman *et al.,* 1992; Jakobsen *et al.,* 1994). Among the mine spoil enriching amendments used, the first flowering was late in mine spoil (59.7 d) and it took more number of days (67.3 d) to complete 50% flowering when compared to red soil, MS + RS @ 1:1 and enriched mine soil (MS + RS + Sand + FYM @ 1:2:1:1) (Table 3). Because in this study, soil fertility would be a major factor regulates plant growth. Unfortunately, the mine spoils often are characterized by low quantities of nutrients. Due to low nutrient availability and poor soil physical conditions, the plant growth was affected and it also delayed the flowering. Whereas, the first flowering was earlier (55.3 d) in enriched mine soil (MS + RS + Sand + FYM @ 1:2:1:1) and also it took minimum number of days (62 d) to complete 50% flowering (Table 3). Early flowering in enriched mine spoil might be due to the favourable action of FYM in improving the physico-chemical and biological characteristics of mine spoils. Also, addition of FYM to mine spoil increased the nutrient availability thereby enhanced the plant growth. Red soil and sand also improve the root and crop growth through releasing the soil compaction and nutrient supply. Among the seed treatments, the first and 50% flowering were observed to be earlier in T_3 (55.3 and 62.8 d), while there was a slight delay in T_2 (56.8 and 64.3 d) and T_1 (59.8 and 66.3 d) (Table 3). Early flowering in T_3 might be due to higher plant growth and physiological activity. The enriched mine spoil (MS + RS + Sand + FYM @ 1:2:1:1) recorded higher dry matter production and plant height of 17.0 and 9.8% higher over mine spoil and 4.2 and 2.7% over red soil and 9.7 and 5.5% over MS + RS @ 1:1, respectively (Table 4 and 5) (Plate 4).

Plate 4. Plant height at physiological maturity stage in mine spoil and enriched mine spoil.

Table 4. Influence of seed hardening, film coating treatments and mine spoil enriching amendments on dry matter production (g plant^{-1}) at different growth stages in sorghum cv. CO(S) 28 under pot culture experiment.

Treatments	Vegetative stage					Flowering stage					Maturity stage					Mean
	M_1	M_2	M_3	M_4	Mean	M_1	M_2	M_3	M_4	Mean	M_1	M_2	M_3	M_4	Mean	
T_1	6.74	7.80	7.34	8.10	7.50	21.70	26.10	24.62	27.11	24.88	33.41	36.96	35.40	38.64	36.10	22.83
T_2	8.72	9.37	9.16	9.56	9.20	24.73	28.45	27.10	29.62	27.48	37.45	41.05	39.12	43.04	40.17	25.61
T_3	9.63	10.26	10.07	10.47	10.11	25.97	29.96	27.46	31.11	28.63	39.21	43.27	41.09	45.39	42.24	26.98
Mean	8.36	9.14	8.86	9.38	8.94	24.13	28.17	26.39	29.28	26.98	36.69	40.43	38.54	42.36	39.50	25.14

Mine spoil enriching amendments mean	M_1	M_2	M_3	M_4
	23.06	25.91	24.60	26.99

	T	M	S	T x M	M x S	T x S	T x M x S
SEd	0.10	0.12	0.10	0.21	0.21	0.18	0.36
CD(P=0.05)	0.21**	0.24**	0.21**	NS	0.41**	0.36**	NS

Table 5. Influence of seed hardening, film coating treatments and mine spoil enriching amendments on plant height (cm) at different growth stages in sorghum cv. CO(S) 28 under pot culture experiment.

Treatments	Vegetative stage					Flowering stage					Maturity stage					Mean
	M_1	M_2	M_3	M_4	Mean	M_1	M_2	M_3	M_4	Mean	M_1	M_2	M_3	M_4	Mean	
T_1	50.5	56.9	54.5	57.2	54.8	120.4	130.4	124.9	134.0	127.4	131.4	137.6	135.3	140.5	136.2	106.1
T_2	61.3	67.6	65.8	70.0	66.2	127.7	137.0	132.9	141.2	134.7	140.5	146.0	144.6	150.1	145.3	115.4
T_3	64.2	71.8	69.0	74.7	69.9	130.6	140.5	136.0	144.9	138.0	144.2	150.7	147.8	153.9	149.2	119.0
Mean	58.7	65.4	63.1	67.3	63.6	126.2	136.0	131.3	140.0	133.4	138.7	144.8	142.6	148.2	143.6	113.5

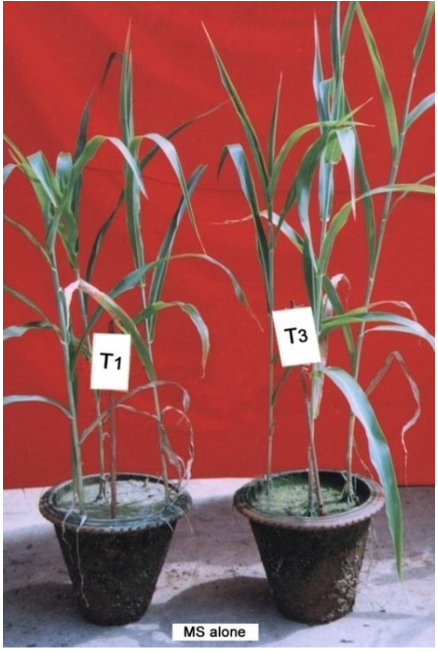
Mine spoil enriching amendments mean	M_1	M_2	M_3	M_4
	107.9	115.4	112.3	118.5

	T	M	S	T x M	M x S	T x S	T x M x S
SEd	0.27	0.32	0.27	0.55	0.55	0.48	0.95
CD(P=0.05)	0.55**	0.63**	0.55**	NS	1.10**	0.95**	NS

The lower dry matter production and plant height in mine spoil might be due to the lack of soil nutrients, organic matter and microorganisms and also due to the poor physical properties of the mine spoil. The possible reason attributed for the improvement in plant height and dry matter production in enriched mine spoil (Mine Spoil + Red Soil + Sand + Farm Yard Manure @ 1:2:1:1) might be due to the incorporation of FYM to mine spoil increased the availability of P from insoluble phosphate and the addition of biologically active organic N_2 to mine spoil through farm yard manure. In addition, farm yard manure increased soil physical properties, released nitrogen slowly and supplied all other macro and micro nutrients (Cooke, 1967). Soils with higher amount of clay and organic matter exhibited higher CEC and were able to retain greater quantities of plant nutrients there by providing a more favourable medium for plant growth. Among the seed treatments, T_3 recorded a higher dry matter production (26.98 g plant^{-1}) and plant height (119.0 cm), which were 18.2 and 12.2% increase over T_1 and 5.3 and 3.1% over T_2 (Table 4 and 5) (Plate 5).

The increased dry matter production might be due to the combined effect of hardening and film coating which enhanced the root-shoot ratio and nutrient uptake (Rangasamy *et al.,* 1993). Increase in dry weight might also due to enhanced lipid utilization through glyoxalate cycle, a primitive metabolic pathway thereby, facilitating the conversion of acetate into nucleic acid as quoted by Vanni and Zini (1972). Ogbonnaya (1992) reported that NK combinations contributed significantly to plant growth, while N alone and NK combination contributed significantly to radial growth and dry matter production.

Plate 5. Effect of seed treatment on plant height at vegetative stage in mine spoil.



Increase in plant height due to polykote, carbendazim, imidachloprid, DAP, micronutrient mixture and biofertilizer (*Azospirillum* and *Rhizobium*) might be attributed to the effect of nutrients present in the coating materials, which could improve the growth resulting in higher plant height (Farley and Draycott, 1978), or due to enhanced seedling establishment and possibly due to activation of metabolic activity of seed (Ponnuswamy and Vijaya, 1997; Thiyageshwari and Ramanathan, 1998).

Table 6. Influence of seed hardening, film coating treatments and mine spoil enriching amendments on total chlorophyll content (mg g^{-1}) at different growth stages in sorghum cv. CO(S) 28 under pot culture experiment.

Treatments	Vegetative stage					Flowering stage					Maturity stage					Mean
	M_1	M_2	M_3	M_4	Mean	M_1	M_2	M_3	M_4	Mean	M_1	M_2	M_3	M_4	Mean	
T_1	1.06	1.44	1.26	1.54	1.33	1.47	2.04	1.80	2.18	1.87	1.01	1.37	1.18	1.43	1.25	1.48
T_2	1.53	1.86	1.74	1.98	1.78	1.83	2.39	2.21	2.53	2.24	1.27	1.64	1.45	1.69	1.51	1.84
T_3	1.65	1.98	1.87	2.09	1.90	1.97	2.55	2.36	2.69	2.39	1.40	1.79	1.58	1.84	1.65	1.98
Mean	1.41	1.76	1.62	1.87	1.67	1.76	2.33	2.12	2.47	2.17	1.23	1.60	1.40	1.65	1.47	1.77

Mine spoil enriching amendments mean	M_1	M_2	M_3	M_4
	1.47	1.90	1.72	2.00

	T	M	S	T x M	M x S	T x S	T x M x S
SEd	0.005	0.006	0.005	0.011	0.011	0.009	0.019
CD(P=0.05)	0.011**	0.013**	0.011**	NS	0.022**	0.019**	NS

Table 7. Influence of seed hardening, film coating treatments and mine spoil enriching amendments on yield and its attributes in sorghum cv. CO(S) 28 under pot culture experiment.

Treatments	Length of earhead (cm)					Weight of earhead (g $plant^{-1}$)					Grain yield (g $plant^{-1}$)				
	M_1	M_2	M_3	M_4	Mean	M_1	M_2	M_3	M_4	Mean	M_1	M_2	M_3	M_4	Mean
T_1	19.0	22.7	21.1	23.8	21.7	29.32	32.01	30.19	33.15	31.17	6.53	8.64	8.00	9.45	8.16
T_2	20.3	24.0	22.3	25.0	22.9	38.05	41.49	39.95	42.84	40.58	8.46	10.50	10.01	11.47	10.11
T_3	21.2	25.2	23.4	26.5	24.1	41.60	45.72	43.74	46.91	44.49	9.54	12.03	11.32	12.98	11.47
Mean	20.2	24.0	22.3	25.1	22.9	36.32	39.74	37.96	40.97	38.75	8.18	10.39	9.78	11.30	9.91

	T	M	T x M	T	M	T x M	T	M	T x M
SEd	0.11	0.13	0.22	0.14	0.16	0.28	0.03	0.03	0.05
CD (P=0.05)	0.23**	0.26**	NS	0.29**	0.34**	NS	0.06**	0.06**	0.11**

The activation of metabolic activity of seed could also be due to hydrophilic polymer present in the coating material, which might improve the rate of water uptake by the seed (Baxter and Waters, 1986) leading to early germination and better seedling establishment, which might also help in better plant height. *Azospirillum* is reported to be capable of fixing nitrogen at the rate of 0.7 kg N ha^{-1} d^{-1} and is responsible for increase in plant height and also N is known to produce excess shoot growth at the expense of root growth (Cornett, 1982). Within the mine spoil enriching amendments used, enriched mine spoil (MS + RS + Sand + FYM @ 1:2:1:1) registered higher total chlorophyll content (2.00 mg g^{-1}) followed by red soil (1.90 mg g^{-1}), Ms + RS @ 1:1 (1.72 mg g^{-1}) and mine spoil (1.47 mg g^{-1}) (Table 6). The increased amount of chlorophyll in enriched mine spoil (M4) might be due to the additional supply of nutrients, which stimulate the production of phytochrome, which ultimately resulted in synthesis of chlorophyll (Prasad and Mohammad, 1987). Farm yard manure contains 0.8% N, 0.3% P_2O_5 and 1% K_2O. Peoples and Koch (1979) reported that potassium promoted CO_2 fixation by direct activation of RuBP carboxylase, thereby favouring the synthesis of chlorophyll. Among the seed treatments, T_3 recorded higher chlorophyll content (1.98 mg g^{-1}) when compared to T_1 (1.48 mg g^{-1}) and T_2 (1.84 mg g^{-1}) (Table 6). It has been shown that K^+ exert control over membrane protein synthesis and binding, which might be the reason for the production of photo assimilatory surface and maintained high chlorophyll content (Usha *et al.,* 1999). The enriched mine spoil recorded higher earhead length (25.1 cm), earhead weight (40.97 g $plant^{-1}$) and grain yield (11.30 g $plant^{-1}$), which were respectively 24.3, 12.8 and 38.1% higher over mine spoil (Table 7).

The lower grain yield in mine spoil might be due to the low fertility status and poor physical properties of mine spoil, which are very essential for crop growth and yield. The increased grain yield in enriched mine spoil (MS + RS + Sand + FYM @ 1:2:1:1) is due to the favourable effect of FYM in improving the soil organic matter, nutrient availability, CEC, water soluble aggregates, hydraulic conductivity and water holding capacity, besides maintaining the soil structural conditions. In addition application of red soil and sand to mine spoil improves the plant growth and yield. When FYM is applied in combination with mineral fertilizer, it reduces the negative effects of acidification, caused by application of such fertilizers. Among the seed treatments, T_3 recoded higher earhead length (24.1 cm), earhead weight (44.49 g $plant^{-1}$) and grain yield (11.47 g $plant^{-1}$), which were 11.1, 42.7 and 40.6% increase over T_1. The interaction effect showed that the seeds of T_3 sowed in enriched mine spoil recorded the highest grain yield of 12.98 g $plant^{-1}$ when compared to other combinations. Among the seed treatments, T_3 recorded increased earhead length (24.1 cm), earhead weight (44.49 g $plant^{-1}$) and grain yield (11.47 g $plant^{-1}$) of 11.1, 42.7 and 40.6% higher, respectively over T_1. The next best treatment was T_2, which recorded 23.9% higher grain yield (10.11 g $plant^{-1}$) over T_1 (Table 7). The yield increase could be attributed to the presence of nutrients in both the treatments, which are the constituent of several dehydrogenase enzymes and also an activator of other enzymes. They are also necessary for the biosynthesis of IAA, the growth regulator, which is essential for normal enlargement of cells. It is also a constituent of amino acids, from which protein and enzymes are synthesized.

The hardening and film coating treatment improved the growth of the plant during early stages of the crop with increased vigour and stronger root system, which in turn derived the available soil moisture and nutrients enabling better growth and higher yield. Kachapur *et al.* (1987) reported that micronutrients play an important role in increasing the earhead length in sorghum. Polymer present in the coating material have also helped in higher rate of water uptake in turn, resulted in the early germination with more seedling vigour and better stand establishment, which ultimately led to better growth and productivity of sorghum. The reason for the increased grain yield might also be due to the increased photosynthetic efficiency through stabilization of chlorophyll, higher production of photosynthates resulting in increased translocation of organic material from the source to sink in the treated plants.

Conclusion

Investigation on the effect of seed hardening and film coating on sorghum revealed that seeds hardened with 2% KH_2PO_4 and film coated with carbendazim @ 2 g kg^{-1} + imidachloprid @ 1 mL in 5 mL of water + 30 g DAP + 20 g micronutrient mixture + pink polykote @ 3 g kg^{-1} + *Azospirillum* @ 40 g kg^{-1} of seed recorded higher germination (98%), vigour index (3695), dehydrogenase activity (0.50 OD value), α-amylase activity (6.2 mm) and total seedling chlorophyll content (1.71 mg g^{-1}) under laboratory evaluation and the same treated seeds sown in enriched mine spoil (MS + RS + Sand + FYM @ 1:2:1:1) recorded higher emergence (96%), root length (23.1 cm) and root volume (3.8 cm^3) at vegetative stage, plant growth parameters, earhead length (26.5 cm), earhead weight (46.91 g $plant^{-1}$) and grain yield (12.98 g $plant^{-1}$) under pot culture evaluation than 2% KH_2PO_4 hardened and pink polykote @ 3 g kg^{-1} + carbendazim @ 2 g kg^{-1} + imidachlorpird @ 1 mL in 5 mL of water + *Azospirillium* @ 40 g kg^{-1} of seed film coated seeds and untreated seeds (control).

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