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Research Article

Standardization of seed ball media for fodder sorghum to increase green cover and fodder availability in degraded lands

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Abstract
Fodder sorghum (*Sorghum bicolor* L.) is a tall, erect annual grass. It is a drought resistant crop due to its effective root system. A seed ball is one of the low-cost technologies which was prepared with locally available materials on the farm. In seed balls, the seeds are protected from external factors. At the same time, vigorous seedling was established through seed ball. In order to improve the degraded lands with green cover, the following experiment was framed and carried out. Seed balls were prepared with a combination of red soil and vermicompost at different ratios with 230-250ml of water per kg of medium to get an optimum size and quality. After the preparation, seed balls were shade dried for 24-36 hrs. Among the different ratio of media combinations, 2:1 and 4:2 ratio was found to be the best media for seed balls preparation with good physical and physiological qualities. The maximum seedling quality parameters speed of germination (7.6), germination (98%), root length (10.6 cm), shoot length (19.4 cm) and vigour index (2900) obtained in the present study were due to vermicompost, which contained an optimum concentration of nutrients that helped improve the seedling vigour. This experiment confirmed that using seed balls with best media combinations for the regeneration of degraded lands was very effective.

Keywords: Best media, Fodder sorghum, Red soil, Seed ball, Vermicompost

INTRODUCTION

Climate change is the major threat faced by the global population. Due to the increased emissions of greenhouse gases, including carbon dioxide, the global temperature is rising which cause extreme climatic irregularities. One of the major reasons for the rise in greenhouse gases is Oxygen-Carbon dioxide imbalance due to deforestation. According to FAOSTAT (2019), a reduction in 0.5% of forest area was there in the last ten years and that could have a great influence on the 11 per cent increase of atmospheric carbon dioxide. If this condition continues, it will lead to an oxygen deficient earth and the only way to withstand this problem is afforestation. Deforestation also leads to lower or non-availability of forage and fodders for grazing animals, which also effects on agricultural crop growth and production by adverse climate changes. Under this situation, natural regeneration on those areas of deforestation is highly essential to bring back the forest cover. Mesquita *et al*. (2015) and Jakovac *et al*. (2016) described that the great potential for natural regeneration in the Amazon region has long been demonstrated, where depending on the intensity of land-use, different successional paths.Most of the regeneration techniques available are not at all cost effective and high cost of regeneration have been a major barrier for up scaling this activity (De Groot *et al*., 2013). Deforestation and land degradation leads the water as well as nutrient stress to the surviving vegetation (Baboo *et al*., 2017; Bargali *et al*., 2018; 2019; Manral *et al*., 2020). Soil water supply is an important environmental factor controlling seed germination and seedling establishment (Kramer and Kozlowski, 1980; Bargali and Bargali, 1999). If the water potential is reduced, seed germination will be delayed or prevented depending on the extent of its reduction (Hegarty, 1977). As a result, primary and secondary bare areas are created frequently and need immediate restoration to arrest environmental degradation (Bargali and Bargali, 2016). The environment of bare site is characterized by wide fluctuations in moisture conditions (Karki *et al*., 2017). In such situation, the seeds of species which have an ability to germinate under fluctuating moisture conditions can germinate and survive (Quinlivan, 1968). Seed germination and early seedling growth are considered the most critical phases for the establishment of any species (Bargali and Singh, 2007; Pratap and Sharma, 2010; Vibhuti *et al*., 2015; Shahi *et al*., 2015).

To increase the green coverage in forest areas, through natural regeneration, the seeds of various species have to be sown directly in the forest areas which are not at all approachable by humans. The seeds which are carried away by birds, animals, wind and water also are not effectively sown in forest areas. The directly sown seeds through afforestation programmes *viz*., aerial seeding is not cost effective but at the same time the birds, rodents and animals feed on the seeds which leads to ultimate loss of seeds available for regeneration. In addition, in the direct-sown seeds, the mortality rate will be more due to non-penetration of the roots from the germinated seeds on the upper surface of the soil. Rasmussen *et al*. (2003) reported that direct seeding of black walnut for regeneration has been inconsistent. Seed predation is listed as the most common reason of failure for direct seed planting in Illinois (Farlee, 2013).

Fodder sorghum (*Sorghum bicolor* L.) is a tall, erect annual grass. It is a drought resistant crop due to its effective root system. It has the ability to grow in higher temperature and in dry condition. The optimal growth condition is 25 to 30ºC at seedling and 30ºC day temperature during growth with an annual rainfall of 400 to 750 mm. It contains lignin component, which is essential for plant health, survival and plant environmental fitness (Pedersen *et al*., 2005). Fodder sorghum has the ability to withstand heavy grazing. Out of 329 million ha of total geographical area in India, 46.7 million ha comes under the degraded area (Anonymous, 2014). Direct sowing can be practised to increase the fodder availability in the forest and degraded regions by conventional methods,. But it is difficult, time-consuming and laborious process and also causes difficulty in having easy accessibility to interior forest areas. Direct sowing of seeds also causes losses by natural predators *viz*., rodents, squirrels, birds, ants, and other animals. To overcome these problems, seed ball techniques can be adopted. Seed ball technology is an ancient method developed from Japan for increasing the greenery with flower and some of the grass species (Fukuoka, 1985), where the seed balls were made up of clay loam, red soil, compost and biofertilizer. This facilitates good seedling establishment and survival. Seed balls also protect the seeds and provide a suitable microclimatic condition by supplying nutrients from compost and biofertilizers.

Seeds balls prepared with clay or soil alone or without any specific ratios of media compositions by crude methods will cause cracks or breakages to seed balls during transport, storage and casual handling due to the less compactness of the medium (Tamilarasan *et al*., 2020). It also leads to reduction in seedling emergence. Moreover, during the dissemination of seed ball, it will cause damages or breakages to seed balls, leading to seed loss by predators that get exposed to the open environment and lead to unfavourable conditions for seeds to germinate. To overcome these complications in seed balls, standardization of specific ratio of seed ball media becomes a crucial factor. Therefore, the objectives of the present study were to standardize the seed ball medium for production of effective seedling establishment for fodder sorghum.

MATERIALS AND METHODS

The present experiment was carried out at the Department of Seed Science and Technology, Tamil Nadu Agricultural University (TNAU), Coimbatore, Tamil Nadu, during 2018-2019. The red soil (RS) from open field was collected and sieved into fine powder to avoid coarse surface and higher dusting while handling. Vermicompost (V) was purchased from the Department of Agronomy, TNAU, Coimbatore. To obtain the media for seed ball preparation, following combination of different ingredients was added at various ratio. Treatment details were as follows: T_0-Control; T_1-Red Soil; T_2-1:1:RS:V; T_3-1:2:RS:V; T_4-1:3:RS:V; T_5-1:4:RS:V; T_6-2:1:RS:V; T_7-2:2:RS:V; T_8-2:3:RS:V; T_9-2:4:RS:V; T_{10}-3:1:RS:V; T_{11}-3:2:RS:V; T_{12}-3:3:RS:V; T_{13}-3:4:RS:V; T_{14}-4:1:RS:V; T_{15}-4:2:RS:V; T_{16}-4:3:RS:V; T_{17}-4:4:RS:V.

As per the above ratio, compositions were mixed thoroughly to get fine media. After mixing, 230-250 ml of water was added to one kg of each media composition to get optimum moisture for making a proper sized and round-shaped seed ball. 10-15g of well-mixed medium in each composition were taken and 2 number of fodder sorghum seeds per ball were kept inside and made into a smooth and round shape seed ball. Then the seed balls were dried for 24-36hrs. Drying duration may depend on atmospheric conditions. To avoid the crack lines and hardness of seed ball, drying under direct sunlight should be avoided.

Then seed balls were subjected to test verify the physical parameters *viz*., seed ball size, seed ball weight, fragmentation test and dissolution rate and physiological parameters *viz*., germination (%), root length (cm) and shoot length (cm), vigour index and dry matter accumulation (g/ 10 seedlings) along with control seeds (seed alone). The observed data were tabulated and analysed with statistical tools.

Seed ball size weight

Randomly selected 100 seed balls were used for size and weight determination. Seed ball size was measured by the traditional method using thread. The thread was circled around seed ball and obtained thread length was measured by measuring scale represented in centimetre (cm).

Seed ball weight

Randomly selected 100 seed balls were used for weight determination. Seed balls were weighed in weighing balance and weight was noted in gram.

Fragmentation test

The fragmentation test was done by taking 100 seed balls in a plastic bag and shaking the seeds manually for one minute. Ten replications of 100 seed balls from each treatment were tested. The fragmentation was evaluated visually and the total number of cracked or broken seed balls were counted (Tamilselvi, 2017).

Dissolution rate

Ten randomly selected seed balls were dropped into water one by one. Time taken to dissolve the seed balls in water was noted and expressed in seconds (Dogan *et al*., 2005).

Speed of germination (Maguire, 1962)

The germinated seedlings from each replication of treatments were counted daily from 1st day onwards up to 10th day of sowing. From the number of seeds germinated on each day, the speed of germination was calculated using the following formula and the result was expressed in number.

Speed of germination = $X_1/Y_1 + (X_2 - X_1)/Y_2 + \ldots\ldots + (X_n - X_{n-1})/Y_n$ …..Eq.1

Where,

X_1- Number of seeds germinated at first count

X_2- Number of seeds germinated at second count

X_n- Per cent germination on n^{th} day

Y_1- Number of days from sowing to first count

Y_2- Number of days from sowing to second count

Y_n- Number of days from sowing to n^{th} count

Germination (%)

The germination test was conducted under shade net condition in a raised bed and the germination percent was calculated as per International Seed Testing Association (2015), 25 seed balls from each treatment in four replications were taken. At the end of 15th day, the final count was taken and the number of normal seedlings were recorded for calculating germination percent.

Germination percent (%) = (No. of normal seedlings / Total no. of seeds sown) x 100 …. Eq.2

Root and shoot length (cm)

Root length was measured from the point of attachment of the cotyledon to the tip of the root. On the day of the final count, randomly selected ten normal seedlings from each replication in each treatment were taken for root length measurement and reported in Centimetre. The same ten seedlings taken for root length were used for measuring shoot length, it has measured from the point of cotyledon attachment to the tip of the leaf.

Dry matter production (g 10 seedlings^{-1})

Ten seedlings selected for measurement of root and shoot length were placed in a paper cover, shade dried for 24 h and dried at 80°C for 16 ±1 h in a hot air oven. Then they were allowed for cooling using a desiccator, weighed and expressed as g 10 seedlings^{-1}.

Vigour index I

Vigour index I was calculated by using the following formula and the mean values were expressed as a whole number (Abdulbaki and Anderson, 1973).

Vigour index = Germination (%) x Total seedling length (cm) …..Eq.3

Statistical analysis

The analysis of variance was carried out and a comparison was made by Duncan's Multiple Range Test (DMRT). The mean difference is significant at the P-values < 0.05. Statistical analysis was performed using the SPSS 16.0 software (SPSS Inc., Chicago, USA).

RESULTS AND DISCUSSION

A significant difference was noticed for physical parameters among various seed ball media *viz.,* control (seed alone), red soil (RS) and vermicompost (V) at various ratio used for the preparation of seed balls. The maximum weight (17.1 g) was observed in the medium of red soil alone and the minimum was recorded from the media RS+V @ 2:3 ratio (8.9 g). Maximum seed ball weight recorded by red soil alone may be attributed to the increased weight of red soil particles, whereas the red soil and vermicompost at various ratios were comparatively lower in weight. The compactness of fine soil particles were more in red soil with low pore spaces where vermicompost has low weight and high pore spaces. This character played a major role in physical parameters responsible for altering the weight of seed balls. While observing seed ball size, no difference was noticed among the treatments because balls were prepared with the same size that ranges from 2.0 to 2.6 cm diameter per ball (Table 1).

Fragmentation was recorded to find out the percentage of seed ball breakage or crack lines during handling and transportation. Maximum number of seed ball breakages were noticed in T_5 (14.1) and minimum in T_{15} (7.3) and T_6 (7.7), respectively (Table 1). Compared to red soil, organic materials have a higher pore space and high disintegration rate while handling. High dissolution rate in water is the desired characteristic of seed balls. Seed balls having more diameter had longer dissolution time. Longer dissolution time lags the absorption of moisture by the seed and inhibits germination (Dogan *et al*., 2005). The dissolution rate of seed balls was observed to define the amount of media disintegrated while watering or during raining at open field condition. It was observed to calculate the percentage of effective seeding rates. In the media of red soil and vermicompost, the fastest dissolution was noticed from T_5 (220 sec.), while T_1 took maximum time to dissolve (375 sec.). The optimum dissolution rate observed in T_6 and T_{15} which were 345 and 360 sec. respectively (Table 1).

The minimum dissolution rate of the media leads to the fastest disintegration of media, which in turn activates the dislocation of seeds placed in the seed ball. The fastest dissolution may be due to the presence of high pore space in the media, which was achieved in the combination of red soil and vermicompost. This combination causes more absorption of water and easy dissolved media. When the time for dissolution was more, the process of seed germination was suppressed by hard base media as well as hinderance in imbibition process. When red soil alone was used as a medium, slower rate of disintegration was observed due to high compactness of media because of the presence of fine soil particles. Fine soil particles have a capacity of higher compact and lower porosity that help in preventing the degradation of media during watering. Minimal and maximal time taken for dissolution of seed balls had a negative impact on seedling emergence; hence an optimum dissolution rate is required for good seedling emergence. Optimum disintegration of media helps in seed germination by providing favourable basic requirements.

Raviv *et al*. (2002) reported that soilless media have more porosity and aeration space as it implies on water

Table 1. Physical parameters of red earth and vermicompost at different ratios on fodder sorghum seed ball medium.

Treatments (T)	Seed ball weight (g ball $^{-1}$)	Size diameter (cm ball^{-1})	Fragmentation (No's)	Dissolution (Sec. ball^{-1})
T_1 - Red Soil	17.1 ± 0.15 ^{j}	2.3 ± 0.04 ^{ns}	8.1 ± 0.12 ^{b}	375 ± 4.47 ^{a}
T_2 -1:1:RS:V	11.5 ± 0.08 ^{dec}	2.4 ± 0.05 ^{ns}	10.8 ± 0.12 ^{f}	308 ± 6.89 ^{d}
T_3 -1:2:RS:V	10.8 ± 0.15 ^{cde}	2.6 ± 0.02 ^{ns}	12.6 ± 0.21 ^{g}	284 ± 6.21 ^{g}
T_4-1:3:RS:V	10.1 ± 0.12 ^{bcd}	2.5 ± 0.06 ^{ns}	13.2 ± 0.03 ^{h}	281 ± 3.77 ^{g}
T_5-1:4:RS:V	9.4 ± 0.20 ^{a}	2.2 ± 0.03 ^{ns}	14.1 ± 0.07 ^{i}	220 ± 5.15 ^{i}
T_6-2:1:RS:V	12.2 ± 0.22 ^{fgde}	2.6 ± 0.04 ^{ns}	7.7 ± 0.23 ^{b}	345 ± 8.80 ^{b}
T_7-2:2:RS:V	11.2 ± 0.20 ^{cd}	2.3 ± 0.03 ^{ns}	10.9 ± 0.06 ^{f}	300 ± 5.31^{def}
T_8-2:3:RS:V	8.9 ± 0.20 ^{ade}	2.6 ± 0.02 ^{ns}	9.3 ± 0.15 ^{c}	288 ± 3.84 ^{fg}
T_9-2:4:RS:V	11.0 ± 0.32 ^{bde}	2.6 ± 0.06 ^{ns}	10.3 ± 0.20 ^{e}	276 ± 1.44 ^{gh}
T_{10}-3:1:RS:V	13.8 ± 0.19 ^{icd}	2.5 ± 0.01 ^{ns}	9.0 ± 0.18 ^{c}	361 ± 4.88 ^{a}
T_{11}-3:2:RS:V	12.6 ± 0.31 ^{ghf}	2.9 ± 0.02 ^{ns}	10.0 ± 0.21 ^{de}	327 ± 5.96 ^{c}
T_{12}-3:3:RS:V	11.8 ± 0.22 ^{efe}	2.7 ± 0.06 ^{ns}	10.9 ± 0.23 ^{f}	289 ± 3.46 ^{efg}
T_{13}-3:4:RS:V	11.2 ± 0.13 ^{cde}	2.7 ± 0.01 ^{ns}	12.4 ± 0.23 ^{g}	262 ± 2.18 ^{h}
T_{14}-4:1:RS:V	13.7 ± 0.21 ^{icd}	2.5 ± 0.01 ^{ns}	9.8 ± 0.09 ^{d}	364 ± 5.08 ^{a}
T_{15}-4:2:RS:V	13.1 ± 0.16 ^{hc}	2.4 ± 0.05 ^{ns}	7.3 ± 0.12 ^{a}	360 ± 8.43 ^{ab}
T_{16}-4:3:RS:V	12.5 ± 0.12 ^{gde}	2.6 ± 0.06 ^{ns}	13.9 ± 0.20 ^{i}	304 ± 4.90 ^{de}
T_{17}-4:4:RS:V	11.7 ± 0.29 ^{def}	2.3 ± 0.04 ^{ns}	11.1 ± 0.03 ^{f}	301 ± 6.06 ^{def}

T_1-Red Soil; T_2-1:1:RS:V; T_3-1:2:RS:V; T_4-1:3:RS:V; T_5-1:4:RS:V; T_6-2:1:RS:V; T_7-2:2:RS:V; T_8-2:3:RS:V; T_9-2:4:RS:V; T_{10}-3:1:RS:V; T_{11} -3:2:RS:V; T_{12}-3:3:RS:V; T_{13}-3:4:RS:V; T_{14}-4:1:RS:V; T_{15}-4:2:RS:V; T_{16}-4:3:RS:V; T_{17}-4:4:RS:V (*RS-Red Soil; V-Vermicompost) Data presented are means from four replicates with standard errors. Within each treatment, different letters at each column indicate significant differences by Duncan's multiple range test at $P < 0.05$.

Table 2. Effect of seed ball medium (red earth and vermicompost) at different ratios on physiological parameters of fodder sorghum.

Treatments (T)	Speed of emergence	Germination (%)	Root length (cm)	Shoot length (cm)	DMP (g 10 seedlings^{-1})	Vigour index I
T_0-Control	6.5 ± 0.10 ^{cde}	88(69.73) ± 0.41 ^{i}	8.3 ± 0.05 ^{hi}	16.4 ± 0.12 ^{fgh}	0.146 ± 0.00 ^{jk}	2174 ± 17.59 ^{j}
T_1 - Red Soil	6.9 ± 0.11 ^{b}	96(78.46) ± 0.99 ^{abc}	8.9 ± 0.21 ^{fg}	16.8 ± 0.12 ^{ef}	0.148 ± 0.01 ^{jk}	2467 ± 14.31 ^{def}
T_2 -1:1:RS:V	5.9 ± 0.08 ^{g}	95(77.07) ± 0.79 ^{cde}	8.6 ± 0.20 ^{gh}	17.3 ± 0.16 ^{cd}	0.152 ± 0.00 ^{ij}	2461 ± 15.76 ^{ef}
T_3 -1:2:RS:V	6.7 ± 0.16 ^{bcd}	95(77.07) ± 0.35 ^{cde}	8.7 ± 0.05 ^{gh}	16.8 ± 0.11 ^{ef}	0.145 ± 0.00 ^{k}	2423 ± 10.09 ^{fg}
T_4-1:3:RS:V	6.9 ± 0.06 ^{b}	93(74.65) ± 0.24 ^{defg}	8.9 ± 0.20 ^{fg}	17.0 ± 0.17 ^{de}	0.156 ± 0.01 ^{i}	2409 ± 15.31 ^{gh}
T_5-1:4:RS:V	6.5 ± 0.08 ^{de}	90(71.56) ± 0.88 ^{hi}	7.6 ± 0.19 ^{j}	16.2 ± 0.22 ^{ghi}	0.168 ± 0.01 ^{gh}	2142 ± 16.81 ^{j}
T_6-2:1:RS:V	7.4 ± 0.12 ^{a}	98(81.86) ± 0.33 ^{a}	10.6 ± 0.09 ^{a}	18.9 ± 0.22 ^{a}	0.246 ± 0.02 ^{a}	2891 ± 17.32 ^{a}
T_7-2:2:RS:V	6.5 ± 0.11 ^{cde}	94(75.82) ± 0.64 ^{cdef}	9.4 ± 0.16 ^{deh}	17.1 ± 0.15 ^{cde}	0.189 ± 0.01 ^{d}	2491 ± 14.26 ^{de}
T_8-2:3:RS:V	6.8 ± 0.12 ^{bcd}	93(74.65) ± 1.11 ^{def}	9.2 ± 0.05 ^{ef}	16.3 ± 0.26 ^{hi}	0.172 ± 0.00 ^{fg}	2372 ± 18.66 ^{h}
T_9-2:4:RS:V	6.3 ± 0.05 ^{ef}	94(75.82) ± 0.20 ^{cdef}	9.9 ± 0.12 ^{b}	16.8 ± 0.15 ^{efg}	0.129 ± 0.00 ^{i}	2510 ± 14.37 ^{d}
T_{10}-3:1:RS:V	6.8 ± 0.07 ^{bc}	94(75.82) ± 1.57 ^{cdef}	9.4 ± 0.16 ^{de}	15.9 ± 0.15 ^{i}	0.201 ± 0.01 ^{bc}	2378 ± 12.38 ^{h}
T_{11}-3:2:RS:V	6.9 ± 0.12 ^{b}	92(73.57) ± 1.21 ^{fgh}	9.8 ± 0.06 ^{bcd}	16.2 ± 0.18 ^{hi}	0.179 ± 0.00 ^{e}	2392 ± 12.10 ^{gh}
T_{12}-3:3:RS:V	5.9 ± 0.04 ^{g}	90(71.56) ± 0.37 ^{ghi}	7.9 ± 0.16 ^{ij}	17.5 ± 0.11 ^{c}	0.206 ± 0.01 ^{b}	2286 ± 20.60 ^{i}
T_{13}-3:4:RS:V	6.0 ± 0.06 ^{fg}	96(78.46) ±1.06 ^{abcd}	8.0 ± 0.20 ^{ij}	16.9 ± 0.15 ^{def}	0.199 ± 0.00 ^{c}	2390 ± 12.70 ^{gh}
T_{14}-4:1:RS:V	6.9 ± 0.15 ^{b}	95(77.07) ±1.17 ^{bcde}	10.1 ± 0.12 ^{b}	18.1 ± 0.12 ^{b}	0.162 ± 0.02 ^{h}	2679 ± 10.58 ^{b}
T_{15}-4:2:RS:V	7.6 ± 0.19 ^{a}	97(80.02) ± 0.76 ^{ab}	10.5 ± 0.15 ^{a}	19.4 ± 0.15 ^{a}	0.249 ± 0.00 ^{a}	2900 ± 14.12 ^{a}
T_{16}-4:3:RS:V	6.9 ± 0.14 ^{b}	95(77.07) ± 0.89 ^{cde}	9.5 ± 0.15 ^{cde}	17.6 ± 0.29 ^{c}	0.196 ± 0.00 ^{c}	2575 ± 22.55 c
T_{17}-4:4:RS:V	6.5 ± 0.04 ^{cde}	94(75.82) ± 0.93 ^{cdef}	8.6 ± 0.11 ^{g}	15.9 ± 0.12 ^{i}	0.175 ± 0.01 ^{ef}	2303 ± 14.53 ^{i}

T_0-Control; T_1-Red Soil; T_2-1:1:RS:V; T_3-1:2:RS:V; T_4-1:3:RS:V; T_5-1:4:RS:V; T_6-2:1:RS:V; T_7-2:2:RS:V; T_8-2:3:RS:V; T_9-2:4:RS:V; T_{10}-3:1:RS:V; T_{11}-3:2:RS:V; T_{12}-3:3:RS:V; T_{13}-3:4:RS:V; T_{14}-4:1:RS:V; T_{15}-4:2:RS:V; T_{16}-4:3:RS:V; T_{17}-4:4:RS:V (*RS-Red Soil; V-Vermicompost) (Figures in parenthesis indicate arcsine values). Data presented are means from four replicates with standard errors. Different letters at each column indicate significant differences within each treatment by Duncan's multiple range test at $P < 0.05$.

holding capacity and wetness. Marinari *et al*. (2000) suggested that more porosity in the soil treated with vermicompost was due to increase in the number of pores. Compost addition in growth media caused a positive increase of moisture content because of more porosity in the soil (Bazzoffi *et al*., 1998). The higher accumulation of soil particles were reported by Munnoli and Bhosle (2008), and vermicompost had recorded increased porosity, aeration and decreased density (Munnoli and Bhosle, 2011) which causes increased water-holding capacity of the media.

Seed balls prepared with a combination of red soil and vermicompost at various ratios were evaluated for seedling parameters under shade net condition. The maximum speed of emergence was noticed in T_{15} (7.6) which was on par with T_6 (7.4) and the minimum speed of emergence was recorded in control (6.5). The highest germination percent was observed in T_6 (98%) followed by T_{15} (97%), whereas control recorded the lowest (88%). The shortest root length was recorded in control (8.3 cm) and the longest in T_6 (10.6 cm), which was on par with T_{15} (10.5 cm). A significant difference in shoot length was observed as higher shoot length in T_{15} (19.4 cm) followed by T_6 (18.9 cm) and the lower shoot length in control (16.4 cm). Dry matter production ranged from 0.146 to 0.249 g among treatments. The maximum accumulation of DMP was noticed in T_{15} (0.249 g) which was on par with T_6 (0.246 g) and minimum was recorded in T_0 (0.146 g). The highest seedling vigour was recorded in T_{15} (2900) followed by T_6 (2891) and the lowest in T_0 (2174) in vigour index I (Fig. 1 & Table 2).

The maximum seedling quality parameters obtained in the present study was due to the presence of vermicompost, which contained an optimum concentration of nutrients that helped in improving the seedling vigour. This result was supported with increased germination rate, seedling length and vigour in muskmelon (Vo and Wang, 2014), increased germination, seedling length and dry matter accumulation in tomato by use of vermicompost (Paul and Metzger, 2005; Gutierrez-Miceli *et al*., 2007). Bachman and Metzger (2008) reported that the application of vermicompost in germination media increased root and shoot length. Arancon *et al*. (2004) and Mishra *et al*. (2005) reported a positive influence of vermicompost on the growth and yield of strawberry and vermicompost had beneficial effects on rice, especially significant increase of many growth parameters, seeds germination and yield. Rekha *et al*. (2018) suggested application of vermicompost in *Capsicum annum* increased root and shoot length, increased number of leaves. During seed ball drying process, the moisture from the seed ball media will be imbibed by seeds, the nutrients and beneficial growth hormones are infused through imbibition. This helps seeds for early and uniform germination through the

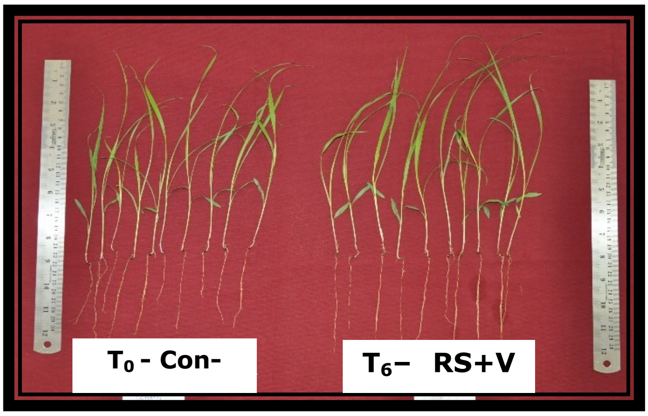

Fig. 1. *Effect of vermicompost on physiological parameters of fodder sorghum seed ball at the optimum dose.*

process of biopriming. Moeinzadeh *et al*. (2010) reported that sunflower seeds primed with rhizobial bacteria positively influenced seed germination by increased seedling vigour. Seed germination and enhanced seedling growth are obtained through seed priming with PGPR in maize (Anitha *et al*. 2013). Tamilarasan *et al*. (2020) reported that the preparation of subabul seed balls with a combination of red soil and vermicompost had an positive effect on seedling quality improvement in subabul seeds.

The use of a high ratio of vermicompost caused a reduction in seed germination and seedling vigour. Levinsh (2011) also reported a reduction in seed germination of radish, cabbage, Swedish turnip, beetroot, beans and peas when grown with more than 50% vermicompost in substrates. Higher content of vermicompost in growth media causes a lower plant growth rate due to the presence of a high concentration of plant growth hormones such as auxin and humic acids produced by microorganisms (Arancon *et al*., 2006).

Conclusion

The results of the study revealed that mixing of different ratio of red soil, vermicompost at different combination had significant effect on both physical and physiological characteristics of seed balls balls speed of germination (7.6), germination (98%) and vigour index (2900) which will have the impact on the seedling emergence and subsequent vigour and establishment of the sorghum plants. The optimum ratio of media had an effect on lesser fragmentation, optimum dissolution rate, which implicated on better seedling emergence with the supply of the required amount of growth hormones and essential nutrients for uniform and earlier seed germination. The combination of red soil + vermicompost at the ratio of 2:1 and 4:1 were found to be optimum for the preparation of seed balls with enhanced physical and physiological parameters that resulted in uniform and vigorous seedling establishment. Therefore, the use of seed balls could also restore the degraded lands.

Conflict of interest

The authors declare that they have no conflict of interest.

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