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CONTENTS

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Consumptive Use, Water Use Efficiency and Moisture Extraction Pattern of Summer Pearl Millet in Western Maharashtra as Influenced by Sowing Times and Irrigation Regimes

P. B. Pawar and D. V. Dahat

Abstract

A field experiment was conducted during summer 2010 and 2011 at Water Management Project Farm, Mahatma Phule Krishi Vidyapeeth, Rahuri, Ahemadnagar, Maharashtra, India to find out appropriate sowing times and irrigation regimes for summer pearl millet. Twelve treatment combinations were investigated in this study: four with sowing times including D_1 - 6th MW (5th - 11th February), D_2 - 8th MW (19th - 25th February), D_3 - 10th MW (5th - 11th March) and D_4 - 12th MW (19th - 25th March) and the remaining three treatments were of irrigation regimes I_1 - 100 mm CPE, I_2 - 125 mm CPE and I_3 - 150 mm CPE. Irrigation water for all treatments was precisely supplied using Replouge flume. The consumptive use of water was more in 8th MW (394.2 mm) followed by 6th MW (391.0 mm) and 10th MW (382.2 mm). The consumptive use of water was more in 100 mm CPE irrigation regime (443.47 mm), followed by 125 mm (379.67 mm) and 150 mm CPE (321.0 mm) irrigation regime. Whereas, reverse trend was noticed for water use efficiency was more in 150 mm CPE (8.16 kg ha^{-1} mm^{-1}) irrigation regime. The soil moisture extraction was more from middle soil moisture layer of 15-30 cm in 6th MW followed by sowing of crop in 8th, 10th and 12th MW during both the years. The soil moisture extraction from surface layer of 0-15 cm was more with 100 mm CPE irrigation regime owing to adequate moisture supply followed 125 mm CPE and 150 mm CPE irrigation regime during both the years. The sowing of summer pearl millet in 8th MW increased grain yield (30.09 q ha^{-1}), consumptive use (394.16 mm) and net monetary returns (Rs. 25742 ha^{-1}) while the 100 mm CPE irrigation regimes increased grain yield (29.48 q ha^{-1}), consumptive use (443.47 mm) and net monetary returns (Rs. 23784 ha^{-1}). Results indicated that 100 mm CPE irrigation treatment gave the highest crop yield, followed by 125 mm CPE and 150 mm CPE irrigation regimes treatments. Increasing water stress sharply decreased biomass production. Water use efficiency (WUE) was increased as inadequate water is supplied to crop (150 mm CPE irrigation regime). Results also proved that summer pearl millet sowing in 8th MW (19-25th February) and irrigating with 100 mm CPE irrigation regime treatment is a practical tool to harvest maximum crop yield, monetary benefits and water use efficiency.

Key words : Pearl millet, yield, consumptive use, Water use efficiency, soil moisture extraction pattern.

Maharashtra ranks second in area and production of pearl millet (Pennisetum glaucum) in India. However, average productivity is relatively low as pearl millet is mostly grown under rainfed condition. Because of high productivity under assured irrigation, pearl millet cultivation in summer season is gaining popularity. Drought is the most important abiotic stress that limits plant productivity and will only worsen in the future when constraints on water resources increase. Plant coping strategies under water deficit are limited and revolve around the need to use water in an efficient way, ensure that water is available for the grain filling period, and maximise water capture from the soil profile. In irrigation scheduling, a climatological approach based on IW/CPE ratio (IW –irrigation water, CPE – cumulative pan evaporation) has been found most appropriate. This approach integrates all the weather parameters that determine water use by the crop and is likely to increase production by at least 15–20% (Dastane 1972). Optimum scheduling of irrigation led to increase

in grain yield and water use efficiency. Pearl millet is a potentially productive, high-quality grain or silage crop that appears superior to sorghum concerning establishment and production under limited soil moisture (Serraj and Sinclair, 2002; Purcell *et al*., 2002; Dakheel *et al*., 2009). Due to these changing environmental conditions, pearl millet is considered to be a good option to grow as a grain crop. The current research tries to achieve the greatest aboveground biomass production per unit of water by two methods. First is the evaluation of optimum time of sowing and second is application of precision irrigation to add the required amount of water when and where needed. Precision irrigation means applying irrigation water in the right place with the right amount at the right time (Almarshadi and Ismail, 2011).

The present experiment was therefore, undertaken to find out suitable sowing time and irrigation regime for summer pearl millet with following objectives.

1. To study the microclimatic conditions of summer pearl millet under different environmental conditions.
2. To study the effect of sowing times and irrigation regimes on growth, yield, nutrient uptake, water requirement, water use efficiency and economics of pearl millet.
3. To study the interaction effects between sowing times and irrigation regimes on growth, yield, nutrient uptake and economics of pearl millet.

Material and methods

A field experiment was conducted during summer 2010 and 2011 at Rahuri (Western Maharashtra) to investigate the effect of sowing times and irrigation regimes on yield, CU, WUE and moisture extraction pattern of summer pearl millet variety Shanti. The treatments were comprised of four sowing times (D_1 - 6th MW (5th - 11th February), D_2 - 8th MW (19th - 25th February), D_3 - 10th MW (5th - 11th March) and D_4 - 12th MW (19th - 25th March)) as the main plots and irrigation regimes (I_1 - 100 mm CPE, I_2 - 125 mm CPE and I_3 - 150 mm CPE) as sub-plots. The experiment was laid out in strip plot design and replicated three times. The soil was sandy clay loam in texture, well drained with high moisture retention capacity (field capacity 32.2%, permanent wilting point 16.0, bulk density 1.38 g cc^{-1}). The soil of experimental plot was low in and N (142 kg ha^{-1}) and medium in available P and high in K. The seeds were sown as per the sowing times during both the years. Common dose of 40 kg N ha^{-1}, 40 kg P_2O_5 ha^{-1} and 40 kg K_2O ha^{-1} was applied in the form of urea, SSP and MOP respectively, as basal and After 30 DAS, top dressing of 40 kg N ha^{-1} was done through urea in between the two rows of crop. Irrigations were scheduled based on CPE values of 100, 125 and 150 mm in respective plots. Daily evaporation data were recorded from the evaporimeter installed in the plot. In all, one common irrigation was applied immediately after sowing for proper germination and establishment of the plants. Remaining irrigations were given as per treatments when CPE reached at respective level and the quantity of water was measured with the help of Replouge flume. Soil moisture studies were started right from sowing and continued up to final harvest of pearl millet crop. The soil samples for soil moisture studies were taken just before irrigation and 24 hours after irrigation from 0-15, 15-30 and 30-45 cm soil depth with the help of screw auger from net plot area of each treatment. Immediately the samples were transferred to aluminium soil moisture boxes and covered with moist gunny bag to avoid moisture losses from soil samples. The moisture boxes containing soil samples were shifted immediately

to laboratory for weighing and drying the soil samples. The soil samples were dried at 1050C for 8 to 10 hours till constant weight was obtained. The loss in moisture was expressed in percentage on oven dry weight basis as suggested by Dastane (1972). Soil moisture studies were also taken up with the help of 'Troxler Model 4302 moisture gauge with Neutron Probe'. The data obtained on moisture percentage as above for each depth were used for calculating consumptive use (CU) of water, water use efficiency and the moisture extraction pattern of pearl millet crop.

The field consumptive use of water by summer pearl millet crop in mm, respectively, is computed by the formula, as given below:

$$CU\ (mm) = \sum_{i=1}^{n}(Eo \times 0.8) + \frac{M_1i - M_2i}{100}(ASi \times Di) + GWC + ER$$

Where, CU = Consumptive use of water in mm, n = Number of soil layers in the root zone, i = Time instant of the respective irrigation schedule (1, 2, 3,...n), Eo= Actual evaporation recorded by U.S.A. 'class A' pan evaporimeter for the period of 48 hours from the respective scheduling of irrigation, M_1i = Moisture content at the first sampling in the ith layer (per cent), M_2i = Moisture content at the second sampling in the ith layer (per cent), ASi= Bulk density of the ith layer (Mg m^{-3}), Di = Depth of soil in the ith layer (cm), GWC = Ground water contribution (mm) and ER = Effective rainfall (mm)

Moreover, from the data on consumptive use of water, the daily water use rates (mm day-1) were also computed for respective schedule of irrigation.

Water use efficiency (WUE) i.e. kg of pearl millet grains (dry) produced mm^{-1} of water hectare-1 in each irrigation treatment and is worked out by the following formula:

$$WUE = \frac{Y}{CU}$$

Where, WUE = Water use efficiency (kg of grains ha^{-1} mm^{-1}), Y = Grain yield (kg ha^{-1}) and CU = Total seasonal consumptive-use of water (mm).

Result and discussion

Effect of sowing times on consumptive use of water and water use efficiency : Consumptive use of water and water use

Table 1. The yield, consumptive use of water, daily water use and water use efficiency as influenced by different treatments

Treatments	2010			2011		
	Yield (q ha^{-1})	CU (mm)	WUE (kg ha^{-1} mm^{-1})	Yield (q ha^{-1})	CU (mm)	WUE (kg ha^{-1} mm^{-1})
Sowing times						
6^{th} MW	29.07	355.90	8.17	28.17	426.10	6.61
8^{th} MW	30.50	358.04	8.52	30.10	430.28	7.00
10^{th} MW	26.69	348.36	7.66	26.82	416.04	6.45
12^{th} MW	25.32	333.86	7.58	25.47	380.02	6.70
Irrigation regimes						
100 mm CPE	30.11	424.83	7.09	29.51	460.12	6.41
125 mm CPE	27.89	348.28	8.01	27.71	411.06	6.79
150 mm CPE	25.69	274.85	9.35	25.69	368.16	6.98
General mean	27.90	349.16	7.99	27.64	413.11	6.69

efficiency were more when the crop was sown in 8th MW (358.04 mm and 8.52 kg ha mm^{-1}) (Table 1), whereas, these values were lower when crop was sown in 12th MW (333.86 mm and 7.58 kg ha mm^{-1}) because of significant improvement in pearl millet grain yield owing to favourable microclimate under former sowing time and significant decrease in pearl millet grain yield under later sowing time owing to adverse microclimate. Similar results were reported by Shinde (2011) and Waghmode (2012).

Effect of Irrigation regimes times on consumptive use of water and water use efficiency : The consumptive use of water was more *viz*., 424.83 and 460.12 mm with 100 mm CPE irrigation regime during the year 2010 and 2011, respectively, followed by 125 and 150 mm CPE irrigation regimes, because of supply of adequate quantity of water under former irrigation regime and inadequate supply of irrigation water under later irrigation regime. Whereas, reverse trend was noticed for water use efficiency where it was more *viz*., 9.35 and 6.98 kg ha^{-1} mm^{-1} under 150 mm CPE irrigation regime during the year 2010 and 2011, respectively followed by 125 and 100 mm CPE irrigation regime owing to efficient utilization of available soil moisture under inadequate water supply of 150 mm CPE irrigation regimes. These results are in the line of Tomar *et al*. (1992), Vyas *et al*. (1994), Gargi and Gautam (2003), Patel and Singh (2004), Sonawane *et al*. (2010), Shinde (2011) and Waghmode (2012).

Effect of sowing times on soil moisture extraction pattern : The soil moisture extraction from the surface layer of 0-15 cm was more when crop was sown in 8th MW followed by sowing of pearl millet in 6th, 10th and 12th MW during both the years. The soil moisture extraction was more from middle soil moisture layer of 15-30 cm in 6th MW followed by sowing of crop in 8th, 10th and 12th MW during both the years. However, soil moisture extraction was more from lower depth of 30-45 cm soil layer with each successive delay in sowing during both the years.

Effect of irrigation regimes on soil moisture extraction pattern : The soil moisture extraction from surface layer of 0-15 cm was more with 100 mm CPE irrigation regime owing to adequate moisture supply followed 125 mm CPE and 150 mm CPE irrigation regime during both the years. Whereas, the soil moisture extraction was more with 150 mm CPE irrigation regime from deep soil layer of 30-45 cm followed by 125 and 100 mm CPE irrigation regimes during both the years of experimentation because of moisture stress condition. This could be due to enhancement of moisture availability in the surface layer with frequent irrigations under 100 mm CPE irrigation regimes. Lack of sufficient soil moisture in the surface layers at 150 mm CPE irrigation regime might have forced the plants for vertical movement to meet water requirement from deeper layers. The maximum configuration of pearl millet roots in the top 30

Table 2. The soil moisture extraction pattern from different soil layers as influenced by different treatments

Treatments	Soil moisture extraction pattern (%)					
	2010			2011		
	Soil layer (cm)			Soil layer (cm)		
	0-15	15-30	30-45	0-15	15-30	30-45
Sowing times						
6th MW	46.78	35.23	17.99	45.85	35.00	19.15
8th MW	48.56	33.46	17.98	47.03	34.18	18.79
10th MW	45.68	33.12	21.20	44.35	34.61	21.04
12th MW	44.68	32.87	22.45	43.80	33.79	22.41
Irrigation regimes						
100 mm CPE	47.30	35.26	17.44	47.68	35.06	17.26
125 mm CPE	45.33	36.02	18.65	45.81	34.98	19.21
150 mm CPE	44.51	36.28	19.21	44.64	34.36	21.00
General mean	46.12	34.61	19.27	45.59	34.57	19.84

cm soil profile explained the moisture extraction pattern by the crop. Similar findings have been reported by Gulati *et al*. (2001).

Conclusion and Recommendation

The findings of this study are very important for decision makers and growers of semi-arid regions. Moisture affected the grain yield, consumptive use, water use efficiency (WUE) and soil moisture extraction pattern of summer pearl millet tested significantly. It can be summarized from above results that summer pearl millet be sown in 8th MW (19-25 February) and irrigated with 100 mm CPE irrigation regimes with an average irrigation interval of 12 days for higher consumptive use, water use efficiency, productivity and better monetary benefits. There is need for further work on the extent to which WUE contribute to drought tolerance in summer pearl millet under field conditions.

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Efficacy and Economics of Some Selected Insecticides Against Shoot and Fruit Borer (*Earias Vittella*) of Okra [*Abelmoschus Esculentus* (L.) Moench]

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Abstract

The current study was carried out at Central Research Farm, SHUATS, Naini, Prayagraj, U.P during *kharif* season of 2021. Two applications of seven insecticides were used against Eariasvittellaand the resultsrevealed that Chlorantraniliprole 18.5% SC had the lowest percent of shoot and fruit infestation with 11.71% and 11.96% followed by Emamectin benzoate 5% SG (12.96% and 14.11%), Spinetoram 11.7% SC (13.28% and 14.70%), Imidacloprid 17.8% SL (14.71% and 16.35%), Flonicamid 50 WG (14.90% and 17.31%), Acephate 75 SP (15.74% and 17.65%) and Diafenthiuron 50 WP (16.39% and 19.61%) respectively as compared to control (water spray) with 20.75% and 24.75%. Benefit cost ratio was found highest in Chlorantraniliprole (1: 4.4) followed by Imidacloprid (1: 4.2), Emamectin benzoate (1: 4.2), Spinetoram (1: 3.4), Diafenthiuron (1: 3.3), Flonicamid (1: 3.3), Acephate (1: 3.1) and Control (1: 1.6).

Key words : Benefit cost ratio, Chlorantraniliprole, *Eariasvittella*, Emamectin benzoate, Insecticides, *Kharif*, Shoot and fruit infestation, spinetoram.

Okra [*Abelmoschus esculentus* (L.) Moench] commonly known as *Bhindi* or lady's finger (family Malvaceace) is a popular fruit vegetable crop due to its high nutritional and medicinal values. Due to their sensitive and supplemental character, as well as their growth in high moisture, okra is planted throughout the summer and *kharif* seasons. Carbohydrate (6.4%), Protein (1.9%), Fat (0.2%), Fibre (1.2%), Minerals (0.7%) and Moisture (89.6%) are all present in okra fruits. Anonymous (2013-14). Gujarat is the largest okra producing state in India, with output of roughly 921.72 thousand tones from an area of 75.27 thousand hectares and a productivity of 12.25 tonnes ha^{-1}, followed by West Bengal (914.86 thousand tones from 77.5 thousand hectares and 11.5 tonnes ha^{-1} productivity). Uttar Pradesh has production of 307.29 tonnes from an area of 22.93 thousand ha with a productivity of 13.40 MT ha^{-1} of okra. NHB(2018-19).

One of the limiting factors is the cultivation of okra is infestation of insect pests. As many as 72 species of insects have been recorded on okra Pandey *et al*. (2019). The major insect pests are shoot and fruit borer, *Earias insulana* (Boisd.), *Earias vittella* (Boisd.); leaf hopper, *Amrasca biguttula biguttula* (Ishida.); leaf roller, *Sylepta derogate* (Fab); whitefly, *Bemisia tabaci* (Genn.); Aphid, *Aphis gossypii* (Glov.) and mite, *Tetranychus cinnabarinus* (Boisd.). Nagar *et al*. (2017).

The shoot and fruit borer (E. *insulana* and E. *vittella*) is one of the most serious pests of okra. The larvae bore into the terminal growing shoots, floral buds, flowers and fruits of okra, resulting in cessation, withering and drying of infested shoots, tender leaves and heavy shedding of floral buds and flowers. The infested fruits become malformed and are rendered unfit for human consumption as well as for procurement of the seeds. The borer has been reported to cause 24.6 to 26.0 percent damage

1. M. Sc. Scholor and 2. Associate Professor,

to okra shoots and 40 to 100 percent loss to fruits. Yadav *et al*. (2017).

Pesticides constitute the key control tactics for management of pests and diseases and the productivity of crops depends on their effective control. Together with high yielding crop varieties and fertilizers, pesticides have helped the Indian farmers in achieving a substantial increase in agricultural productivity. Birthal *et al*. (2000). The area under plant protection has been continuously increasing in India which is why this study has been carried out to find out the efficacy of some selected insecticides in order to control Eariasvittella of okra.

Materials and Methods

During the *kharif* season of 2021, a field research was carried out at Central Research Farm, Sam Higginbottom University of Agriculture, Technology and Sciences (SHUATS), Prayagraj, U.P. The okra seeds of variety 'Abhay' were planted at 45 cm x 30 cm spacing.

The experiment was laid down in randomized block design (RBD) with eight treatments replicated thrice with each plot size of 2m x 2m and proper irrigation was provided. The treatments comprising of Spinetoram 11.7% SC, Emamectin benzoate 5% SG, Chlorantraniliprole 18.5% SC, Flonicamid 50% WG, Acephate 75% SP, Imidacloprid 17.8% SL and Diafenthiuron 50% WP were applied two times using knapsack sprayer. The shoot damage (due to Earias vittella) was recorded at weekly interval while fruit damage at each picking from randomly selected five plants. The observations recorded one day before spray followed by 3, 7 and 14 days after spraying. After the last picking, total of all pickings of individual plots produce were calculated to work out the yield of the treatments. Yield of healthy fruits was converted into quintal per hectare. The extent of damage was computed by using the formula:

Percent shoot infestation

$$\text{Percent shoot damage} = \frac{\text{Number of infested shoots}}{\text{Total number of shoots}} \times 100$$

Percent fruit infestation

$$\text{Percent fruit damage} = \frac{\text{Number of damaged fruit}}{\text{Total number of fruits}} \times 100$$

$$\text{Benefit Cost Ratio} = \frac{\text{Gross returns}}{\text{Total cost}}$$

Results and Discussion

Efficacy of treatments : The data so obtained through observation were subjected to statistical analysis wherever necessary. From the data on mean of shoot infestation of first spray revealed that the treatment Chlorantraniliprole 18.5 percent SC (11.71 percent) caused the least shoot damage, followed by Emamectin benzoate 5 percent SG (12.96 percent), Spinetoram 11.7 percent SC (13.28 percent), Imidacloprid 17.8 percent SL (14.17 percent), Flonicamid 50 percent WG (14.90 percent), Acephate 75 percent SP (15.74 percent), and Diafenthiuron 50 percent WP (16.39 percent) was the least effective treatment. (See Table 1) (Fig. 1).

These results are in support with Shirale *et al*. (2012) Naidu and Kumar (2019) who reported that Chlorantraniliprole proved superior over other insecticides in reducing infestation of L. *orbonalis*. Reshma and Behera (2018) reported Emamectin benzoate as effective treatment.Muthukrishnan *et al*. (2013) reported Spinetoram as effective treatment.

The data on mean of fruit infestation of second spray revealed that the treatment Chlorantraniliprole 18.5 percent SC (11.96

Table 1. Efficacy of some insecticides against shoot and fruit borer of okra [*Abelmoschus esculentus* (L.) Moench] (First spray)

Treatments	% Shoot infestation				
	Before spraying	**3 DAS**	**7 DAS**	**14 DAS**	**Mean**
T_1 - Spinetoram 11.7% SC	18.968 (25.768)*	12.768 (20.936)*	11.771 (20.064)*	15.312 (23.022)*	13.283 (21.346)*
T_2 - Emamectin benzoate 5% SG	20.021 (26.577)*	12.277 (20.505)*	11.553 (19.868)*	15.078 (22.836)*	12.969 (21.077)*
T_3 - Chlorantraniliprole 18.5% SC	20.158 (26.672)*	11.349 (19.653)*	10.007 (18.440)*	13.776 (21.785)*	11.710 (19.972)*
T_4 - Flonicamid 50% WG	18.968 (25.768)*	14.107 (22.057)*	12.824 (20.969)*	17.788 (24.940)*	14.906 (22.664)*
T_5 - Acephate 75% SP	20.021 (26.577)*	14.713 (22.554)*	14.611 (22.393)*	17.919 (25.033)*	15.747 (23.357)*
T_6 - Imidacloprid 17.8 SL	20.158 (26.672)*	13.082 (21.179)*	12.920 (21.028)*	16.532 (23.988)*	14.178 (22.087)*
T_7 - Diafenthiuron 50% WP	20.021 (26.577)*	15.020 (22.799)*	14.888 (22.690)*	19.288 (26.049)*	16.398 (23.850)*
T_0 - Control	18.801 (25.683)*	19.182 (25.974)*	20.258 (26.732)*	22.811 (28.516)*	20.750 (27.084)*
F - test	NS	S	S	S	S
S. Ed. (±)	1.109	0.714	1.431	1.004	0.412
C. D (P = 0.05)	-	1.539	3.073	2.157	0.892

*Figures in parenthesis are arc sin transformed values. DAS : Days After Spray

percent) caused the least fruit damage of the seven insecticides tested against the shoot and fruit borer, followed by Emamectin benzoate 5 percent SG (14.11 percent), Spinetoram 11.7 percent SC (14.70 percent), Imidacloprid 17.8 percent SL (16.35 percent), Flonicamid 50 percent WG (17.31 percent), Acepahte 75 percent SP (17.65 percent) and Diafenthiuron (19.61 percent) was the least effective treatment. (See Table 2) (Fig. 2).

These results are in support with Tripura*et al*. (2017)[10] and Kumar *et al*. (2017) [11] reported that Chlorantraniliprole recorded lowest fruit damage. Parthiban *et al*. (2014) recorded that Emamectin benzoate on fruit yield was the most effective. Bade *et al*. (2017) found Spinetoramas the most effective in reducing the incidence of shoot and fruit borer of brinjal.

Cost benefit ratio : There was a considerable difference in yield between the treatments. In comparison to control (1: 1.6), Chlorantraniliprole (1: 4.4) produced the best yield, followed by Imidacloprid (1: 4.2), Emamectin benzoate (1: 4.2), Spinetoram (1: 3.4), Diafenthiuron (1: 3.3), Flonicamid (1: 3.3), and Acephate (1: 3.1). (See Table 3).

The present results are similar with Kumar *et*

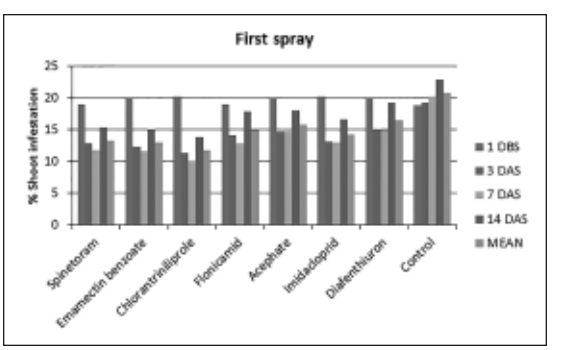

Fig 1. Efficacy of some selected insecticides against shoot and fruit borer of okra. (first spray)

Table 2. Efficacy of some selected insecticides against shoot and fruit borer of okra [*Abelmoschus esculentus* (L.) Moench] (Second spray)

Treatments	% Fruit infestation				
	Before spraying	3 DAS	7 DAS	14 DAS	Mean
T_1 - Spinetoram 11.7% SC	24.309 (29.536)*	14.011 (21.980)*	12.515 (20.715)*	17.584 (24.791)*	14.703 (22.497)*
T_2 - Emamectin benzoate 5% SG	24.309 (29.536)*	13.776 (21.785)*	11.847 (20.117)*	16.709 (24.121)*	14.110 (22.016)*
T_3 - Chlorantraniliprole 18.5% SC	23.596 (29.057)*	11.275 (19.616)*	10.307 (18.716)*	14.312 (22.217)*	11.964 (20.192)*
T_4 - Flonicamid 50% WG	24.033 (29.349)*	16.944 (24.296)*	15.661 (23.311)*	19.337 (26.075)*	17.314 (24.569)*
T_5 - Acephate 75% SP	24.309 (29.536)*	18.653 (25.575)*	15.961 (23.536)*	18.340 (23.345)*	17.651 (24.831)*
T_6 - Imidacloprid 17.8 SL	23.596 (29.057)*	15.195 (22.931)*	15.473 (23.142)*	18.389 (25.386)*	16.352 (23.833)*
T_7 - Diafenthiuron 50% WP	23.809 (29.197)*	20.490 (26.900)*	17.725 (24.895)*	20.623 (27.005)*	19.612 (26.274)*
T_0 - Control	23.596 (29.057)*	24.084 (29.381)*	23.358 (29.566)*	25.833 (30.543)*	24.758 (29.837)*
F - test	NS	S	S	S	S
S. Ed. (±)	0.836	1.048	1.723	1.029	0.741
C. D (P = 0.05)	-	2.256	3.701	2.214	1.599

*Figures in parenthesis are arc sin transformed values. DAS : Days After Spray

al. (2017) and Kushwaha and Painkra (2016) recorded highest B:C ratio in Chlorantraniliprole. Nemade *et al*. (2015) [16]concluded that in terms of higher incremental cost benefit ratio, Imidacloprid was found superior. Devi *et al*. (2014) and Singh *et al*. (2018) observed higher B:C ratio in Emamectin benzoate. Ghosal *et al*. (2013) observed highest yield and B:C ratio in Spinetoram.

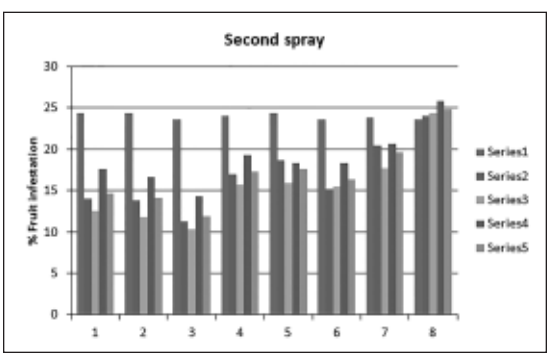

Fig 2. Efficacy of some selected insecticides against shoot and fruit borer of okra. (second spray)

Conclusion

From the experiment discussed above, the results revealed that the most efficient pesticide against shoot and fruit borer was found to be Chlorantraniliprole, followed by Emamectin benzoate and Spinetoram with Diafenthiuron being the least effective. Chlorantraniliprole had the best cost-benefit ratio followed by Imidacloprid, Emamectin benzoate and Spinetoram.

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Table 3. Economics of treatments for management of shoot and fruit borer

Treatments	Yield (q ha^{-1})	Cost of yield	Total cost of yield (Rs.)	Common cost (Rs.)	Treatment cost (Rs.)	Total cost (Rs.)	Cost: Benefit ratio
Spinetoram 11.7% SC	137.9	1500	206850	47278	12050	59328	1: 3.4
Emamectin benzoate 5% SG	140.5	1500	210750	47278	2480	49758	1: 4.2
Chlorantraniliprole 18.5% SC	162.4	1500	243600	47278	8000	55278	1: 4.4
Flonicamid 50% WG	107.2	1500	160800	47278	1280	48558	1: 3.3
Acephate 75% SP	103.3	1500	154950	47278	1454	48732	1: 3.1
Imidacloprid 17.8 % SL	151.8	1500	227700	47278	5800	53078	1: 4.2
Diafenthiuron 50% WP	110.6	1500	165900	47278	2480	49758	1: 3.3
Control	52	1500	78000	47278	-	47278	1: 1.6

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Author contribution statement

Sanjana kulkarni[1] and Ashwani kumar[2]

KS is a M.Sc (entomology) student who has conducted the whole trial right from layout to sowing of seeds, observation of pests, spraying of insecticides and harvesting of okra fruits which was done under the guidance of KA, Associate professor. The present article is taken from the M.Sc thesis submitted by KS to SHUATS (Sam Higginbottom University of Agriculture, Technology and Sciences) Prayagraj, U.P.

Conflicts of interest/Competing interests

The author (s) declare (s) no known conflict of interests that could have appeared to influence the work reported in this paper.

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Genetic Variability of Yield and its Components in Little Millet [*Panicum sumatrense* L.]. Local Germplasm

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Abstract

The fifty little millet genotypes were used to study Genetic variability, heritability and genetic advance. The highest estimates of GCV and PCV values were recorded seed yield plant^{-1} and iron content. Moderate estimates of GCV and PCV values were recorded panicle weight plant^{-1}, total number of tillers plant^{-1}, days to 50 per cent flowering and productive tillers plant^{-1}. Almost all the characters showed high percentage of heritability except productive tillers plant^{-1} and panicle length showed medium heritability, while number of branches panicle^{-1} showed low heritability. It indicates that charactersis least influenced by the environmental effect, suggesting scope for improvement of respective characters. The characters iron content, seed yield plant^{-1}, panicle weight plant^{-1}, total number of tillers plant^{-1} and productive tillers plant^{-1} showed high heritability accompanied with high genetic advance, it indicates that selection is effective for this characters.

Key words : Genetic variability,Heritability, Genetic advance, GCV and PCV, Little millet.

Millets are in the family of cereals grown in different parts of the world for human consumption and as feed and fodder for animal. Little millet (*Panicum sumatrense* L.) belongs to family *Poeceae* (*Graminae*), sub family *Panicoideae* and genus *Panicum*. It is considered as self-pollinated crop. Little millet is diploid (2n=36) in nature.It is known by different vernacular name in different states of India, is commonly called kutki and Shaban in Hindi. It is also known as sava,vari and halvi in Marathi, gajro and kuri in Gujrati, same and sama in Kannada, samai in Tamil, samalu in Telugu, sama in Bengali and swank in Panjabi.

Little millet is cultivated to a limited extent in India, Sri Lanka, Pakistan, Myanmar, and other South East Asian countries (Hiremath *et al*., 1990). In India it is important to tribes of the Eastern Ghat Mountains and grown in combination with other millets (Hiremath *et al*., 1990). The major little millet growing states are Orissa, Gujarat, Maharashtra, Karnataka, Andhra Pradesh and Madhya Pradesh. In India it is cultivated over an area of 2.34 lakh ha with total production of about 1.27 lakh tones and with productivity of 544 kg/ha during the year 2015-16. (Anonymous., 2018).

Little millet is a domesticated form of the weedy species *Panicum psilopodium* (De Wet *et al*., 1983). They are cultivated in diverse and adverse environments, mostly in the dry, semi-arid to sub-humid drought-prone agro ecosystems. It is a quick growing, short duration cereal which can withstand both drought and water logging. Its cultivation is restricted to hilly regions up to an altitude of 2000m. It cannot withstand colder temperatures below 10°C.

The little millet contains 8.7 gram protein, 75.7 gram carbohydrate, 5.3 gram fat and 1.7 gram mineral and 9.3 mg iron in per 100 gram grain. Its high fiber helps to reduce the fat depositions in the body. Little millet has a significant role in providing nutraceutical components such as phenols, tannins and phytates along with other nutrients.

Information on genetic variability, heritability and genetic advance is most essential for formulating effective selection schemes in any crop improvement programme. A very limited work of this kind has been previously done on little millet. Therefore, the present investigations were undertaken to determine genetic variability, heritability and genetic advance in moth bean.

Materials and methods

The experimental materials consisting fifty germplasm of little millet collected from NARP, research station Igatpuri, Nashik and remaining from Ahmednagar, Dhule and Nandurbar districts of Maharashtra (Table 2). Sowing of fifty genotypes of little millet on raised seed bed 2nd July, 2020 and transplanting was done on 31st July, 2020. The experiment was laid out in RBD with two replications at Department of Botany, College of Agriculture, Dhule (M.S.). By adopting a spacing of 30 cm between rows and 10 cm between plants respectively, at recommended package of practices were followed to raise good and healthy crop stand. Data were collected on twelve yield and yield contributing characters *viz*., days to 50% flowering, days to maturity, plant height (cm), total number of tillers plant^{-1}, productive tillers plant^{-1}, panicle length (cm), number of branches panicle^{-1}, panicle weight plant^{-1} (g), seed yield plant^{-1} (g), 100 ml volume weight, protein content (%) and iron content (mg).

The mean of five plants was subjected to statistical analysis. The data for different characters were statistically analyzed for significance by using analysis of variance technique described by Panse and Sukhatme (1985). The adapted design was Randomized Block Design (RBD) with two replications. The significance of mean sum of square for each character was tested against the corresponding error degrees of freedom using "F" Test (Fisher and Yates, 1967). The components of variances were used to estimate genetic parameters like phenotypic and genotypic coefficient of variation (PCV and GCV) as per the formula given by Burton and De Vane (1953). Heritability in broad sense was calculated according to the formula given by Allard (1960) and expressed in percentage. Genetic advance was estimated by using Burton (1955). Statistical analysis was done by using WINDOSTAT program.

Table 1. Analysis of variance for different characters in little millet

Characters	Mean sum of square		
	Replication	Genotype	Error
Days to 50 per cent flowering	1.0000	192.9722**	22.79592
Days to maturity	7.2900	226.3676**	32.18796
Plant height (cm)	80.4609	89.51078**	21.97355
Total number of tillers plant^{-1}	0.38440	0.751355**	0.11991
Productive tillers plant^{-1}	0.3249	0.645651**	0.165716
Panicle length (cm)	7.6176	7.214114**	2.112702
Number of branches panicle^{-1}	0.75516	2.575013**	1.365753
Panicle weight plant^{-1} (g)	12.9600	31.00144**	5.626939
Seed yield plant^{-1} (g)	1.3432	16.50176**	1.470063
100 ml volume weight (g)	9.4556	11.15253**	2.532317
Protein content (%)	0.000066	0.740318**	0.041422
Iron content mg 100^{-1} (g)	0.1844	4.919818**	0.046271

*, ** Indicates significance at 5% and 1% level, respectively.

Results and Discussion

Analysis of variance revealed significant differences among genotypes for all the characters. (Table 1). The characters seed yield plant^{-1} and iron content showed higher estimates of GCV and PCV, indicating presence of large variation among the genotypes for these characters (Table 3). Therefore, simple selection can be practiced for further improvement of these characters. These results were in conformity with the finding of Subramanian *et al*. (2010), Salini *et al*. (2010), Tyagi *et al*. (2011), Selvi *et al*. (2014), Nandini *et al*. (2016), Ashok *et al*. (2016 a), and Madhavilatha *et al*. (2020). The character panicle weight plant^{-1}, total number of tillers plant^{-1}, days to 50 per cent flowering and productive tillers plant^{-1}. Similar finding were also reported by Nirmalakumari *et al*. (2010) and Geetha *et al*. (2018) for days to 50 per cent flowering, Sasamala *et al*. (2015), Suryanarayana and Sekhar *et al*. (2018) for number of productive tillers plant^{-1}, days to 50 per cent flowering observed moderate GCV and PCV for these characters.

The charactersdays to maturity, panicle length, plant height, protein content, number of branches panicle^{-1} and 100 ml volume weightshowed low genotypic and phenotypic coefficient of variation. It indicates that low range of variation found in these characters thus offers little scope for further improvement of these characters. Similar results was recorded by Nirmalakumari *et al*. (2010) and Ashok *et al*. (2016 a) for plant height, Anuradha *et al*. (2017) for plant height, Brunda *et al*. (2014) for days to maturity andplant height, Savankumar *et al*. (2018) for days to maturity, number of branches panicle^{-1} and plant height and Selvi *et al*. (2014) and Madhavilatha *et al*. (2020) for panicle length.

High heritability coupled with high genetic

Table 2. List of little millet genotypes with origin

Genotype	Village	Tahsil	District
IGPLM-19-01	Khodala	Javhar	Thane
IGPLM-19-03	Dhondali	Igatpuri	Nashik
IGPLM-19-04	Vaitarana	Igatpuri	Nashik
IGPLM-19-05	Dhond-maryachi	Timbakeshwar	Nashik
IGPLM-19-08	Devgaon	Timbakeshwar	Nashik
IGPLM-19-10	Korapgaon	Igatpuri	Nashik
IGPLM-19-13	Devgaon	Timbakeshwar	Nashik
IGPLM-19-14	Dhargaon	Igatpuri	Nashik
IGPLM-19-16	Korapgaon	Igatpuri	Nashik
IGPLM-19-17	Bahuli kh	Igatpuri	Nashik
IGPLM-19-18	Ondasi	Igatpuri	Nashik
IGPLM-19-19	Devgaon	Timbakeshwar	Nashik
IGPLM-19-22	Dhondmar-yachiyate	Timbakeshwar	Nashik
IGPLM-19-24	Kalamwadi	Mokhada	Thane
IGPLM-19-26	Khodala	Javhar	Thane
IGPLM-19-27	Kalamwadi	Mokhada	Thane
IGPLM-19-28	Khodala	Javhar	Thane
IGPLM-19-29	Bahirwadi	Javhar	Thane
IGPLM-19-30	Dhargaon	Igatpuri	Nashik
IGPLM-19-31	Korapgaon	Igatpuri	Nashik
IGPLM-19-32	Bhavali	Igatpuri	Nashik
IGPLM-19-34	Devgaon	Timbakeshwar	Nashik
IGPLM-19-36	Khodala	Javhar	Thane
IGPLM-19-37	Dhargaon	Igatpuri	Nashik
IGPLM-19-38	Dhargaon	Igatpuri	Nashik
IGPLM-20-01	Manhere	Igatpuri	Nashik
IGPLM-20-02	Manhere	Igatpuri	Nashik
IGPLM-20-03	Gavande	Igatpuri	Nashik
IGPLM-20-04	Gavande	Igatpuri	Nashik
IGPLM-0-05	Bari	Igatpuri	Nashik
IGPLM-20-06	Bari	Igatpuri	Nashik
IGPLM-20-07	Gavande	Igatpuri	Nashik
IGPLM-20-08	Manhere	Igatpuri	Nashik
IGPLM-20-09	Manhere	Igatpuri	Nashik
IGPLM-20-10	Manhere	Igatpuri	Nashik
DHLM-1	Bhandardara-1	Akole	A'dnagar
DHLM-2	Bhandardara-2	Akole	A'dnagar
DHLM-3	Bhandardara-3	Akole	A'dnagar
DHLM-4	Khed	Akole	A'dnagar
DHLM-5	Rajur-1	Akole	A'dnagar
DHLM-6	Rajur-2	Akole	A'dnagar
DHLM-7	Charanmal	Sakri	Dhule
DHLM-8	Kudashi	Sakri	Dhule
DHLM-9	Nawapata	Sakri	Dhule
DHLM-10	Pimpalner	Sakri	Dhule
DHLM-11	Dhadgaon-1	Dhadgaon	Nandurbar
DHLM-12	Dhadgaon-2	Dhadgaon	Nandurbar
DHLM-13	Amli	Akkalkuwa	Nandurbar
DHLM-14	Amli Bari	Akkalkuwa	Nandurbar
Phule Ekadashi (check)	MPKV, Rahuri	Rahuri	A'dnagar

advance reveals the presence of lesser environmental influence and prevalence of additive gene action in their expression (Panse, 1957). Lower values of genetic advance indicate the prevalence of narrow range of variability, high G X E interaction (non-additive gene action).

High heritability values recorded for most the characters. Iron content, protein content, seed yield plant^{-1}, days to 50 per cent flowering, days to maturity, total number of tillers per plant, panicle weight, 100 ml volume weight and plant height indicating least influence of environment on these characters. These results were conformity with Salini *et al*. (2010), Nirmalakumari *et al*. (2010 a), Ganapathy *et al*. (2011), Patil and Mane (2013), Sasamala *et al*. (2015), Jyothsna *et al*. (2016 a), Ashok *et al*. (2016, a) and Savankumar*et al*. (2018).

While medium heritability was observed for productive tillers plant^{-1}, panicle length. Similar finding were reported by Selvi *et al*. (2014) and low heritability was observed for number of branches panicle^{-1}.

In the present study, high heritability coupled with high genetic advance was observed for iron content followed by seed yield plant^{-1}, panicle weight plant^{-1}, total number of tillers plant^{-1} and productive tillers plant^{-1} suggesting that these characters are govern by additive genes and phenotypic selection for these characters may be effective. Previously similar results were reported by Subramaian *et al*. (2010), Selvi *et al*. (2014), Jyothsna *et al*. (2016, a), Ashok *et al*. (2016, a),Salini *et al*.(2010), Nirmalakumari *et al*. (2010, a), Ganapathy *et al*. (2011), Anuradha *et al*. (2017), Patel *et al*. (2018), Nirmalakumari *et al*. (2010, b), Patil and Mane (2013), Sasamala *et al*. (2015).

High heritability coupled with medium genetic advance was observed for protein content, days to 50 per cent flowering and days to maturity. This indicates the presence of both additive and non-additive gene action for these traits. Nirmalakumari *et al*. (2010 b) and Savankumar*et al*. (2018) for days to 50 per cent flowering are also reported similar result.

High heritability coupled with low genetic advance was observed for 100 ml volume weight and plant height suggesting preponderance of non-additive gene action and selection for these

Table 3. Parameters of genetic variability for different characters in Little millet

Characters	General mean	σ^2g	σ^2p	σ^2e	GCV (%)	PCV (%)	ECV (%)	h^2 (BS %)	GA	GA as per cent of mean
Days to 50% flowering	94.94	85.088	107.884	22.796	9.716	10.940	5.029	78.90	16.876	17.775
Days to maturity	129.43	97.090	129.278	32.188	7.613	8.785	4.383	75.10	17.591	13.591
Plant height (cm)	149.037	33.769	55.742	21.974	3.899	5.010	3.145	60.60	9.317	6.252
Total no. of tillers plant^{-1}	4.006	0.316	0.436	0.120	14.026	16.476	8.644	72.50	0.985	24.598
Productive tillers plant^{-1}	3.759	0.240	0.406	0.166	13.032	16.944	10.830	59.20	0.776	20.647
Panicle length (cm)	26.822	2.551	4.663	2.113	5.954	8.051	5.419	54.70	2.433	9.072
No. of branches panicle^{-1}	13.7451	0.605	1.970	1.366	5.657	10.212	8.502	30.70	0.887	6.456
Panicle weight plant^{-1} (g)	18.536	12.687	18.314	5.627	19.216	23.088	12.797	69.30	6.107	32.948
Seed yield plant^{-1} (g)	9.1081	75.16	8.986	1.470	30.100	32.912	13.312	83.60	5.156	56.707
100 ml volume weight (g)	73.8555	4.310	6.842	2.532	2.811	3.542	2.155	63.00	3.394	4.596
Protein content (%)	7.1064	0.349	0.391	0.041	8.318	8.798	2.864	89.40	1.151	16.203
Iron content mg 100^{-1} (g)	5.5762	2.437	2.483	0.046	27.995	28.259	3.858	98.10	3.186	57.129

traits may not be rewarding. Brunda *et al*. (2014) and Ashok *et al*. (2016, b) indicated same result for plant height.

Low heritability with low genetic advance was observed for character number of branches panicle^{-1} and panicle length suggesting that environment had a major role in their expression, indicating predominant role of non-additive gene action for this trait and selection would be ineffective. This was in conformity with the result of Selvi *et al*. (2014) for panicle length are also reported similar result.

In conclusion, the material chosen differed in their genotypic make up as evidenced by the significant differences among them in respect of all the quantitative characters studied. Phenotypic coefficients of variations estimate was slightly higher than the genotypic coefficients of variation for all the trait, indicating low environmental influence on the expression of all the traits.

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Studies on Effect of Foliar Applications on Productivity and Economics of Rainfed Crops on Farmers Field

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Abstract

Most of the part of the Marathwada region is comes under assured rainfall zone. The region receives mean annual rainfall of 880 mm. Rainfall in uncertain and erratic in this region and sometimes suffers from severe droughts. Major crops of the region are soybean, cotton and pigeon pea which grown on large area in Marathwada region of Maharashtra State and are being a preferred crops in *Kharif* season by the marginal and small rainfed farmers. The productivity of these crops particularly in Marathwada region is uncertain due to occurrence of frequent dryspells. Occurrence of 3 to 4 dryspells in July to September is a common feature of the region. The productivity of all crops decreases with either deficiency of rainfall and its distribution or due to moisture stress in critical growth period due to dryspells occurred in July and August. Participatory trials were conducted on farmers' fields during 2019-20 to 2021-22 under the project "National Innovations in Climate Resilient Agriculture" (NICRA) which is in operation at village Babhulgoan in Parbhani District in Marathwada region of Maharashtra. The rainfall data was collected from the nearest rain gauge station. The duration of dryspells and number of dryspells were recorded every year. Farmers were advocated to apply potassium nitrate as foliar spray on major crop The data on crop yield in both the field i.e. with foliar application of potassium nitrate and without its application were recorded. Accordingly, the additional per cent increase in yield was analyzed. This study clearly indicated the advantage of foliar application of KNO_3 during the dryspell for higher yield of soybean, pigeon pea and cotton. The results hold promise for improvement in production potential of dryland crops which can be effectively make crops resilient towards recurring drought events

Key words : Dry spell, Evapo-transpiration, Foliar application, Potassium nitrate

Rainfed agriculture supports to 40 per cent of human population and its contribution is 44 per cent of total food production. The fate of rainfed agriculture oscillates with the quantity and spatial distribution of monsoon. The way of stabilize and enhance productivity in agriculture lies with rain water conservation. Total Agricultural production fails in every season due to occurrence of drought situation in any of the part of the country. The farmer in dry areas will suffer the most from climate change and will require a range of coping strategies to adapt to changing climates.

Marathwada region of Maharashtra state, comprised of eight districts, lies between 170 35' to 200 40' N latitude and 74 0 40' to 780 16' E longitude. The altitude ranges between 300 to 900 m above mean sea level. The climate of Marathwada experiences wide inters districts and intra districts variability. The region experiences wide variability within and in between districts in respect of rainfall situation and also different soil type predominant in various parts of region. Occurrence of frequent droughts, unseasonal rains and hailstorms are the features of climate change in the region.

Soybean is grown on 13 lakh ha area in Marathwada region of Maharashtra state. Majority of the small and marginal farmers prefer to grow soybean during *kharif* season.

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The average productivity of soybean varies depending of monsoon behavior. Occurrence of frequent dryspells affects the productivity of soybean in the region. Marathwada region of Maharashtra state comprises 8 districts with average annual precipitation of 807 mm. The region is dominated by medium black cotton soils (60 %) and followed by heavy and shallow soils 15- 20% each. Assured rainfall zone covers 60-70% area followed by 10-15% by moderate to moderately high rainfall and 15-20% scarcity rain area. Though the majority area falls under assured rainfall zone, it is characterized by 2-3 prolonged dry spells during crop growth.

It is known that the most important factors limiting crop productivity are environmental stresses. This lack of water occurs when the rate of transpiration exceeds water uptake and is a component of several different stresses including drought, salinity and low temperature. Plants have different mechanisms to avoid water deficit. Among them, stomatal conductance is reduced as a part of the systemic response triggered by a signal that originates in the root system. (Mata and Lamattina. 2001). In this context, the study on application of foliar spray of potassium nitrate (KNO_3) to cope with drought situations for attaining sustainable crop yields was undertaken on farmer's field under NICRA programme since 2019-20 to 2021-22.

Materials and Methodology : Participatory trials were conducted on farmers' fields during 2016-17 to 2020-21 under the project "National Innovations in Climate Resilient Agriculture" (NICRA) which is in operation at village Babhulgoan in Parbhani District in Marathwada region of Maharashtra.

Most of the farmers were cultivating soybean under rainfed condition. Farmers were advocated to apply potassium nitrate as foliar spray on soybean crop. Demonstration fields were selected based on the willingness of the farmers to engage in participatory research to evaluate the science based strategy.

The rainfall data was collected from the nearest rain gauge station. The duration of dryspells and number of dryspells were recorded every year. The data on crop yield in both the field i.e. with foliar application of potassium nitrate and without its application were recorded. Accordingly, the gross and net returns were worked out and thus the additional per cent increase in yield was analyzed.

Results and Discussions

Rainfall and dryspells : The data on annual rainfall, crop seasonal rainfall, number of dryspell, dryspell duration and period during 2019-20 to 2021-22 is presented in Table 1.

Table 1. Annual, crop seasonal rainfall, and dry spell details during 2019-20 to 2021-22

Year	Annual rainfall, mm	Crop seasonal rainfall, mm	No. of dry-spell	Dura-tion, Days	Dryspell period
2019	964.2	859.7	4	10	01/07/2019 to 10/07/2019
				13	14/07/2019 to 26/07/2019
				16	15/08/2019 to 30/08/2019
				18	02/10/2019 to 19/10/2019
2020	1098.7	1004.5	4	09	17/06/2020 to 25/06/2020
				12	30/07/2020 to 10/08/2020
				10	28/08/2020 to 06/09/2020
				09	02/10/2020 to 10/10/2020
2021	1610.8	1196.8	4	07	29/06/2021 to 05/07/2021
				22	25/07/2021 to 15/08/2021
				08	23/08/2021to 30/08/2021
				14	18/10/2021 to 31/10/2021

In the last three years, 4 dryspells were observed every year which has resulted moisture stress during crop period.

Effect of Foliar spray on crop yield : The data on mean grain yield, % increase in yield, net returns, RWUE and BC ration as effect of application of foliar spray (KNO_3) on soybean crop is presented in Table 2.

Data indicated that soybean grain yield was found significantly increase by 18.99 per cent due to foliar application during dryspell. The mean soybean grain yield with application of foliar spray was recorded as 1159 kg ha^{-1} as against the grain yield of 974 without foliar spray. The net returns of Rs. 23375 ha^{-1} was observed due to foliar application with BC ratio of 1.97 as against the BC ratio of 1.60 without foliar application. The rain water use efficiency (RWUE) was recorded as 1.97 with foliar application.

Adkine *et al.*, (2011), Gowthami and Rama Rao (2014) and Shruthi (2013) studied the effect of boron, molybdenum and potassium nitrate on growth, yield and economic of soybean. They found that application of potassium nitrate resulted in increase in soybean yield. Similar results were obtained in the present study related to yield enhancement of soybean due to application of potassium nitrate during dryspell.

The data on mean grain yield, % increase in yield, net returns, RWUE and BC ration as effect of application of foliar spray (KNO_3) on pigeon pea crop is presented in Table 3.

Data indicated that cotton yield was found significantly increase by 23.90 per cent due to

Table 2. Effect of foliar spray of KNO_3 on soybean productivity and economics

Intervention	Soybean grain yield (kg ha^{-1})				% increase in yield	RWUE (kg ha^{-1} -mm)	Net returns (Rs. ha^{-1})	B:C ratio
	2018-19	2019-20	2020-21	Mean				
With foliar spray of KNO_3	1170	992	1315	1159	18.99	1.76	23375	1.97
Without foliar spray of KNO_3	870	772	992	974		1.34	16477	1.60

Table 3. Effect of foliar spray of KNO_3 on pigeon pea productivity and economics

Intervention	Pigeon pea grain yield (kg ha^{-1})				% increase in yield	RWUE (kg ha^{-1} -mm)	Net returns (Rs. ha^{-1})	B:C ratio
	2018-19	2019-20	2020-21	Mean				
With foliar spray of KNO_3	1272	1344	1235	1284	21.47	1.83	43140	2.24
Without foliar spray of KNO_3	1096	1098	978	1057		1.39	30100	1.94

Table 4. Effect of foliar spray of KNO_3 on cotton productivity and economics

Intervention	Cotton yield (kg ha^{-1})				% increase in yield	RWUE (kg ha^{-1} -mm)	Net returns (Rs. ha^{-1})	B:C ratio
	2018-19	2019-20	2020-21	Mean				
With foliar spray of KNO_3	1411	1350	1298	1353	23.90	1.89	42608	2.29
Without foliar spray of KNO_3	1145	1120	1011	1092		1.62	36609	1.92

foliar application during dryspell. The mean cotton yield with application of foliar spray was recorded as 1353 kg ha^{-1} as against the grain yield of 1092 without foliar spray. The net returns of Rs. 42608 ha^{-1} was observed due to foliar application with BC ratio of 2.29 as against the BC ratio of 1.92 without foliar application. The rain water use efficiency (RWUE) was recorded as 1.89 with foliar application.

Earlier researchers like Jabeen, *et al.*, (2011) studied the effect of foliar application of potassium nitrate affects the growth and nitrate reductase activity in sunflower and safflower leaves and salinity. Shinde et al., (1994) studied the effect of potassium nitrate and urea on growth and yield of cowpea (Vigna unguiculata. Patel and Pater (2008) observed changes in flower abscission, fruit drop and yield in mungbean bean as influenced by foliar spray of PGRs, urea and KNO_3. The results of the present study confirms with the results of previous work.

Conclusion

This study clearly indicated the advantage of foliar application of KNO_3 during the dryspell for higher yield of soybean, pigeon pea and cotton. The results hold promise for improvement in production potential of dryland crops which can be effectively make crops resilient towards recurring drought events. Hence foliar spray of KNO_3 can be recommended for dryland region of Marathwada to ensure higher returns for farmers.

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Effect of Straw Mulching on *In-situ* Moisture Conservation, Productivity and Profitability of Rainfed Soybean on Farmer's Field

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Abstract

Soybean is a major *kharif* crop grown in Marathwada region of Maharashtra under rainfed condition and is being a preferred crop by the marginal and small rainfed farmers. Though, most of the part of the region is comes under assured rainfall zone but it suffers from occurrence of frequent dryspells. The region receives mean annual rainfall of 880 mm. Rainfall in uncertain and erratic in this region. The productivity of soybean particularly in Marathwada region is uncertain due Occurrence of 3 to 4 dryspells in July to September. The crop productivity decreases with either deficiency of rainfall or its distribution or due to moisture stress in critical growth period due to dryspells occurred in July and August. Thus, to conserve the rainwater and to reduce soil evaporation, straw mulching in inter row space was advocated to farmers to avoid moisture stress and to cope with dryspells. The research demonstrations were conducted on farmer's field for 3 year since 2019-20 to 2021-22. Results indicated that straw mulch was found effective in in-situ moisture conservation. It was observed that soybean productivity was increased by 21.77 per cent due to application of straw mulch. Similarly, GMR and NMR was increased by 22.25% and 30.84% respectively, due to application of straw mulch. Straw mulch was found effective in additional 22% moisture conservation and found effective in avoiding moisture stress particularly during dryspell period.

Key words : Dry spell, Evaporation, Moisture conservation, Rainfed, Straw mulch.

Marathwada region of Maharashtra state is characterized by rainfed and majoe part comes under assured rainfall zone. The climate of Marathwada experiences wide inters districts and intra districts variability. The region experiences wide variability within and in between districts in respect of rainfall situation and also different soil type predominant in various parts of region. Occurrence of frequent droughts, unseasonal rains and hailstorms are the features of climate change in the region. Total Agricultural production fails in every season due to occurrence of drought situation in any of the part of the region. The farmer in dry areas will suffer the most from climate change and will require a range of coping strategies to adapt to changing climates.

Soybean is grown on 13 lakh ha area in Marathwada region of Maharashtra state. Majority of the small and marginal farmers prefer to grow soybean during kharif season. The average productivity of soybean varies depending of monsoon behavior. Occurrence of frequent dryspells affects the productivity of soybean in the region. The region is dominated by medium black cotton soils (60 %) and followed by heavy and shallow soils 15-20% each. Assured rainfall zone covers 60-70% area followed by 10-15% by moderate to moderately high rainfall and 15-20% scarcity rain area. Though the majority area falls under assured rainfall zone, it is characterized by 2-3 prolonged dry spells during crop growth.

Decreased crop productivity in arid and semi-arid regions is due to water shortage (Tavakkoli and Oweis 2004) and thus water

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availability is important for the stability of grain yield. The increase in soil water storage is possible with addition of straw mulch as a surface mulching material, which increases the soil water content, water use efficiency (WUE), and crop production (Wang *et al*. 2012). Generally, the addition of residues such as straw mulching increases the grain yield (Wang et al. 2012). It was also noted that straw mulching increased soil moisture content in the maize-wheat cropping system in the north-western regions of India, and thus enhanced crop productivity (Sharma *et al*. 2010). Gajri et al. (1994) reported that maize productivity was increased by mulching.

The limitation of water resources is the major constraint for crop production (Rockström et al. 2007). Keeping in view the importance of mulching and limited documentation of mulching effects on water storage, RWUE and soybean production in semi-arid regions, this study was planned to evaluate the effect of straw mulching on productivity and profitability of soybean with *in-situ* moisture conservation on farmer's field.

Materials and Methods

Research demonstrations were conducted on farmers' fields during 2019-20 to 2021-22 under FLD at village Babhulgoan in Parbhani District in Marathwada region of Maharashtra. Most of the farmers were cultivating soybean under rainfed condition. Farmers were advocated to apply straw mulch in inter row of soybean crop. Demonstration fields were selected based on the willingness of the farmers as participatory research to evaluate the science based strategy.

The rainfall data was collected from the nearest rain gauge station. The duration of dryspells and number of dryspells were recorded every year. The data on crop yield in both the field i.e. with straw mulch and without straw mulch were recorded. Accordingly, the gross and net returns (GMR and NMR), Rainwater use efficiency (RWUE) were worked out and thus the additional per cent increase in yield was analyzed. Similarly, the soil moisture was recorded periodically and additional moisture conservation due to straw mulch was analyzed.

Results and Discussions

Rainfall and dryspells : The data on annual rainfall, crop seasonal rainfall, numbers of dryspell, dryspell duration and period during 2019-20 to 2021-22 is presented in Table 1.

In the last three years, 4 dryspells were observed every year which has resulted moisture stress during crop growth period.

Table 1. Annual, crop seasonal rainfall, and dry spell details during 2019-20 to 2021-22

Year	Annual rainfall, mm	Crop seasonal rainfall, mm	No. of dry-spell	Dura-tion, Days	Dryspell period
2019	964.2	859.7	4	10	01/07/2019 to 10/07/2019
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				16	15/08/2019 to 30/08/2019
				18	02/10/2019 to 19/10/2019
2020	1098.7	1004.5	4	09	17/06/2020 to 25/06/2020
				12	30/07/2020 to 10/08/2020
				10	28/08/2020 to 06/09/2020
				09	02/10/2020 to 10/10/2020
2021	1610.8	1196.8	4	07	29/06/2021 to 05/07/2021
				22	25/07/2021 to 15/08/2021
				08	23/08/2021to 30/08/2021
				14	18/10/2021 to 31/10/2021

Crop productivity and Economics : The data on soybean productivity, GMR, NMR and BC ratio during 2019-20 to 2021-22 is presented in Table 2.

Data indicated that soybean grain yield was found significantly increase by 21.77 per cent due to application of straw mulch. The mean soybean grain yield with application of straw mulch was recorded as 1001 kg ha^{-1} as against the soybean grain yield of 822 without application of straw mulch.

Bu *et al*., (2013) studied the effects of mulching on maize growth, yield in a semi-arid region and found that grain yield was increased due to application of mulch. Similarly, Wang *et al*., (2012) studied the effect of tillage and crop residue on rainfed wheat and maize production in northern China and found that crop productivity was enhanced due to application of crop residue. Kumar *et al*. (1998) reported that different mulching materials resulted in increase in crop yield. Sekhon *et al*. (2005) studied the response of soybean (*Glycine max* Mer.) to wheat straw in different cropping seasons and found that soybean yield was increased due to application of straw mulch. Similar results are found in the present study.

Data indicated that gross and net monetary returns were found significantly increase by 22.25 and 30.84 per cent respectively, due to application of straw mulch. The mean gross and net returns in soybean production with application of straw mulch were found as Rs. 36725 ha^{-1} and Rs. 17062 ha^{-1} as against the mean GMR and mean NMR of Rs. 30040 ha^{-1} and Rs. 13040 ha^{-1} without application of straw mulch. The BC ratio of 1.87 was observed due to application of straw mulch as against the BC ratio of 1.78 without application of straw mulch.

The data on mean soil moisture during crop growth period during 2019-20 to 2021-22 is presented in Table 3.

Table 2. Soybean productivity, GMR, NMR and BC ratio during 2019-20 to 2021-22

Intervention	Soybean grain yield (kg ha^{-1})			
	2019-20	2020-21	2021-22	Mean
With mulching	1010	872	1121	1001
Without mulching	890	752	824	822
GMR, Rs. ha^{-1}				
With mulching	34330	32351	43495	36725
Without mulching	30251	27899	31971	30040
NMR Rs. ha^{-1}				
With mulching	14340	16351	20495	17062
Without mulching	13251	13899	11971	13040
BC ratio				
With mulching	1.71	2.02	1.89	1.87
Without mulching	1.77	1.99	1.60	1.78

Table 3. Mean soil moisture during crop growth period

Intervention	Mean soil moisture (%)			
	2019-20	2020-21	2021-22	Mean
With mulching	29.12	30.36	29.98	29.82
Without mulching	24.18	24.95	24.17	24.43

Data indicated that, with application of straw mulch, 29.82 per cent mean soil moisture was recorded during crop growth period as against the soil moisture of 24.43 per cent in the treatment of without mulching. Due to application of straw mulch, additional moisture of 22.06 per cent was conserved. Aulakh and Sur (1999), Jalota and Prihar (1979) conducted study on effect of mulching on soil moisture and found that due to mulching, additional soil moisture was conserved.

Conclusions

- Soybean grain yield was found significantly increase by 21.77 per cent due to application of straw mulch.

- The gross and net monetary returns were found significantly increase by 22.25 and 30.84 per cent respectively, due to application of straw mulch.
- The BC ratio of 1.87 was observed due to application of straw mulch as against the BC ratio of 1.78 without application of straw mulch.
- Due to application of straw mulch, additional moisture of 22.06 per cent was conserved.

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Effect of Changing Rainfall Situation on Yield of Pearl millet in Medium Deep Soil of Scarcity Zone of Maharashtra

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Abstract

The present invitation entitled " Effect of changing rainfall situation on yield of pearl millet in medium deep soil of scarcity zone of Maharashtra." was carried out during 2016-20 at Zonal Agricultural Research Station, Solapur, Mahatma Phule Krishi Vidyapeeth, Rahuri, Maharashtra (India). The experiment was conducted in split plot design with three replications. Nine treatment combinations were formed considering different cultivars *viz*., V_1(ICTP-8203), V_2 Mahyco Hybrid and V_3 Dhanashakti and sowing windows *viz*., (S_1) 2nd fortnight of June (25th June), (S_2) - 2nd fortnight of July (27th-July) S_3 - 2nd fortnight of August (24th - August). Among the three pearl millet sowing window crop sown in second fortnight of July (S_2) produced significantly higher grain yield (1518.9 kg ha^{-1}), biomass yield (2658.1 kg ha^{-1}), total monetary returns (Rs. 33090 ha^{-1}),CUM(383.7 mm), (MUE) (3.95 Kg ha^{-1} mm), GDD (1941-20610 days) and RUE (1.19g MJ^{-1}) than other sowing dates. Among the genotypes Dhanashakti produced significantly higher grain yield (1369.9 kg ha^{-1}), biomass yield (2525.5 kg ha^{-1}) and total monetary returns (Rs. 29994 ha^{-1}) than other cultivars. Under changing rainfall situation sowing of *Kharif* pearl millet contingent crop variety Dhanashakti upto 02nd September (Meteorological week no. 34-35) in medium deep soil of scarcity zone of Maharashtra is recommended for more sustainability in production. Following regression equation based on weather parameters for predicting the yield (prior to 2 weeks) is recommended. √Yield= -101.38 + (-0.21 x Tmin) + (2.49 x RH-1) + (-1.34 x RH-2) + (0.08 x RF).

Key words : *Kharif* pearl millet, sowing windows, yield attributes, cultivars.

Pearl millet (*Pennisetum glaucum* L.) formerly known as pearl, bulrush, spiked or cat-tail millet. Besides providing food and fodder, pearl millet is grown in the hot and dry climate and also can be grown in areas like arid or semi-arid where rainfall is not sufficient as received erratic and variable amount and also have characteristics to drought tolerant warm season (Sharma *et al*., 2010). Rainfall, temperature and radiation are major meteorological parameters, which influence all aspects and stages of growth of the crop. It has been reported that millet has many nutritious and medical functions (Yang *et al*. 2001).Pearl millet grains are also used as a food for poultry and green fodder or dry kadbi for cattle. Sowing time is the most important non-monetary input influencing crop yield. Sowing at optimum time improves the productivity by providing suitable environment at all the growth stages. Upadhyay *et al*. (2001) have reported higher grain yield of summer pearl millet when sown on 15 march and found reduction in grain yield with delay in sowing. Time of sowing varies with the variety, agro climatic conditions and crop growing season. In fact, proper planting date is important for maximizing cereal grain yields (Witt, 1996) because optimum seeding dates establish healthy and vigorous plants. A significant reduction in grain yield is associated with delayed seeding for a wide range of climatic conditions (Knapp and Knapp, 1978, Dahlk*eet al*. 1993). Lawn *et al*. (1993) found that differences in development of cereals sown at different times may be explained

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by considering an optimum temperature. It was reported that the drastic reduction in yield under delayed sowing (Ramshe *et al*.1986).Keeping in view of the importance the study was aimed to investigate influence of weather parameters on pearl millet (*Pennisetum glaucum* L.) varieties under Solapur condition.

Material and Methods

The study was conducted at research farm of Zonal Agricultural Research Station, Solapur, Mahatma Phule Krishi Vidyapeeth,Rahuri, Maharashtra (India) during in year 2016-2020 in the *Kharif* season. The area is positioned at 75° 65' N latitude 75° 90'E longitude and at the altitude of 483.6 meters above the sea level. The experiment was conducted in split plot design with three replications. Nine treatment combinations were formed considering different cultivars *viz*., V_1 (ICTP-8203), V_2 Mahyco Hybrid and V_3 Dhanashakti and sowing windows *viz*., (S_1) 2nd fortnight of June (25th June), (S_2) - 2nd fortnight of July (27th-July) , S_3 - 2nd fortnight of August (24th-August). The soil comes under the vertisol (medium black) clayey loam in texture and slightly alkaline (pH-7.2) in nature and having the depth up to 90 cm. The monsoon lasts from June to the end of September, with moderate rainfall. It has an average rainfall of about of 545 mm per year. The annual maximum and minimum temperature ranged between 25.0 to 43.2°C and 7.3 to 27.1°C, respectively. The gross and net plot sizes were 15.0 x 6.3 m2and 10.0 x 4.5 m^2, respectively. All the cultivars are were dibbled as per different sowing windows at a spacing of 45 cm x 20cm.

Result and Discussion

Agronomic studies : The crop sown in second fortnight of July (S_2) produced significantly higher grain yield (1518. 9 kg ha^{-1}), biomass yield (2658.1 kg ha^{-1}) and total monetary returns (Rs. 33090/- ha^{-1}) and it was found at par with crop sown in second fortnight of June (S_1). It might be due to crop sown at

Table 1. Pooled grain yield (kg ha^{-1}) of *kharif* pearl millet as influenced by various sowing dates and varieties (2016 to 2020)

Treatment	2016	2017	2018	2019	2020	Mean	Sur/def (%)	SYI
Main = 3 Sowing dates								
S_1 = MW 26 (June 26-July01) 2nd fortnight of June	1719.8	888.1	1146.7	867.2	1147.9	1154.0	3.8% less over mean	0.47
S_2 = MW 30 (July 23-29) 2nd fortnight of July	2185.3	1099.8	1503.8	1253.5	1551.9	1518.9	26.54% high over mean	0.50
S_3 = MW 35 (August 27-2 Sept) 2nd fortnight of August	1328.7	710.7	812.6	744.2	1044.9	928.2	22.6% less over mean	0.50
Mean	1744.6	899.5	1154.4	954.9	1248.2	1200.3		0.48
Sub=Three varieties								
V_1 = ICTP-8203	1598.5	769.1	1025.4	823.8	1127.3	1068.8	10.9% less over mean	0.46
V_2 = Mahyco hybrid	1682.7	852.6	1155.9	936.3	1227.3	1162.3	3.1% less over mean	0.50
V_3 = Dhanshakti	1952.6	1076.9	1281.8	1104.9	1390.0	1369.9	14.1% high over mean	0.51
Mean	1744.6	899.5	1154.4	954.9	1248.2	1200.3		0.48
S.E.± (Sowing dates)	74.5	70.3	60.81	67.1	69.1	44.5		
C.D. at 5%	292.5	275.9	238.77	263.6	221.4	145.2		
S.E.+ (Varieties)	52.0	48.1	63.67	62.5	63.8	20.7		
C.D. at 5 %	160.3	148.1	196.19	192.7	196.7	60.5		
S.E.± (SD x V)	90.1	83.2	110.28	108.3	110.6	35.9		
C.D. at 5 %	NS	NS	NS	NS	NS	NS		

second fortnight of July (S_2) gets sufficient period for its biological and reproductive development and ultimately resulted into higher grain yield, biomass yield and total monetary returns. Where as, adverse situation of all these parameters were experienced by delayed sown crop in 34th and early sowing 26th MW resulted in decreased values of these yield contributing characters. Similar findings were reported by Kaushik and Gautam (1984), (Siddig *et al.* 2013) and (Maiti and Soto, 1990). It also indicates that crop sown at second fortnight of

Table 2. Mean Fodder yield (kg ha^{-1}) of *kharif* pearl millet as influenced by various sowing dates and varieties (2016 to 2020)

Treatment	2016	2017	2018	2019	2020	Mean	SYI
Main = 3 Sowing dates							
S_1 = MW 26 (June 26-July01) 2nd fortnight of June	3046.7	1828.0	2144.0	1744.3	1958.8	2144.4	0.53
S_2 = MW 30 (July. 23-29) 2nd fortnight of July	3393.2	2035.9	2563.40	2484.5	2813.3	2658.1	0.63
S_3 = MW 35 (August 27-2 Sept) 2nd fortnight of August	2665.4	1599.3	1882.5	1625.3	1784.4	1911.4	0.55
Mean	3035.1	1821.1	2196.7	1951.4	2185.5	2237.9	0.58
Sub = 3 varieties							
V_1 = ICTP-8203	2723.7	1634.2	2041.9	1662.7	1946.9	2001.9	0.57
V_2 = Mahyco hybrid	2984.8	1790.9	2112.1	1938.5	2106.2	2186.5	0.57
V_3 = Dhanshakti	3396.9	2038.1	2436.0	2253.0	2503.4	2525.5	0.59
Mean	3035.1	1821.1	2196.7	1951.4	2185.5	2237.9	0.58
S.E.± (Sowing dates)	109.7	65.8	92.87	104.3	151.9	66.5	
C.D. at 5%	430.6	258.4	364.6	409.6	496.6	216.8	
S.E.+ (Varieties)	120.7	72.4	84.76	68.7	129.4	37.6	
C.D. at 5 %	371.8	223.1	261.18	211.7	398.6	109.6	
S.E.± (SD x V)	209.0	125.4	146.81	119.0	224.1	65.1	
C.D. at 5%	NS	NS	NS	NS	NS	NS	

Table 3. Mean total monetary returns (Rs ha^{-1}) of *kharif* pearl millet as influenced by various sowing dates and varieties (2016 to 2020)

Treatment	2016	2017	2018	2019	2020	Mean	SYI
Main = 3 Sowing dates							
S_1 = MW 26 (June 26-July01) 2nd fortnight of June	31891	22332	2829421665.6		22957	25428.1	0.65
S_2 = MW 30 (July. 23-29) 2nd fortnight of July	39566	27086	3648431281.1		31037	33090.9	0.71
S_3 = MW 35 (August 27-2 Sept) 2nd fortnight of August	25261	18212	2095718948.0		20897	20855.3	0.71
Mean	32239	22543	2851823964.9		24964	26458.1	0.69
Sub=3 varieties							
V_1 = ICTP-8203	29425	19467	2561320592.9		22545	23528.7	0.66
V_2 = Mahyco hybrid	31210	21529	2839823572.0		24546	25851.2	0.70
V_3 = Dhanshakti	36082	26634	3172527729.8		27800	29994.5	0.72
Mean	32239	22543	2851823964.9		24964	26458.1	0.69
S.E.± (Sowing dates)	1290.0	1522.6	1380.8	1576.5	1382	738.1	
C.D. at 5%	5065.2	5978.4	5422.0	6190.0	5227	2407.1	
S.E.± (Varieties)	725.3	993.0	1240.3	1400.9	1276	443.3	
C.D. at 5%	2234.9	3059.7	3821.7	4316.5	3933	1293.9	
S.E.± (SD x V)	1256.3	1719.9	2148.2	2426.4	2211	767.8	
C.D. at 5%	NS	NS	NS	NS	NS	NS	

Table 4. Mean CUM and MUE as influenced by sowing windows and varieties in *Kharif* pearl millet (2016 to 2020)

Treatment	GY (kg ha^{-1})	CUM (mm)	MUE (kg ha^{-1} mm)
S_1V_1	1023.2	340	3.01
S_1V_2	1124.3	360	3.12
S_1V_3	1314.3	369	3.56
S_2V_1	1412.4	378.2	3.73
S_2V_2	1444.4	382.3	3.78
S_2V_3	1699.8	390.6	4.35
S_3V_1	770.8	300	2.57
S_3V_2	918.3	304	3.02
S_3V_3	1095.5	309	3.55

June (S_1) get sufficient uniform availability of moisture during its life span helps for better yield and monetary benefits. However among the genotypes Dhanshakti produced significantly higher grain yield (1369.9 kg ha^{-1}), biomass yield (2525.5 kg ha^{-1}) and total monetary returns (Rs. 29994/- ha^{-1}). This indicates sustainability of Dhanshakti variety over other varieties. This might be due to short duration life span of Dhanshakti than other varieties and at reproductive stage ICTP-8203 and Mahyco hybrid might be faced moisture stress condition. The results were collaborated with finding of Bashir *et al*. (2014) and Uzoma *et al*. (2010). Sustainable Yield Index (SYI) was used as an approach to evaluate the minimum yield likely to be achieved in relation to changes in sowing windows. SYI of July sown crop is higher (0.50) as compared early and late sown crop. In response to change in climate treatment S_3 i.e. August sown pearl millet found better in respect of SYI further, on the basis of SYI it can be included as a contingent crop for its sustainable yield.

Meteorological studies : The mean consumptive use of moisture CUM (383.7 mm)

Table 5. Mean number of days required to attain phenological stages as influenced by sowing windows and varieties in *kharif* pearl millet (2016 to 2020)

Sowing time	Phenological stage							
	Emer.	3 leaf	PI	Flag leaf	50 % flowering	Soft dough	Hard dough	Phy. maturity
S_1V_1	6	7	15	26	8	13	9	17
Cumulative	13	20	35	61	69	82	91	108
S_1V_2	7	6	15	27	9	14	10	18
Cumulative	13	19	34	61	70	84	94	112
S_1V_3	8	7	16	28	10	15	11	13
Cumulative	15	22	38	66	76	91	102	115
S_2V_1	6	7	15	26	8	13	9	17
Cumulative	13	20	35	61	69	82	91	108
S_2V_2	7	6	15	27	9	14	10	18
Cumulative	13	19	34	61	70	84	94	112
S_2V_3	8	7	16	28	10	15	11	13
Cumulative	15	22	38	66	76	91	102	115
S_3V_1	6	7	15	26	8	13	9	17
Cumulative	13	20	35	61	69	82	91	108
S_3V_2	7	6	15	27	9	14	10	18
Cumulative	13	19	34	61	70	84	94	112
S_3V_3	8	7	46	28	10	15	11	13
Cumulative	15	22	68	96	106	121	132	145

and mean moisture use efficiency MUE (3.95 Kg ha^{-1} mm) was significantly higher recorded by crop sown in second fortnight of July (S_2) over rest of the sowing windows. It indicates that early and delay in sowing of crops results in recording low value of CUM and MUE. This might be due to July sown crop gets sufficient period to utilize available soil moisture along with good weather for grain production. Dhanshakti recorded highest mean value of CUM (356.2

Table 6. Mean growing degree days (°C) required to attain growth stages as influenced by sowing windows and varieties in *kharif* pearl millet(2016-20)

Sowing time	Phenological stage							
	Emer.	3 leaf	PI	Flag leaf	50 % flowering	Soft dough	Hard dough	Phy. maturity
S_1V_1	101	119	250	439	130	220	147	262
Cumulative	220	339	589	1028	1158	1378	1525	1787
S_1V_2	118	102	250	455	148	237	160	275
Cumulative	220	322	572	1027	1175	1412	1572	1847
S_1V_3	135	120	267	468	168	250	173	193
Cumulative	255	375	642	1110	1278	1528	1701	1894
S_2V_1	112	130	270	469	142	231	158	299
Cumulative	242	372	642	1111	1253	1484	1642	1941
S_2V_2	130	112	270	486	159	252	171	319
Cumulative	242	354	624	1110	1269	1521	1692	2011
S_2V_3	149	129	287	503	178	265	192	229
Cumulative	278	407	694	1197	1375	1640	1832	2061
S_3V_1	101	119	246	431	125	190	133	231
Cumulative	220	339	585	1016	1141	1331	1464	1695
S_3V_2	118	102	246	448	139	203	147	241
Cumulative	220	322	568	1016	1155	1358	1505	1746
S_3V_3	135	120	261	461	150	218	150	161
Cumulative	255	375	636	1097	1247	1465	1615	1776

Table 7. Mean radiation use efficiency (g MJ^{-1}) as influenced by sowing windows and varieties in *kharif* pearl millet (2016 to 2020)

Sowing time	Phenological stage						
	Emer.	PI	Flag leaf	50 % flowering	Soft dough	Hard dough	Phy. maturity
S_1V_1	0.11	0.17	0.75	1.18	1.06	0.86	0.96
S_1V_2	0.13	0.23	1.06	1.37	1.23	1.06	1.24
S_1V_3	0.15	0.30	1.28	1.54	1.30	1.16	1.27
S_2V_1	0.12	0.34	1.29	1.45	1.29	1.04	1.24
S_2V_2	0.15	0.40	1.47	1.57	1.33	1.25	1.28
S_2V_3	0.16	0.47	1.66	1.72	1.42	1.39	1.52
S_3V_1	0.09	0.24	0.97	1.10	1.03	0.89	1.01
S_3V_2	0.11	0.27	1.06	1.24	1.14	0.99	1.12
S_3V_3	0.11	0.32	1.23	1.30	1.23	1.02	1.26

Table 8. Correlation coefficient between grain yield and different weather parameters during different phenophases of *kharif* pearl millet

Pheno-phase	MAXT (°C)	MINT (°C)	RH1 (%)	RH2 (%)	WS (kmph)	RF (mm day^{-1})	SS (hrs day^{-1})	EVP (mm day^{-1})
P1	-0.270	0.220	-0.308	0.355	0.805**	-0.147	-0.471	0.411
P2	-0.148	0.246	-0.461	-0.250	0.607	-0.095	-0.314	0.435
P3	0.746*	0.419	-0.859**	-0.671*	0.451	-0.768*	-0.025	0.525
P4	-0.608	0.584	0.641	0.758*	0.400	0.334	-0.613	0.668*
P5	-0.438	0.678*	0.771*	0.683*	0.170	0.823**	-0.475	0.748*
P6	0.353	0.398	0.328	0.159	0.080	0.250	0.066	0.836**
P7	0.326	0.303	0.105	0.239	0.012	0.028	-0.125	0.213
P8	0.153	0.176	-0.043	0.082	0.264	0.159	0.022	0.396

mm) and MUE (3.82 Kg ha^{-1} mm). This indicates that the Dhanshakti variety utilized the moisture most efficiently for productions of grains. The mean number of days required to attain the physiological maturity stages recorded higher in July sown crop (S_2) (Table 5). This might be due to more favourable conditions prevailed in case early sown crop and vice versa. Dhanshakti required more mean number of days to attain physiological stages (125 days) than ICTP- 8203 (108 days) and Mahyco hybrid (95 days). This indicates Dhanshakti variety required more number of days to attain physiological maturity than other varieties during *Kharif* season under dryland conditions.

The growing degree days (GDD), the function of maximum, minimum and base temperature were presented in Table 6. The data revealed that the growing degree days required was 1787-18940 days, 1941-20610 days and 1695-17760 days for S_1, S_2 and S_3 sown crop. Further, it is seen that S_2 sown crop required more growing degree days to attain physiological maturity. However, among the varieties the values were higher in Dhanshakti followed by Mahyco hybrid and ICTP-8203 variety. This is due to more duration required by S_2 sown crop and Dhanshakti variety. Further, it was also noticed that the early sown crop not received fairly good amount of rainfall during its growth period due to which soil moisture available was less, however, late sown crop favours due to moisture availability during flowering and grain filling stage which resulted in more duration required for maturity and good yield. The second fortnight of July (S_2) sown crop required more number of days to attain various growth stages. This is due to existence of favourable condition for crop growth and development. This is because the GDD which is function of temperature which in turn is a function of bright sunshine hours.

The highest mean values of RUE recorded by the crop sown in second fortnight of July (1.19 - 1.85g MJ^{-1}) at 50 per cent flowering stage in almost all the sowing dates and genotypes. It was also revealed that with delayed sowing recorded low mean values of LAI and RUE. This indicated that the rate of conversion of light i.e.

Table 9. Stepwise multiple regression of different weather parameters with yield of *kharif* pearl millet at 50% flowering stage (2013 to 2017)

Weather parameter	Regression coefficient	R^2
Intercept	-101.38	0.81
Minimum Temperature (Tmin)	-0.21	
Relative Humidity (RH-1)	2.49	
Relative Humidity (RH-2)	-1.34	
Rainfall (RF)	0.08	

photosynthetically active radiation (PAR) was considerably high at 50 per cent flowering stage, thereafter the conversion rate was declined due to ageing of leaves. Among the sowing windows maximum mean RUE values were higher in July sown crop than late sown crop. Further, it was seen that Dhanshakti showed higher values of RUE than Mahyco and ICTP-8203 variety for conversion of light into dry matter in all the dates of sowing. The data in respect of mean total dry matter showed that the maximum values were recorded by Dhanshakti variety in all the windows of sowing. The July (S_2) sown crop has taken maximum number of days than late sown crops to attain the different growth stages during the crop growth period. This is due to better amount of moisture available and low values of temperature during the crop growth period of July sown crops. The same trend was obtained in case of GDD this indicates that GDD is a function of bright sunshine hours which reflected into a better grain yield.

Correlation and regression studies : The weather parameter influence their contribution and performance in *Kharif* pearl millet crop sown in different sowing windows were assessed in tenure of phasewise correlation and regression.

The influence of weather parameter and agrometeorological indices on performance of *Kharif* pearl millet crop sown at different windows with different varieties were assured in terms of phase-wise correlation of grain yield with weather parameters. It is revealed that the wind speed had significant positive correlation at emergence phase (P_1). T_{max} had significant positive influence and RH-I, RH-II and RF has significant negative influence at panicle initiation phase (P_3). RH-II and Epan had significant positive correlation at flag leaf stage (P_4). Significant positive correlation was found with T_{min}, RH-I, RH-II, RF and Epan at 50% flowering stage (P5) while at soft dough stage Epan had significant positive association with grain yield. Significant negative association with grain yield by T_{min}, RH-I, RH-II and RF at panicle initiation phase (P_3) indicates that at early growth stages *Kharif* pearl millet not favour moisture stress condition. Significant positive association with grain yield at 50% flowering stage by T_{min}, RH-I, RH-II, RF and Epan indicates *Kharif* pearl millet responds well to available moisture and low temperature conditions. It is revealed that panicle initiation stage (P_3) and 50% flowering stage (P_5) are more crucial growth stages to contribute grain production.

Table 10. Observed and predicted yield by using linear regression equations.
$\sqrt{Yield} = -101.38 + (-0.21 \times T_{min}) + (2.49 \times RH\text{-}1) + (-1.34 \times RH\text{-}2) + (0.08 \times RF)$

Treatment	Actual yield	Predicted yield	Residuals	Standardized residual
Main treatment - Sowing time				
S_1 = MW 26 (June 26-July01) 2nd fortnight of June	1533.4	1501.5	-31.9	-0.63
S_2 = MW 30 (July. 23-29) 2nd fortnight of July	1757.0	1829.2	72.2	1.15
S_3 = MW 35 (August 27-Sept 2) 2nd fortnight of August	1034.2	1008.0	-26.2	-0.53
Sub treatment - variety				
V_1 = ICTP-8203	1418.6	1298.6	-120.0	-1.15
V_2 = Mahycohybrid	1365.9	1425.3	59.4	0.51
V_3 = Dhanshakti	1540.1	1614.8	74.7	0.65

Standard Residual > 3 is outleter, T_{min} = Min. Temperature (°C), RH-I = Morning relative humidity (%), RH-II = Evening relative humidity (%), RF = Rainfall (mm)

It is observed that the significantly positive correlation (Table 10) of weather parameters namely T_{min}, RH-I, RH-II and RF with grain yield at 50% flowering phase. The predicted grain yield and actual pooled grain yield is presented in Table no. 12. The regression equation is developed by using this weather parameters i.e. Yield= -101.38 + (-0.21 x T_{min}) + (2.49 x RH-I) + (-1.34 x RH-II) + (0.08 x RF). This equation is helpful to predict grain yield after completion of 50% flowering phase (P_5).

The consumptive use of moisture (CUM) during total growth period of *kharif* pearl millet Fig.1 showed a polynomial relationship with grain yield (y=0.0121 x^2 + 0.801 x R^2 = 0.8414). The CUM of 390 mm was found to be optimum for getting higher grain yield. The moisture use efficiency (MUE) during total growth period of *kharif* pearl millet Fig. 2 showed a linear relationship with grain yield (y = 526.76 x - 596.15 R^2 = 0.9274). The MUE of 2.5 to 4.3 kg ha mm^{-1} was found to be optimum for getting higher grain yield. The RUE studies depicted in Fig. 3 showed linear relationship with grain yield. This indicated that radiation interception is directly related with grain yield (y = 618.86 x + 259.84 R^2 = 0.7064).

The GDD was correlated with the grain yield of pearl millet and depicted in Fig. 4. It showed a linear relationship with grain yield (y = 2.297 x -3076.6 R^2 = 0.9607). This indicated that with increase of GDD there was increase in grain yield upto 2061 GDD. The T_{max} was correlated with the grain yield of pearl millet and depicted in Fig. 5. It showed a polynomial

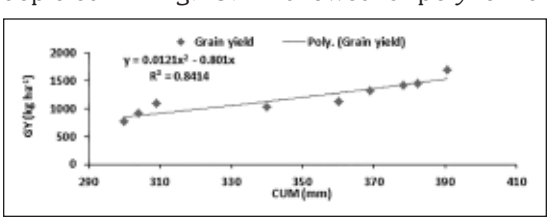

Fig. 1. Grain yield with CUM in pearl millet

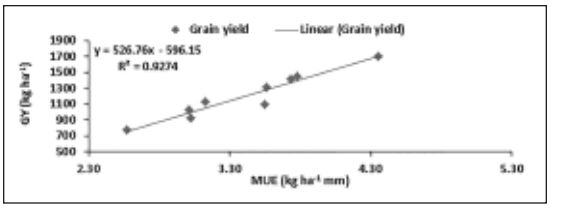

Fig. 2. Grain yield with MUE in pearl millet

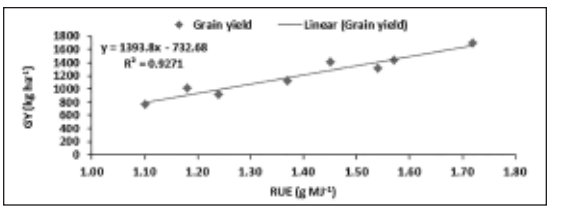

Fig. 3. Grain yield with RUE in pearl millet

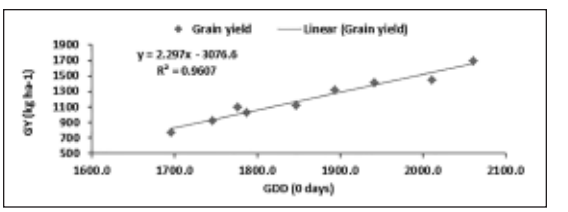

Fig. 4. Grain yield with GDD in pearl millet

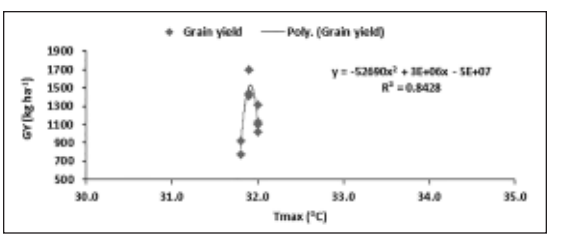

Fig. 5. Grain yield with Tmax in pearl millet

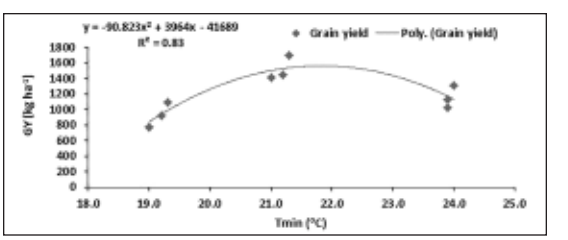

Fig. 6. Grain yield with T_{min} in pearl millet

relationship with grain yield (y =- 52690 x^2 + 3E + 06x-5E + 07 R^2 = 0.8428). This indicated that with increase of T_{max} there was increase in

grain yield upto 31.8°C and later on yield decrease with increase in T_{max}. The T_{min} was correlated with the grain yield of pearl millet and depicted in Fig. 6. It showed a polynomial relationship with grain yield ($y=-90.823\ x^2 + 3964x - 41689\ R^2 = 0.83$). This indicated that with increase of T_{min} there was increase in grain yield upto 21.0°C later on yield decrease with increase in T_{min}.

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Evaluation of Tomato (*Solanum lycopersicum* L.) Genotypes for Qualitative and Quantitative Characteristics

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Abstract

The investigation was carried out at Research Farm of the Tomato Improvement Scheme, Department of Horticulture, Mahatma Phule Krishi Vidyapeeth, Rahuri during the summer season of 2020. The data exhibited significant variations in 36 tomato genotypes for different qualitative and quantitative characters. The maximum plant height (124.59cm) was recorded in the genotype RHRT-15-21.The genotypes RHRT-15-4, RHRT-15-17, RHRT-15-19, RHRT-15-20, RHRT-15-21, RHRT-17-1, RHRT-17-2 and RHRT-17-5 were observed indeterminate plant growth habit. The maximum number of branches plant^{-1} observed in RHRT-15-4. Genotype RHRT-15-7 and RHRT-15-4 were found early flowering which required 30 and 31 days for 50% flowering,respectively.Number of fruits plant^{-1} recorded highest in RHRT-15-4 and RHRT-15-23. The maximum polar diameter of the fruit was recorded by the genotype RHRT-15-3 (6.91cm) followed by RHRT-17-9, RHRT-17-4 and RHRT-15-14. The maximum equatorial diameter shown by RHRT-17-9 (5.96cm) followed by RHRT-15-23 and RHRT-15-4, respectively. The fruit yield plant^{-1} of tomato evaluated varied significantly among the 36 genotypes, ranging from 0.68 to 1.93 kg plant^{-1}. The general mean value of genotypes was 1.15 Kg. The minimum fruit yield plant^{-1} was recorded with genotype RHRT-17-10, while maximum with genotype RHRT-15-4. The genotype RHRT-15-4 gave the highest yield of 51.57 t ha^{-1}. The highest TSS content of fruit was recorded with the genotype RHRT-15-24. The findings of this study may provide valuable information about phenotypic characteristics of tomato genotypes for crop improvement programme, vegetable experts and vegetable growers under summer season.

Keywords :Tomato, genotypes, evaluation, qualitative, quantitative.

Tomato (*Solanum lycopersicum* L.), a fruit that is universally treated as a vegetable, a perennial plant from *Solanaceae* family, which is commonly cultivated as an annual (Rick, 1978). It is one of the significant vegetables cultivated all over the world and believed to be originated from Andean region that includes the parts of Colombia, Ecuador, Peru, Bolivia and Chile. The wild tomato (*Lycopersicon esculentum* var. *cerasiforme*) is supposed to be the ancestor of the cultivated tomato. *Lycopersicon esculentum* is a day neutral self-pollinated crop but some cross-pollination also occurs. It is a warm-season crop that is heat and drought tolerant and thrives well in a wide range of soil and climatic conditions. In India, every vegetable curry is considered incomplete without tomato in it; it is an important part of everyone's daily diet. It is mostly used as a fresh vegetable, salad and also as processed products like paste, juice, sauce, ketchup and powder or as a whole peeled tomato. Once tomato was considered as poisonous is now gaining popularity among the consumers, which is accelerated with added discovery of higher contents of antioxidants like vitamin C, lycopene and β-carotene. Yellow tomatoes have higher vitamin-A content than red tomatoes, but red tomatoes contain lycopene, an antioxidant that may contribute to protection against carcinogenic substances. Lycopene is the major antioxidant responsible for the red colour is the result of chlorophyll degradation in addition to synthesis of and other carotenoids.

Tomato is also known as protective food because of its special nutritive values. Its vitamin-C content ranges from 15 to 35 mg 100^{-1} g fruit, while vitamin A and has a high amount of nutritional content (Gould, 1971). It has commercial value in the extraction of tomatine, a steroidal hormone, used as substitute of diosgenin. According to American Cancer Research Association, tomato is beneficial to control prostate cancer (American Cancer Society, 2008). The increasing consumption of tomato makes it a high value crop for generating income of the farmers. Tomato is cultivated in every state of India and occupying an area of about 0.81 M ha with production about 20.51 m MT (Anon. 2018-2019) and production share of India to different countries are 11.2% and having productivity 16.1 MT ha^{-1}. The major tomato producing states in the country are Maharashtra, Andhra Pradesh, Uttar Pradesh, Orissa, Karnataka, West Bengal, Tamil Nadu, Bihar, Madhya Pradesh, Assam, Telangana, Haryana and Gujrat. These states account for about 90% of the total production of country.

Tomatoes are grown in area of about 50.7 thousand hectares with production of 1124.89 MT (Anonymous, 2018) in Maharashtra. The Share of tomato in Maharashtra is 5.51% (Anonymous, 2018). It is grown in Nashik, Pune, Solapur, Sangli, Satara, Ahmednagar and Nagpur districts of Maharashtra.Being an important commodity and dollar earning crop it is mostly exported to Pakistan, UAE, Bangladesh, Nepal and Maldives from India. In the world India is second major tomato producing country after China. Major tomato producing countries are China, India and USA, respectively. The cultivation tomato fetches higher prices in market to growers but there are some natural menaces, which devastate the crop *viz*., ToLCV disease. Different viruses were observed in tomato but the ToLCV is the extremely significant and most serious constraints for the production of tomato, which reduces the yield drastically all over India (Srivastava *et al.*, 1995).Hence, in keeping the above facts in mind, the present investigation was undertaken to identify suitable genotypes capable of giving higher fruit yield and good quality traits.

Materials and Methods

The experimental material for the present studies comprised oftomato 34 lines along with two standard checks H-24 (resistance check) and Punjab Chhuhara (susceptible check) was collected from Tomato Improvement Scheme, Department of Horticulture, MPKV, Rahuri and these were tested for one year during summer season of 2020 at farm of Tomato Improvement Scheme, Department of Horticulture, Mahatma Phule Krishi Vidyapeeth, Rahuri. Geographically, central campus of MPKV, Rahuri which is situated at 73°15'0" to 76°22'12" North latitude and 15°46'48" to 22°3'0" East longitude and has elevation of 556 m above mean sea level. The place experiences hot dry summer, hot summer and humid rainy season and cold winter months, the maximum temperature goes upto 38°-41°C during summer (April to May) and minimum temperature falls to 13°C during winters. The individual experiment was carried out in Randomized block design with three replications. The uniform, healthy seedlings were transplanted on ridges at the distance of 90 x 30 cm. The observations were recorded on five randomly selected plants of each genotype and replication, Average was calculated for quantitative characters such as Plant height (cm), Average number of branches $plant^{-1}$, Days to 50% flowering, Number of fruits $plant^{-1}$, Average weight of fruit (g), Equatorial diameter of fruit (cm), Polar diameter of fruit (cm), Number of locules $fruit^{-1}$, Pericarp thickness (mm), Yield $plant^{-1}$ (kg), Yield $plot^{-1}$ (kg), Yield $hectare^{-1}$ (t ha^{-1}). Observations also recorded forqualitative characters like Fruit colour, Fruit

shape, a drop of tomato juice from each individual genotype was put on the prism of hand refractometer and reading was noted for total soluble solids (°Brix). Also, morphological observations were recorded for plant growth habit i.e., determinate or indeterminate and leaf type which is tomato or potato type of leaf.

Results and Discussion

The results obtained from the present investigation on growth and development parameters exhibited significant difference by the genotypes. The mean performance of different genotypes for different characters and grand mean for different characters are presented in Table 3. The plant height is an important growth contributing character of tomato. The maximum plant height (124.59 cm) was recorded in the genotype RHRT-15-21, followed by RHRT-15-19 and RHRT-15-17 recorded their height 115.40 cm and 100.54 cm, respectively. Whereas the lowest plant height 48.10 cm in the genotype RHRT-15-6. The results obtained are in close agreement with the observations recorded by Ahmed *et al*., (2010), Olakojo and Adetula (2014), Jamdhade (2016), Jatav *et al*., (2017), Samad *et al*., (2017) and Nalla and Rana (2021) for average plant height. The genotypes RHRT-15-4, RHRT-15-17, RHRT-15-19, RHRT-15-20, RHRT-15-21, RHRT-17-1, RHRT-17-2 and RHRT-17-5 were observed indeterminate type of plant growth habit andrest of all thegenotypes along with two standard checks were recorded determinate in growth habit. The results are in accordance with the findings of Hossain *et al*., (2017) and Nadia *et al*., (2018) for plant growth habit. The maximum number of primary branches plant^{-1} five recorded in the genotype RHRT-15-4 and the remaining genotypes ranged between 3 and 4 primary branches plant^{-1}. Similar trends of results were reported by Jatav *et al*., (2017) and Kumara *et al*., (2017). All the genotypes were observed large tomato type of leaf that is having serrated leaf margins. The results are in accordance with the findings of Nadia *et al*., (2018) for leaf type which is tomato type of leaf.

The performance of different genotypes forflower and fruit development characters are presented in Table 3. Significant differences were observed among the entries with respect to days to 50% flowering. The value ranged from 30 to 39 days. It is lowest in RHRT-15-7 (30 Days), followed by RHRT-15-4 (31 Days) and highest in RHRT-15-17 (39 Days). The results are in conformity with the findings of Raju *et al*., (2014), Kumar *et al*., (2012), Dar*et al*., (2012), Jamdhade (2016), Spaldon and Hussain, (2017) and Samad *et al*., (2017) for 50% flowering. So, RHRT-15-7 genotype as an early maturing in crop improvement programmes to dissect the gene responsible for early flowering and transfer to other genotypes in order to get superior varieties. The wide

Table 1. List of the 34 tomato lines and two standard checks included in the study

Sr. No.	Lines	Sr. No.	Lines
1.	RHRT-15-2	19.	RHRT-15-20
2.	RHRT-15-3	20.	RHRT-15-21
3.	RHRT-15-4	21.	RHRT-15-22
4.	RHRT-15-5	22.	RHRT-15-23
5.	RHRT-15-6	23.	RHRT-15-24
6.	RHRT-15-7	24.	RHRT-15-26
7.	RHRT-15-8	25.	RHRT-15-28
8.	RHRT-15-9	26.	RHRT-17-1
9.	RHRT-15-10	27.	RHRT-17-2
10.	RHRT-15-11	28.	RHRT-17-3
11.	RHRT-15-12	29.	RHRT-17-4
12.	RHRT-15-13	30.	RHRT-17-5
13.	RHRT-15-14	31.	RHRT-17-6
14.	RHRT-15-15	32.	RHRT-17-7
15.	RHRT-15-16	33.	RHRT-17-8
16.	RHRT-15-17	34.	RHRT-17-9
17.	RHRT-15-18	35.	H-24 (RC)
18.	RHRT-15-19	36.	PunjabChhuhara (SC)

Note- (RC-Resistance Check) and (PC-Susceptible Check)

variation in growth parameters of all the genotypes might be due to their genetic makeup, which indirectly governs the morphology of the plant that has a direct impact on the formation of floral buds since all the genotype were grown under the same climatic condition. A wide variation was found among the genotypes fornumber of fruits plant^{-1}, which significantly varied from 11 to 24 fruits plant^{-1} among the genotypes. The findings are closely similar to the results of Salwa *et al*., (2015), Kumara*et al*., (2017), Nadia *et al*., (2018), Kumar and Singh (2018). The lowest number of fruits plant^{-1} were produced by the check Punjab

Table 2. Evaluation of tomato genotypes for growth, development and qualitative characters

Genotypes	Plant growth habit	Leaf type	Fruit color	Fruit shape
RHRT-15-2	Determinate	Tomato type	Orange Red	Oval
RHRT-15-3	Determinate	Tomato type	Orange Red	Oval
RHRT-15-4	Indeterminate	Tomato type	Orange Red	Round
RHRT-15-5	Determinate	Tomato type	Orange Red	Oval
RHRT-15-6	Determinate	Tomato type	Orange Red	Oval
RHRT-15-7	Determinate	Tomato type	Orange Red	Oval
RHRT-15-8	Determinate	Tomato type	Orange Red	Oval
RHRT-15-9	Determinate	Tomato type	Orange Red	Oval Round
RHRT-15-10	Determinate	Tomato type	Orange Red	Oval
RHRT-15-11	Determinate	Tomato type	Orange Red	Oval
RHRT-15-12	Determinate	Tomato type	Orange Red	Oval
RHRT-15-13	Determinate	Tomato type	Orange Red	Oval
RHRT-15-14	Determinate	Tomato type	Orange Red	Oval
RHRT-15-15	Determinate	Tomato type	Orange Red	Oval
RHRT-15-16	Determinate	Tomato type	Orange Red	Oval
RHRT-15-17	Indeterminate	Tomato type	Orange Red	Oval
RHRT-15-18	Determinate	Tomato type	Orange Red	Oval
RHRT-15-19	Indeterminate	Tomato type	Orange Red	Round
RHRT-15-20	Indeterminate	Tomato type	Orange Red	Round
RHRT-15-21	Indeterminate	Tomato type	Orange Red	Oval Round
RHRT-15-22	Determinate	Tomato type	Orange Red	Round
RHRT-15-23	Determinate	Tomato type	Orange Red	Round
RHRT-15-24	Determinate	Tomato type	Orange Red	Round
RHRT-15-26	Determinate	Tomato type	Orange Red	Round
RHRT-15-28	Determinate	Tomato type	Orange Red	Round
RHRT-17-1	Indeterminate	Tomato type	Orange Red	Oval
RHRT-17-2	Indeterminate	Tomato type	Orange Red	Round
RHRT-17-3	Determinate	Tomato type	Orange Red	Round
RHRT-17-4	Determinate	Tomato type	Orange Red	Oval
RHRT-17-5	Indeterminate	Tomato type	Orange Red	Oval
RHRT-17-6	Determinate	Tomato type	Orange Red	Oval
RHRT-17-7	Determinate	Tomato type	Orange Red	Round
RHRT-17-8	Determinate	Tomato type	Orange Red	Oval
RHRT-17-9	Determinate	Tomato type	Orange Red	Oval
(H-24)	Determinate	Tomato type	Orange Red	Oval Round
(Punjab Chhuhara)	Determinate	Tomato type	Orange Red	Oval

Chhuhara 10 fruits plant^{-1} followed by genotypes RHRT-15-10 and RHRT-17-9 *viz*., 11 fruits plant^{-1}, RHRT-15-4 and RHRT-15-23 (24 Fruits plant-1) the highest number of fruits plant^{-1}. It was at par with those recorded by the genotype RHRT-15-7, RHRT-15-18, RHRT-

Table 3. Mean performance of tomato genotypes

Genotypes	Av. plant height (cm)	Av. no. of branches plant^{-1}	Days to 50% flowering	No. of fruits plant^{-1}	No. of locules fruit-1	Pericarp thickness (mm)
RHRT-15-2	68.60	4.00	32	14	2.33	5.34
RHRT-15-3	69.90	3.67	33	14	2.33	4.24
RHRT-15-4	87.50	5.00	31	24	2.33	6.01
RHRT-15-5	69.11	4.33	34	13	2.33	5.88
RHRT-15-6	48.10	4.33	34	18	3.00	4.65
RHRT-15-7	57.40	4.33	32	23	3.00	4.38
RHRT-15-8	75.40	3.67	33	19	3.00	5.54
RHRT-15-9	71.54	3.67	35	13	3.00	5.69
RHRT-15-10	73.67	4.00	36	11	2.67	6.54
RHRT-15-11	60.12	4.00	34	13	3.00	6.48
RHRT-15-12	70.45	3.67	36	16	2.67	5.98
RHRT-15-13	75.00	3.67	32	16	3.00	5.47
RHRT-15-14	73.46	3.67	33	17	3.00	7.47
RHRT-15-15	62.35	4.00	35	19	3.00	5.36
RHRT-15-16	68.84	3.67	37	17	3.00	6.51
RHRT-15-17	100.54	4.33	39	16	3.00	6.67
RHRT-15-18	76.98	3.67	32	24	3.00	5.38
RHRT-15-19	115.40	4.33	33	21	4.00	5.44
RHRT-15-20	81.26	3.67	32	21	4.00	6.27
RHRT-15-21	124.59	4.00	36	15	3.00	4.99
RHRT-15-22	61.40	3.67	35	14	2.67	4.67
RHRT-15-23	78.50	3.67	37	23	2.67	4.78
RHRT-15-24	80.45	3.67	36	17	3.00	3.71
RHRT-15-26	64.97	3.67	38	19	3.00	3.78
RHRT-15-28	55.48	4.00	34	17	3.00	4.55
RHRT-17-1	83.22	3.67	32	19	2.00	5.57
RHRT-17-2	85.69	3.67	33	17	3.00	4.87
RHRT-17-3	72.64	3.67	35	18	3.00	6.01
RHRT-17-4	74.80	4.00	36	18	2.67	6.24
RHRT-17-5	83.00	3.67	33	18	3.00	6.17
RHRT-17-6	74.89	3.67	37	14	3.00	5.00
RHRT-17-7	58.60	4.00	35	20	2.67	5.17
RHRT-17-8	57.69	4.00	36	12	3.67	5.26
RHRT-17-9	78.98	3.67	38	11	3.00	5.14
(H-24)	74.00	4.00	33	19	2.67	4.98
(Punjab Chhuhara)	64.28	3.67	35	10	3.67	5.38
Mean	74.41	3.89	34.44	16.94	2.92	5.43
S.Em (±)	2.48	0.19	3.08	1.18	0.22	0.24
C.D. at 5%	7.01	0.56	9.27	3.35	0.63	0.69

15-19 and RHRT-15-20. The number of locules per fruitvaried from 2 to 4. The minimum numbers of locules (2) were found in RHRT-17-1 and the maximum number of

Table 3. (Contd…) Mean performance of tomato genotypes

Genotypes	Av. fruit weight (g)	Polar diameter of fruit (cm)	Equatorial diameter of fruit (cm)	Yield plant-1 (Kg)	Yield plot-1 (Kg)	Yield hectare (ton)	Total soluble solids (°Brix)
RHRT-15-2	52.00	5.89	4.24	0.82	26.19	22.05	4.6
RHRT-15-3	50.80	6.91	4.11	0.80	25.59	21.54	4.5
RHRT-15-4	70.80	5.81	5.47	1.93	61.26	51.57	4.8
RHRT-15-5	66.10	5.52	4.51	1.06	31.49	26.51	4.7
RHRT-15-6	51.00	5.02	4.61	1.72	32.71	27.54	4.9
RHRT-15-7	60.08	4.81	4.21	1.33	49.59	41.75	5.4
RHRT-15-8	55.00	4.91	4.04	1.06	37.53	31.59	5.0
RHRT-15-9	53.20	4.58	4.45	0.74	24.83	20.90	5.0
RHRT-15-10	65.00	5.28	4.04	0.68	25.59	21.54	4.2
RHRT-15-11	67.20	5.5	4.8	0.97	31.34	26.39	4.4
RHRT-15-12	56.20	4.91	4.51	1.18	32.68	27.51	5.4
RHRT-15-13	70.60	5.8	4.7	1.22	40.78	34.33	5.0
RHRT-15-14	67.80	6	4.91	1.31	41.41	34.86	4.4
RHRT-15-15	60.40	4.9	4.12	1.27	41.14	34.63	4.5
RHRT-15-16	61.00	5.3	4	1.13	37.34	31.43	4.1
RHRT-15-17	58.20	5.31	4.31	0.95	33.49	28.19	4.8
RHRT-15-18	69.00	5.8	4.8	1.69	57.11	48.07	5.1
RHRT-15-19	68.80	4.1	4.27	1.25	53.59	45.11	5.0
RHRT-15-20	68.00	4.21	4.29	1.52	51.43	43.29	4.9
RHRT-15-21	65.80	4.25	4.12	1.26	35.48	29.87	4.8
RHRT-15-22	68.60	4.57	5.34	1.05	34.47	29.02	5.3
RHRT-15-23	31.80	5.41	5.91	1.04	27.04	22.77	4.8
RHRT-15-24	66.80	3.5	3.61	0.86	40.93	34.46	5.7
RHRT-15-26	58.90	4.52	4.88	1.01	40.50	34.10	5.2
RHRT-15-28	64.60	4.41	4.7	0.93	39.48	33.23	4.6
RHRT-17-1	67.80	5.64	4.99	1.48	46.34	39.01	4.4
RHRT-17-2	74.20	5.21	5.31	1.40	45.35	38.17	4.9
RHRT-17-3	71.80	5.41	5.26	1.24	46.45	39.10	4.9
RHRT-17-4	64.20	6.14	4.85	1.23	41.51	34.94	5.3
RHRT-17-5	73.20	5.6	5.18	1.35	47.27	39.79	4.9
RHRT-17-6	54.60	5.01	4.21	1.07	27.53	23.18	5.5
RHRT-17-7	50.20	4.36	4.54	1.11	35.60	29.97	5.3
RHRT-17-8	62.00	5.67	4.58	0.92	26.49	22.30	5.4
RHRT-17-9	61.00	6.15	5.96	0.85	24.10	20.29	5.1
(H-24)	69.40	5.94	5.81	1.33	48.47	40.80	5.4
(Punjab Chhuhara)	78.20	6.21	4.26	0.70	28.14	23.69	4.6
Mean	62.62	5.24	4.66	1.15	38.06	32.04	4.90
S.Em (±)	2.61	0.18	0.22	0.07	3.45	2.91	0.21
C.D.at 5%	7.40	0.52	0.63	0.18	9.77	8.23	0.59

locules (4) was found in genotype RHRT-15-19 and RHRT-15-20. Dar *et al*., (2012), Kumara *et al*., (2017), Jatav *et al*., (2017), Spaldon and Hussain (2017), Kumar and Singh (2018) found similar results for the number of locules fruit^{-1}. The pericarp thickness varied from 3.71 to 7.47 mm. The genotype RHRT-15-14 was found to have maximum pericarp thickness 7.47 mm, followed by the genotypes RHRT-15-17, RHRT-15-10, RHRT-15-16, RHRT-15-11 and RHRT-15-20. The minimum pericarp thickness 3.71 mm was found in the genotype RHRT-15-24. The results are in close agreement with Dar *et al*., (2012), Spaldon and Hussain (2017) and Kumara *et al*., (2017).

In the consideration ofqualitativeattributesall the genotypes under study had showed orange red fruit colour. The genotype RHRT-15-9, RHRT-15-21 and H-24 recorded Oval round fruit shape. The genotype RHRT-15-4, RHRT-15-19, RHRT-15-20, RHRT-15-22, RHRT-15-23, RHRT-15-24, RHRT-15-26, RHRT-15-28, RHRT-17-2, RHRT-17-3 and RHRT-17-7 observed round type of fruit shape, remaining all other genotypes including Punjab chhuhara showed oval shape of fruits.The genotypes for the character total soluble solids (°Brix) differed significantly showing average TSS of the tomato genotypes ranged from 4.1 to 5.5 °Brix. The genotype RHRT-15-24 recorded the highest TSS among all of the other genotypes. The lowest TSS was recorded by the genotype RHRT-15-16 (4.1°Brix). These results are in confirmity with the findings of Aoun *et al*., (2013), Islam *et al*., (2014), Ghasemi *et al*., (2015) Kumara *et al*., (2017), Vijeth *et al*., (2018) and Mandali and Vijayalakshmi (2020).

The fruit weight is an important yield contributing character of tomato. Fruit weight plant^{-1} showed significant result in different tomato genotypes. The data revealed that the genotypes differed significantly. The average fruit weight of the genotypes ranged between 31.80 to 78.20 g. The genotype Punjab chhuhara recorded the highest average fruit weight (78.20 g) followed by RHRT-17-2 recorded the 74.20 g . The genotype RHRT-15-23 recorded the lowest fruit weight 31.80 g. The fruit weights recorded by rest of the genotypes were in between 31.80 to 78.20 g. The results are in close agreement with Bharadwaj and Thakur (1994), Alam *et al*., (2005), Olakojo and Adetula (2014), Islam *et al*., (2014), Ghasemi *et al*., (2015), Meena *et al*., (2015), Kumara *et al*., (2017), Nadia *et al*., (2017) and Vijeth *et al*., (2018). The lowest polar diameter was found in the genotype RHRT-15-24 (3.5 cm) and highest polar diameter was recorded in the genotype RHRT-15-3 (6.91cm) followed by RHRT-17-9, RHRT-17-4 and RHRT-15-14, which was recorded 6.15 cm, 6.14 cm and 6.0 cm, respectively. The average equatorial diameter varied from 4.04 to 5.96 cm. The maximum equatorial diameter was found in the genotype RHRT-17-9, which was 5.96 cm. It was followed by the genotypes RHRT-15-23 and RHRT-15-4. In all genotypes the lowest equatorial diameter of fruit was recorded by the genotype RHRT-15-10, which is 4.04 cm. In case of polar and equatorial diameter, similar results were obtained by Mehraj *et al*., (2014), Ghasemi *et al*., (2015), Meena *et al*., (2015), Kumar and Singh (2018), Nalla and Rana (2021).

The genotypes under study differed significantly amongst themselves for yield plant^{-1} (Kg). The fruit yield plant^{-1} of tomato evaluated varied significantly among the 36 genotypes, ranging from 0.68 to 1.93 kg plant^{-1}. The genotype RHRT-15-4 gave the highest yield of 1.93 kg plant^{-1}. The lowest yield plant^{-1} of 0.68 kg was recorded in genotype RHRT-17-10. The results are in line with the results were observed by Alam *et al*., (2005), Lapidot *et al*., (2006), Islam *et al*., (2014), Meena *et al*., (2015), Kumara *et al*., (2017) and Nadia *et al*., (2018).The genotypes differed

significantly for yield plot^{-1} of fruits varied very widely between 24.10 and 61.26 kg plot^{-1}. The genotype RHRT-15-4 gave the highest yield of 61.26 kg plot^{-1}. The lowest yield plot^{-1} 24.10 kg plot^{-1} was recorded in the genotype RHRT-17-9. The results are in line with the results were observed by Islam *et al*., (2014), Meena *et al*., (2015), Kumara *et al*., (2017) and Nadia *et al*., (2018).The genotypes differed significantly among themselves, according to present findings yield by weight of fruits varied very widely between 20.29 and 51.57 t ha^{-1}. The genotype RHRT-15-4 gave the highest yield of 51.57 t ha^{-1}. The lowest yield 20.29 t ha^{-1} was given by the genotype RHRT-17-9. Similar trends of results for yield hectare^{-1} were reported by Kalloo and Banerjee (2000), Vijaya *et al*., (2003), Alam *et al*. (2005), Dar *et al*., (2012), Olakojo and Adetula (2014), Kumara *et al*., (2017), Vijeth *et al*., (2018) and Mandali and Vijayalakshmi (2020). Hence there is a great possibility of improvement in attributes of this vegetable crop.

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Studies on Rainfall-Runoff Relationship for Assessment of Rainwater Harvesting Potential under Marathwada Region

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Abstract

The rainfall available in the watershed is key factor for determining the availability of water to fulfill the different demand mainly for agriculture, hydropower water supply, industry, etc. A watershed is that contributes runoff water to a common point Runoff is one of the important hydrologic variables used in most of the water resource applications. Runoff is the total surface flow from a given drainage area. Rainfall duration, intensity and aerial distribution influence the rate and volume of runoff. Watershed characteristics such as slope, shape and size, cover of soil and duration of rainfall have a direct effect on the peak flow and volume of runoff from any area (Chandler and Walker, 1998). Rainfall and runoff are significant constitute the sources of water for recharge of ground water in the watershed. Estimation of runoff in a watershed is very important to manage the water resources efficiently. Most of the part of the Marathwada region is comes under assured rainfall zone. The region receives mean annual rainfall of 880 mm. Rainfall in uncertain and erratic in this region and sometimes suffers from severe droughts. The rainfall data for Aurangabad, Parbhani and Nanded stations were collected from the Agro-meteorological station under VNMKV, Parbhani. Runoff was estimated using SCS curve number method considering the all parameters like soil type, vegetation etc. The rainfall runoff relationship was worked out for further planning of small water harvesting structures like farm ponds. The runoff potential for Aurangabad, Parbhani and Nanded station is found to be 20.07 %, 28.31 % and 31.69 % respectively, indicating a good scope for rainwater harvesting and thereby, many more rainwater harvesting structures can be constructed based on site specific conditions. A relation between rainfall and runoff for Aurangabad, Parbhani and Nanded stations were worked out as Y = 0.301X - 55.711 (R^2 value - 0.75), Y = 0.4043X - 88.882 (R^2 value - 0.8687) and Y = 0.6018X - 209.2 (R^2 value -0.9575) respectively. The linear rainfall-runoff relation obtained can be used for finding out runoff corresponding to any rainfall occurring in the area. The rainfall runoff relationship will be useful for determination of rainwater harvesting potential and its reuse for enhancing production potential of various rainfed crops.

Key words : Micro-catchment, Rainfall, Runoff.

Water resource has the prime concern for any future planning and development of water harvesting structures in watershed. The rainfall available in the watershed is key factor for determining the availability of water to fulfill the different demand mainly for agriculture. Rainfall and runoff are significant constitute for the sources of water. Evaluation of water availability by understanding of rainfall and runoff is essential. Global warming affects the rainfall change which influence the stream flow rate, hydrologic cycle, water demand (especially in agriculture) requires review in planning, design and management of hydraulic structures (Deasy Nalley,2012). Estimation of runoff in a watershed is very important to manage the water resources efficiently. Changes in run-off and its distribution will depend on likely future climate scenarios. Runoff in a watershed affected by geomorphological factors, particularly, land use change affects the runoff volume and the runoff rate significantly. Due to uneven distribution of rainfall and mismatch between demand and water availability requires large storage structures to control the natural

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flow according to the requirement of the region (S. Kundu, D. Khare *et al.*, 2015). A direct plotting of rainfall against runoff for individual storms produce a satisfactory correlation. The rainfall-runoff relation may be greatly enhanced by taking into account as parameters, some influencing factors such as storm frequency, condition of initial soil moisture, duration of storm and the year. Runoff is one of the important hydrologic variables used in most of the water resource applications. The amount of runoff from a given drainage area depends on many inter related factors. Watershed characteristics such as slope, shape and size, cover of soil and duration of rainfall have a direct effect on the peak flow and volume of runoff from any area (Chandler and Walker, 1998). Intensity of rainfall has dominating effect on the runoff yield.

Marathwada region of Maharashtra state, comprised of eight districts, lies between 17° 35' to 20° 40' N latitude and 74° 40' to 78° 16' E longitude. The altitude ranges between 300 to 900 m above mean sea level. The region experiences wide variability within and in between districts in respect of rainfall situation and also different soil type predominant in various parts of region. Occurrence of frequent droughts, unseasonal rains and hailstorms are the features of climate change in the region. Marathwada region of Maharashtra state is basically a rainfed area with average annual precipitation of 890 mm. Though the majority area falls under assured rainfall zone, it is characterized by 2-3 prolonged dry spells during crop growth period which resulted in variations in crop production and productivity and overall socioeconomic condition of farmers. The average productivity of all *kharif* crops varies depending of monsoon behavior.

Agro-climatically Marathwada region is divided into three zones. The Central Maharashtra plateau zone is the biggest one with assured rainfall pattern with Parts of Aurangabad, Beed, Jalna, Osmanabad, Latur, Nanded, Hingoli and Parbhani. Towards the western end, the parts of Aurangabad, Beed & Osmanabad come under the scarcity, whereas the north eastern part of the region i.e. Hingoli and Nanded has moderately high rainfall. The region receives annual rainfall in the range of 500 to 1100 mm and comes under assured rainfall zone (60%), moderately high rainfall zone (20%) and scarcity zone (20%). The soils in the region are deep black, medium black, coarse and shallow. The information on jurisdiction, rainfall pattern, soil and crops under various agro-climatic zones of Marathwada region is given as under;

Particulars	**Scarcity Zone**	**Assured Rainfall Zone**	**High rainfall zone)**
Jurisdiction	Aurangabad (7T) Beed (3T) Osmanabad (4T)	Aurangabad (3T) Jalna (3T) Beed (4T) Osmanabad (3T) Latur (4T) Parbhani (6T) Nanded (4T) Hingoli (2T)	Hingoli (3T) Nanded (5T)
Latitude longitude	74°.40' to 76°.20' 19°.40' to 20°.40'	76°.20' to 77°.30' 18°.20' to 20°.40'	77°.30' to 78°.16' 18°.20' to 19°.40'
Mean annual rainfall	500-700 mm	700-900 mm	900-1250 mm
Distribution of rainfall and soils	Bi-modal distribution of rain-June-Sept,monsoon & Oct-Dec, post monsoon Deep black (11%) Medium black (65%) Shallow/coarse textured (24%)	Bi-modal distribution of rain-June-Sept,monsoon & Oct-Dec, post monsoon Deep black (23%) Medium black (60%) Shallow/coarse textured (17%)	Bi-modal distribution of rain-June-Sept,monsoon & Oct-Dec, post monsoon Deep black (24%) Medium black (48%) Shallow/coarse textured (28%)
T = Taluka			

In the present case study, surface runoff was estimated for the three stations viz. Parbhani, Aurangabad and Nanded each from assured rainfall zone, rain scarcity zone and moderately high rainfall zone respectively for further

planning of small rainwater harvesting structures.

Methodology

The daily rainfall data for the years 2011-2021 have been collected from Meteorological Observatory, All India Coordinated Research Project on Agro-Meteorology, VNMKV, Parbhani. The daily runoff for the each runoff producing rainfall event was estimated using SCS curve number method. The rainfall and runoff data was analyzed and grouped in as fortnightly manner.

The SCS curve number techniques is based on recharge capacity of the watershed. The recharge capacity was determined by antecedent moisture condition and by physical characteristics of the watershed. Antecedent moisture condition (AMC) was used as an index of watershed wetness. (Ponce and Hawkins 1996).

Three levels of AMC are used.

AMC I: Lowest runoff potential

AMC II: Average condition

AMC III: Highest runoff potential

The criteria of AMC as presented in Table 3.5.

Table 3.5 Rainfall limits for estimating antecedent moisture condition

Antecedent moisture condition	5-days total antecedent rainfall, mm		Runoff production condition
	Dormant season	Growing season	
AMC – I	< 12.7	< 35.6	Lowest runoff potential
AMC – II	12.7 to 27.9	35.6 to 53.5	Moderate runoff potential
AMC – III	> 27.9	> 53.3	Highest runoff potential

Hydrological Soil Group (HSG) plays an important role in runoff production from a particular land surface of watershed. Following are the four hydrological soils groups.

HSG-A : Low runoff potential, sandy or gravel soils, high infiltration rate

HSG-B : Moderately low runoff potential, moderately deep soils, well drained Moderately coarse textured soil with moderate infiltration rate.

HSG-C : Moderately high runoff potential soils, moderately clay soil with low infiltration rate

HSG-D : High runoff potential soils, deep clay, high swelling potential, low infiltration rate

The selection of curve numbers is based on various hydrologic soil cover, land use, treatment or cultivation practices, hydrological condition of the area and hydrological soil group.

The equation for Indian condition for black soil region for AMC II is as follow;

$$CN = \frac{25400}{54 + S} \quad \ldots (1)$$

Where, S = Potential maximum retention, mm

Hence, the runoff depth was calculated using following formulae;

$$Q = \frac{(P - 0.3\,S)^2}{(P - 0.7\,S)} \quad \text{for AMC I} \quad \ldots(2)$$

$$Q = \frac{(P - 0.1\,S)^2}{(P - 0.9\,S)} \quad \text{for AMC II and III} \quad \ldots(3)$$

Where; Q = Depth of runoff, cm, P =

Precipitation, cm and S = Potential maximum retention, cm

Considering the available maps of land use/ land cover and hydrological soil group, the area of each class of land was worked out. Assigning the suitable curve numbers for respective land use and HSG to each area, the weighted curve number was determined and used in estimation of runoff potential.

Amutha and Porchelvan (2009), Bansode and Patil (2014), Bhura *et al*. (2015) and Mishra *et al.* (2005) used SCS curve number method for runoff estimation. Similar technique was used in this study for estimation of runoff potential.

Result and Discussion

Estimation of Cure Numbers : CN values were estimated based on hydrologic soil group, average slope of land and land use pattern of the area for the three stations *viz.*, Aurangabad, Parbhani and Nanded. The weighted values of curve numbers for three AMC condition were calculated as per USDA SCS-CN method and presented in Table 1.

The hydrologic soil group of Aurangabad was observed as 'C' with slope rage of 1-3 %. The weighted curve numbers for Aurangabad station was calculated as 71, 85 and 94 for AMC I, II and III respectively. The hydrologic soil group of Parbhani was observed as 'D' with slope rage of 0.5-3.5%. The weighted curve numbers for Parbhani station was calculated as 77, 89 and 95 for AMC I, II and III respectively. The hydrologic soil group of Nanded was observed as 'D' with slope rage of 0.5-4.0%. The weighted curve numbers for Nanded station was calculated as 79, 91 and 97 for AMC I, II and III respectively.

Estimation of runoff volume : From the rainfall data of last 11 years (2011-2021), the daily surface runoff was estimated and thereby, the yearly runoff was calculated for all the three stations *viz*, Aurangabad, Parbhani and Nanded. The average runoff of 11 years was calculated and also noticed the maximum runoff year.

Table 1. Curve Numbers for Parbhani, Nanded and Aurangabad stations

Soil type	Aurangabad	Parbhani	Nanded
	Light to medium	**Medium to deep black**	**Medium to deep black**
Hydrological soil group	C	D	D
Slope range of land	1-3	0.5 to 3.5	0.5 to 4.0
AMC			
I	71	77	79
II	85	89	91
III	94	95	97

The Year-wise rainfall, runoff and % runoff for Aurangabad station is presented in Table 2.

Data revealed that the average rainfall causing runoff for Aurangabad station was found to be 635.55 mm which generated mean runoff of 131 mm i.e. 20.07 per cent. The maximum rainfall which causes runoff was recorded as 1046.6 mm in the year 2020 which generated runoff of 314 mm i.e 30.42 per cent. This runoff potential information will be useful in planning of rainwater harvesting structures in the area.

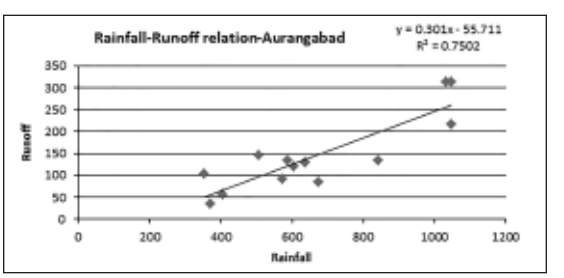

Fig. 1. Rainfall-runoff relationship for Aurangabad Station.

Table 2. Year-wise rainfall, runoff and % runoff for Aurangabad station

Year	Annual rainfall, mm	Total rainfall which contributes runoff, mm	Runoff, mm	% Runoff	Runoff coefficient
2011	589.2	586.2	135	23.02	0.230
2012	375.5	369.4	36	9.74	0.097
2013	736.4	673.9	86	12.76	0.127
2014	527.3	405.9	57	14.04	0.140
2015	595.3	505.1	147	29.10	0.291
2016	612.2	604.6	120	19.84	0.198
2017	576.3	573.7	92	16.03	0.163
2018	358.9	352.3	103	29.23	0.292
2019	881.2	841.3	134	15.92	0.159
2020	1061.2	1046.6	217	20.73	0.207
2021	1109.5	1032	314	30.42	0.304
Average	674.81	635.55	131	20.07	0.200
Maximum	1109.5	1046.6	314	30.42	0.304

Rainfall-runoff depth relation for Aurangabad station : The rainfall-runoff relationship for Aurangabad station is graphically represented in Fig. 1.

The relation obtained can be used for finding out runoff corresponding to any rainfall occurring in the area. For the study area, the relation was found to be linear. The relation obtained was $Y = 0.301X - 55.711$ and the R^2 value was 0.75.

The Year-wise rainfall, runoff and % runoff for Parbhani station is presented in Table 3.

Data revealed that the average rainfall causing runoff for Parbhani station was found to be 853.43 mm which generated mean runoff of 257 mm i.e. 28.31 per cent. The maximum rainfall which causes runoff was recorded as 1196.4 mm in the year 2020 which generated runoff of 385 mm i.e. 37.98 per cent.

Rainfall-runoff depth relation for Parbhani station : The rainfall-runoff relationship for Parbhani station is graphically represented in Fig. 2.

Table 3. Year-wise rainfall, runoff and % runoff for Parbhani station

Year	Annual rainfall, mm	Rainfall, mm	Runoff, mm	% Runoff	Runoff coefficient
2011	677.5	636	164	25.78	0.339
2012	688.2	678	140	20.64	0.206
2013	1217.1	1134.4	345	30.41	0.304
2014	560.2	422.7	60	14.19	0.141
2015	574.8	414.1	70	16.90	0.169
2016	1159.5	1142.1	385	33.70	0.337
2017	995.7	987.2	375	37.98	0.379
2018	808.1	802.4	304	37.88	0.378
2019	968.6	950.8	299	31.44	0.314
2020	1098.7	1023.6	376	36.73	0.367
2021	1719.3	1196.4	309	25.82	0.258
Average	951.60	853.43	257	28.31	0.283
Maximum	1719.3	1196.4	385	37.98	0.378

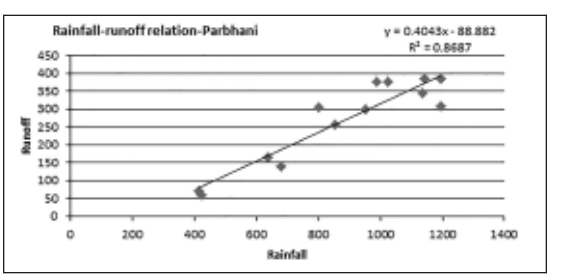

Fig. 2. Rainfall-runoff relationship for Parbhani Station

The relation obtained can be used for finding out runoff corresponding to any rainfall occurring in the area. For the study area, the relation was found to be linear. The relation obtained was Y = 0.4043X – 88.882 and the R^2 value was 0.8687

The Year-wise rainfall, runoff and % runoff for Nanded station is presented in Table 4.

Data revealed that the average rainfall causing runoff for Nanded station was found to be 816.81 mm which generated mean runoff of 280.78 mm i.e. 31.69 per cent. The maximum rainfall which causes runoff was recorded as 1230.3 mm in the year 2021 which generated runoff of 550 mm i.e. 44.7 per cent.

Table 4. Year-wise rainfall, runoff and % runoff for Nanded station

Year	Annual rainfall, mm	Rainfall,	Runoff,	% Runoff	Runoff coeffi-cient
2011	708.1	697.1	205.3	29.45	0.294
2012	662.7	662.7	122.2	18.43	0.184
2013	1111.9	1091.6	414.2	37.94	0.379
2014	436.5	434	99	22.81	0.228
2015	599	465.2	71	15.26	0.152
2016	1124.8	1094	479.7	43.84	0.438
2017	641.8	633.6	161.5	25.48	0.254
2018	799.5	749.8	272.8	36.38	0.363
2019	1027.1	1007.7	344	34.13	0.341
2020	924.7	918.9	368.9	40.14	0.401
2021	1293.4	1230.3	550	44.7	0.447
Average	848.13	816.81	280.78	31.69	0.316
Maximum	1293.4	1230.3	550	44.7	0.44

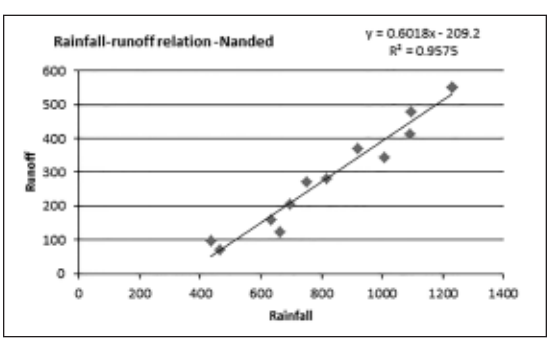

Fig. 3. Rainfall-runoff relationship for Nanded Station

Rainfall-runoff depth relation for Nanded station : The rainfall-runoff relationship for Nanded station is graphically represented in Fig. 3.

The relation obtained can be used for finding out runoff corresponding to any rainfall occurring in the area. For the study area, the relation was found to be linear. The relation obtained was Y = 0.6018X – 209.2 and the R^2 value was 0.9575.

Satheesh kumar *et al*. (2017) conducted study on rainfall–runoff estimation using SCS–CN and GIS approach in the Pappiredipatti watershed of the Vaniyar sub basin, South India and found simialr results. Similarly, Vinithra and Yeshodha (2013) used rainfall-runoff modelling using SCS-CN method as a case study of Krishnagiri district, Tamilnadu and found similar results which confirms with results of the current study.

Conclusion

Rainwater harvesting appears to be one of the most promising alternatives for the escalating demand of fresh water for rainfed agriculture. Hydrological analysis is the basic criteria for design of any rainwater harvesting structure. Rainfall-runoff relationship proved to be the most valuable information for identification of runoff potential at any station. Similarly, SCS curve number method also proved to be the most appropriate method for estimating runoff. Following conclusions were drawn from the current study.

1. The runoff potential for Aurangabad, Parbhani and Nanded station is found to be 20.07%, 28.31% and 31.69% respectively, indicating a good scope for rainwater

harvesting and thereby, many more rainwater harvesting structures can be constructed based on site specific conditions.

2. A relation between rainfall and runoff for Aurangabad, Parbhani and Nanded stations were worked out as Y = 0.301X – 55.711 (R^2 value - 0.75), Y = 0.4043X – 88.882 (R^2 value - 0.8687) and Y = 0.6018X – 209.2 (R^2 value -0.9575) respectively.

3. The linear rainfall-runoff relation obtained can be used for finding out runoff corresponding to any rainfall occurring in the area.

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Studies on Dehydration of Fig (*Ficus carica* L.)

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Abstract

The fresh, ripe fig fruits of cultivar 'Poona' were subjected to pre-treatments of dipping oil with two concentrations i.e. 34 and 38 ppm. The fruits were dipped in dipping oil for 1 minute and then subjected to sulphur fumigation for 2 h. Fig fruits were then dipped in three concentrations of sugar syrup i.e. 50, 60 and 70°Brix for 48 hour to reach desired total soluble solids and then dried at 55°C temperature till 18-20 per cent (wb) moisture content was attained. While drying, moisture content, drying rate and moisture ratio were monitored at 1 hour interval. It was observed that rate of moisture reduction as well as drying rate was higher for figs treated with higher concentration of dipping oil (38 ppm) as well as immersed in sugar syrup solution of high concentration (60°Brix). Drying process showed only a falling rate period. The exponential equation of moisture ratio verses drying time provides excellent fit to the experimental data on drying of fig sample with highest drying constant (k) and R^2 value.

Key word : Dehydration, fig, sugar syrup, drying characteristics, dipping oil.

The fig (*Ficus carica* L.) is deciduous, subtropical plant belongs to family Moraceae and it is not only most ancient fruit but also a nutritive one. The total area under fig in the world is estimated about 4,19,000 ha (Crisosto *et al*., 2010). According to FAO, 2009, world total fig production is about to 11,85,000 tonnes (Gozlekci, 2011). The total area under fig cultivation in India is about 6000 ha (Shelar, 2010), of which 2000 ha is in Maharashtra with a production of 2705 MT (Joshi *et al*., 2009).

Fresh fig fruits are rich in amino acids, proteins, carbohydrates, fibers, minerals etc. (Aksoy *et al*., 2001 and Wang *et al*., 2003). The total mineral content of fig is two to four times that of other fresh fruits. Fig is richer in iron and copper content than most other fresh fruits as well as dry fruits and vegetables. According to USDA data for the Mission variety, dried figs are richest in fibre, copper, manganese, magnesium, potassium, calcium and vitamin K, relative to human needs (Joseph and Raj, 2011, Patil *et al*., 2017).

Fig is delicious, nutritive fruit and has medicinal properties such as reducing risk of cancer and heart diseases (Vinson, 1999). Figs have a laxative effect and contain many antioxidants. Dried fig is rich in minerals and highly recommended during pregnancy and for children because of its high iron content (Vinson, 1999; Miller *et al*., 2000).

Though the fresh ripe fruits are very delicious, they are highly perishable at room temperature, showing early senescence, fermentation and decay that limits their storage period and marketing life (Karabulut *et al*., 2009, Kad *et al*., 2011 and Yenge *et al*., 2018). Fungal decay of figs can result in extensive losses for the grower (Michailides *et al*., 2008). The post-harvest losses of fruits are reported to range from 30-40 percent in our country which reduces per capita availability by

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25 g (Subrahamanyam, 1986). Being highly perishable, fig cannot be stored for longer period even at refrigerated conditions (Hardenburg *et al.*, 1986; Piga *et al.*, 1995). Fully ripe fresh figs have shelf-life of about a week at 0°C with 90 per cent humidity. Whereas the dried figs can be stored for 6–8 months (Venkataratnam, 1988). Also, dehydration offers many advantages, such as reduced weight, inexpensive packaging, dry shelf stability and negligible deterioration in quality due to enzymatic changes.

Sun drying is the conventional method used to obtain dried figs, requiring only low capital, simple equipment and low energy input. But the general sun drying process dramatically increases the potential for Aspergillus fungal contamination, resulting in greater chances of aflatoxin development (Tosun and Delen, 1998). Moreover, the produce is exposed to direct solar radiations and as the drying parameters cannot be controlled, the product quality is low. Sun-drying is, therefore, not homogeneous, and the final product is caramelized and crusted. Direct exposure to the sun also destroys the color, vitamins, and flavor of the figs.

Mechanical air dehydration has gained importance because it has many advantages over sun-drying such as better sanitary conditions, drying parameters can be controlled thus, a more consistently uniform product can be achieved with less quality degradation, labor costs are lower (Barbosa-Ca & Vega-Mercado 1996). But figs dried by mechanical method possess some problem with the organoleptic properties (burnt taste) and structural collapse occurred (Papoff *et al.*, 1998).

Poona fig is the major variety under commercial cultivation in Maharashtra. But this variety is not suitable for drying because of low sugar content and leathery appearance of the final product. Thus to get good quality dehydrated product from Poona fig, osmotic dehydration in combination with other drying methods is useful. Osmotic dehydration consists of partial removal of moisture from the produce by placing it in concentrated sugar or salt solution. Two simultaneous cross flows are induced: the solute in the solution penetrates into the product and the water in the products flows into the solution. This method of dehydration has potential advantage of less heat damage, good blanching effect, less enzymatic browning, better retention of flavour, colour, texture and energy saving because no phase change occurs

(Chaudhary *et al.*,1993). Moreover, for fruits and vegetables, the osmotic pretreatment prior to other drying methods improves its nutritional, sensorial and functional properties (Islam and Flink, 1982; Ertekin and Cataloz, 1996; Pokharkar, 2001 and Shelar *et al.*, 2015).

Considering these points, there is greater scope and need for drying of figs for making it available throughout the year in good quality. The present investigation was, therefore carried out with an aim to study the drying behavior of fig.

Material and Methods

Fresh fig fruits of Cv "Poona" were obtained directly from the farmer's field located at Saswad (Pune, Maharashtra) and Kopargaon (Ahmednagar, Maharashtra) villages. Well matured fruits of uniform size and colour were harvested, randomly selected and brought to the laboratory. Pedicles of selected fruits were removed and fruits were washed with clean water and wiped dry.

Pretreatments : Prior to drying, fruits were pretreated, in order to reduce non enzymatic browning and speed up the drying process. Pretreatments were, dipping in 34 and 38 ppm dipping oil (ESSAR MK, Pune) for 1 min

followed by sulphitation by fumigation of sulphur powder at the rate of 2 g per kg of fruits for 2 hour.

Osmo-Dehydration of fig fruits : The pretreated fruits were then dipped in 50, 60 and 70°Brix sugar syrup for 48 h to reach desired total soluble solids (TSS) and for partial dehydration of pretreated fig fruits. The soaked fruits were removed from sugar syrup after 48 h and surface of fruit was wiped out using cloth. Subsequently, these fruits were subjected to drying in the cabinet dryer at 55°C for 14-18 h to reduce moisture content to safe level of 18 to 20 percent w.b. (Thonta and Patil, 1988).

Drying rate and moisture ratio : During drying, moisture content was determined at regular interval of 1 h. Moisture content was determined in hot air oven at 70°C by standard A.O.A.C. (1990) method. Drying rate and moisture ratio was then calculated by using the formula given by Chakraverty and De (1981).

$$\text{Drying rate (g/min-100 g of d.m)} = \frac{\text{Amounr of moisture removed (g)}}{\text{Time taken min x Total bone dry weight of sample (g)}} \quad \ldots(i)$$

$$\text{M. R.} = \frac{M - M_e}{M_0 - M_e} \quad \ldots(ii)$$

where, M.R. = Moisture Ratio, M_0 = Initial Moisture Content, % (d.b.), M = Intermediate Moisture Content, % (d.b.) and Me= Equilibrium Moisture Content, % (d.b.).

Drying kinetics were calculated by plotting moisture content vs. drying time; drying rate vs. average moisture content and moisture ratio vs. drying time. The mathematical relationship between drying rate and drying time is developed for each sample and is given in Table 1.

The drying behavior of fig sample can be predicted using equation (i) i.e. first order kinetic model.

$$\frac{M - M_e}{M_0 - M_e} = e^{-kt} \quad \ldots(iii)$$

i.e. M. R. = e^{-kt}

O_1 - 34 ppm dipping oil, O_2 - 38 ppm dipping oil, S_1 - 50°Brix sugar syrup solution S_2 - 60°Brix sugar syrup solution, S_3 - 70°Brix sugar syrup solution

Chemical analysis : The fresh as well as dried figs were analyzed for moisture content (%), total soluble solids (°Brix), titratable acidity (%), reducing sugar content (%) and total sugars content (%). The moisture content and TSS was determined by standard A.O.A.C method (1990) method. Reducing, non-reducing and total sugars were determined using Lane and Eynon method (1923)

Sensory evaluation : The samples of dried figs were evaluated for colour, texture, taste and overall acceptability by a panel of 10 judges on the basis of 9- point hedonic scale (Amerine *et al*., 1965.

Statistical analysis : The data obtained by chemical and sensory analysis was statistically analyzed in Factorial Completely Randomized Design (FCRD) with three replications as per the procedure described by Panse and Sukhatme (1967).

Results and Discussion

Chemical characteristics of fresh fig fruits : Data pertaining to chemical characteristics of fresh fruits are reported in Table 1. The moisture content of fresh Poona fig was ranged from 78.00 to 84.00 per cent. The average moisture content of twenty fruits recorded for moisture estimation was 80.00 per

Table 1. Chemical composition of fresh fig

	Moisture content (% w.b.)	TSS (°Brix)	Titratable acidity (%)	Reducing sugar content (%)	Total sugar content (%)
Fresh fig	80.00	19.34	0.24	13.76	16.01

cent (w.b.). All the chemical parameters i.e. moisture content, total soluble solids, titratable acidity, reducing sugars and total sugars were in the range reported for this species.

Drying kinetics

Partial Dehydration : The data pertaining to effect of different pretreatments on moisture content of fresh Poona fig during partial dehydration for 48 h are presented in Table 2. From this data, it was observed that the rate of moisture loss increases with increase in dipping oil concentration as well as with increase in sugar syrup concentration. The maximum moisture loss was observed for figs treated with 38 ppm dipping oil and 70°B sugar syrup concentration.

Table 2. Effect of partial dehydration on moisture content of figs

Treatment	M.C. of fresh sample % w. b.	M.C. after osmosis, % w. b.	% reduction in M.C.
O_1S_1	80.00	75.49	5.64
O_1S_2	80.00	75.23	5.96
O_1S_3	80.00	74.81	6.49
O_2S_1	80.00	74.75	6.56
O_2S_2	80.00	74.40	7.00
O_2S_3	80.00	74.00	7.50

Effect of dipping oil treatments and drying time on moisture content of figs for different sugar syrup concentrations are plotted in Fig. 1. From the data, it was found that as the dipping oil concentration increased from 34 to 38 ppm, the rate of moisture loss was also increased.

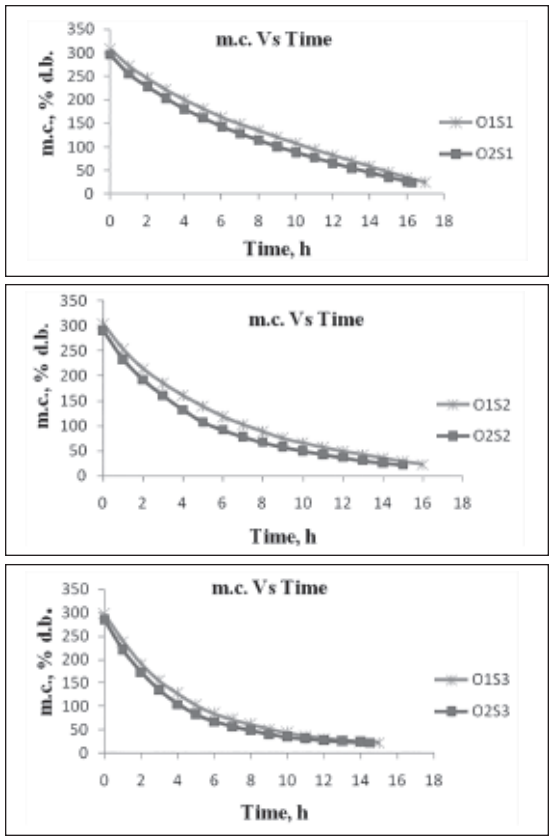

Fig. 1. Effect of dipping oil treatments (O_1 and O_2) on moisture content of osmotically dried figs at 50, 60 and 70°B sugar syrup (S_1, S_2 and S_3) concentrations.

Thus, minimum moisture content was observed with 38 ppm dipping oil treatment for all the sugar syrup concentrations. The time required for drying of fig fruits was decreased with increase in dipping oil concentration.

Moisture content and drying time : The effect of different sugar syrup concentrations and drying time on moisture content of dried figs for two different dipping oil treatments are plotted in Fig. 2. The rate of moisture loss increased with increase in sugar syrup concentration. This was due to increase in osmotic syrup concentration, increased diffusion changes and the osmotic pressure exerted on

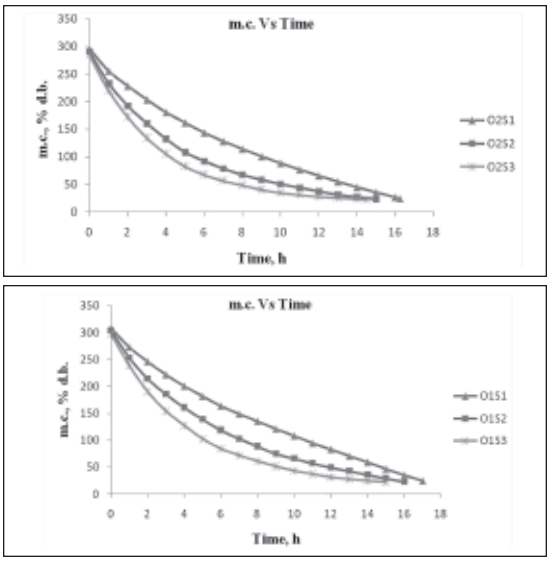

Fig. 2. Effect of different sugar syrup concentrations (S_1, S_2 and S_3) on drying rate of osmotically dried figs for 34 and 38 ppm dipping oil treatment (O_1 and O_2).

the fruit cell structure which consequently resulted in greater moisture reduction in more concentrated solutions. Higher solution concentration facilitated greater water-solute transfer between the fruit and the osmotic solution. This accounted for the decrease in instantaneous moisture content, with increasing osmotic solution concentration. Higher solution concentration promotes greater osmotic drive, due to higher solute penetration, which initiates the water flow out of the fruit (Falade *et al*., 2003). Also, drying time was decreased with increase in the sugar syrup concentration. Falade *et al*. (2003) reported the instantaneous moisture content (d.b) of osmosed cashew apples decreased with increasing immersion time and osmotic solution concentration. Jalali *et al*. (2008) found that the rate of moisture reduction was increased with increase in osmotic syrup concentration. From the experiment, it was revealed that the moisture content was decreased exponentially.

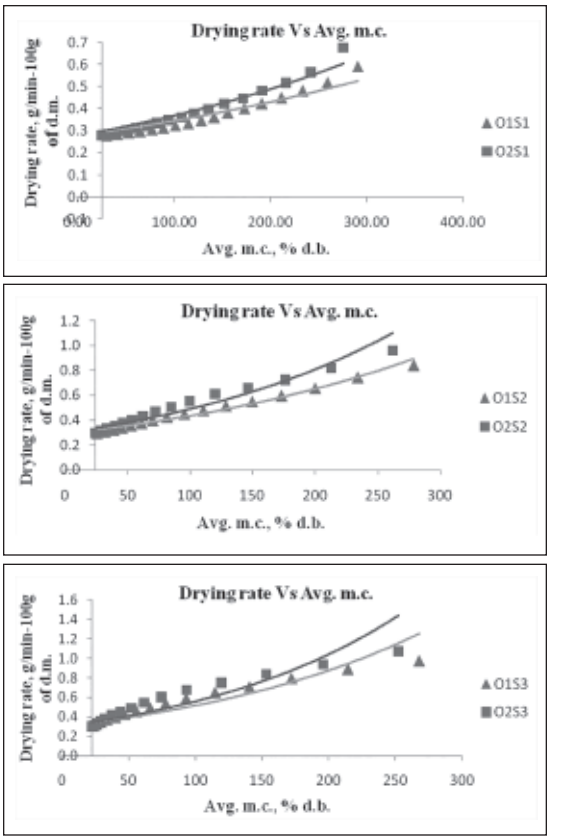

Fig. 3. Effect of dipping oil treatments (O_1 and O_2) on drying rate of osmotically dried figs at 50, 60 and 70°B sugar syrup (S_1, S_2 and S_3) concentrations.

Effect of dipping oil treatments and drying time on drying rate of figs for different sugar syrup concentrations are plotted in Fig. 3. The effect of different sugar syrup concentrations and drying time on drying rate of figs for two different dipping oil treatments is plotted in Fig. 4. The effect of drying time on drying rate showed all curves of exponential type. The drying rate was faster initially and then goes on decreasing with decreasing rate. Thus, drying process showed only a falling rate period. From the data, it was observed that the drying rate was increased with increase in sugar syrup concentration as well as dipping oil concentration. The similar results were obtained

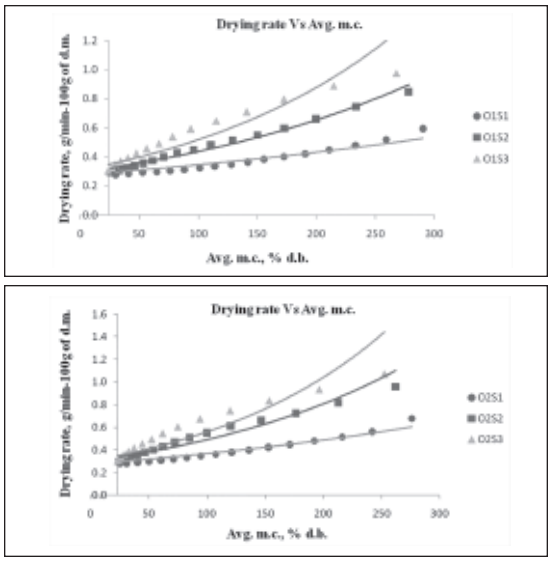

Fig. 4. Effect of different sugar syrup concentrations (S_1, S_2 and S_3) on drying rate of osmotically dried figs for 34 and 38 ppm dipping oil treatment (O_1 and O_2)

for drying of red bell peppers by Sanjuan *et al*., (2003).

Moisture ratio : The effect of drying time on moisture ratio of fig sample shows all curves of exponential type **(Fig. 5 and Fig. 6)**. The effect of drying time on moisture ratio of fig samples decreased from initial value of one to almost zero for all the treatments. From the plots of moisture ratio Vs drying time (Fig. 5 and Fig. 6), it was observed that the moisture ratio was decreased slowly for 34 ppm as compared to 38 ppm dipping oil treatment and rate of decrease was slow for 50°Brix as compared to 60 and 70°Brix sugar syrup concentrations. Equation (i) provides excellent fit to the experimental data on drying of fig samples.

The drying constant (K) was maximum for the 38 ppm dipping oil treatment with 70°Brix sugar syrup concentration (O_2S_3). This was because of higher drying rate for the same treatment. The moisture content at the desired time interval could be predicted using value of drying constant if initial and equilibrium moisture contents are known.

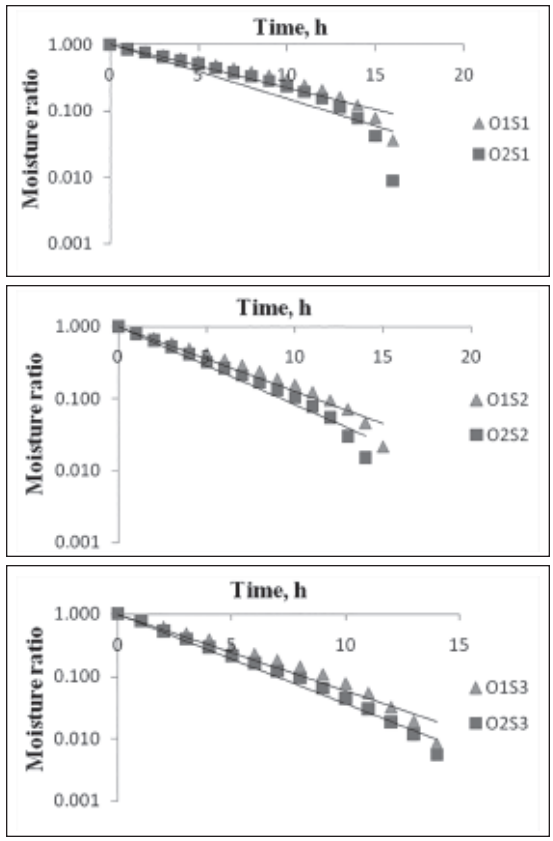

Fig. 5. Effect of dipping oil treatments (O_1 and O_2) on moisture ratio of osmotically dried figs at 50, 60 and 70°B sugar syrup (S_1, S_2 and S_3) concentration.

Chemical analysis of dried figs : The data pertaining to various chemical parameters of dried fig are reported in Table 4. There was reduction in moisture content and titratable acidity of dried fig after drying whereas TSS, reducing sugars and total sugars were increased after drying. The effect of dipping oil treatment and sugar syrup concentration on acidity content of dried fig was found to be non significant but acidity decreases with increase in the sugar syrup

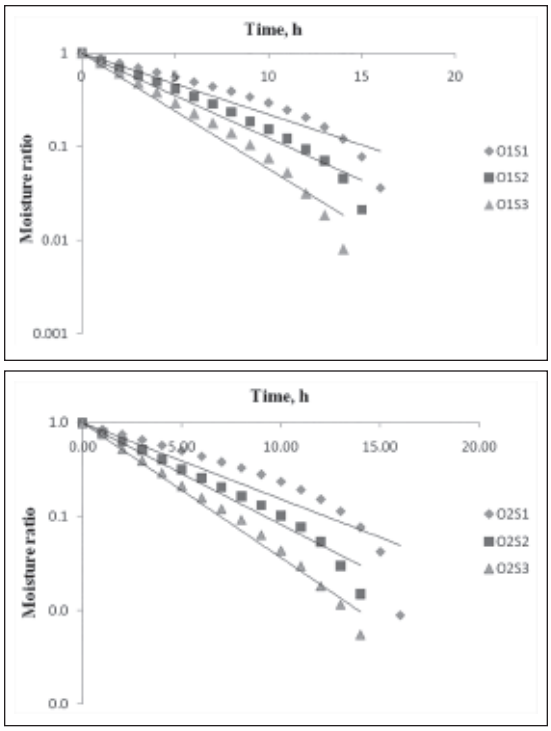

Fig. 6. Effect of different sugar syrup concentrations (S_1, S_2 and S_3) on moisture ratio of osmotically dried figs for 34 and 38 ppm dipping oil treatments (O_1 and O_2).

Table 3. K and R^2 values of mathematical expression for different treatments of fig sample

Treatments	K value, h^{-1}	R^2
O_1S_1	0.15	0.893
O_1S_2	0.20	0.953
O_1S_3	0.28	0.954
O_2S_1	0.18	0.818
O_2S_2	0.25	0.960
O_2S_3	O.33	0.982

concentration. The decrease in acidity with sugar concentration has been reported in dried guava and papaya fruit (Mehta and Tomar, 1980) and in mango, guava slices and in aonla segment (Kumar and Sagar, 2009). Dried figs pretreated with 38 ppm dipping oil and osmosed with 60°Brix sugar syrup solution contained maximum chemical constituents.

Table 4. Chemical composition of fresh dehydrated figs

Treatments	Moisture content (%)	TSS (°Brix)	Titratable acidity (%)	Reducing sugar content (%)	Total sugar content (%)
O_1S_1	19.56	50.50	0.090	53.55	56.10
O_1S_2	18.70	53.00	0.086	55.34	58.10
O_1S_3	18.38	55.21	0.084	53.21	56.18
O_2S_1	19.24	51.50	0.088	54.49	57.14
O_2S_2	18.30	54.13	0.085	56.21	59.15
O_2S_3	18.09	55.89	0.083	53.71	56.82
SEm(±)	0.028	0.030	0.118	0.042	0.050
CD at 5%	0.079	0.086	NS	0.120	0.143

Sensory evaluation of dried figs : Sensory score appear to be useful to select the best osmotic concentration and dipping oil treatment as chemical constituents were very indistinctness. The mean values for colour, appearance, texture, taste and overall acceptability of dried figs are presented in Table 5.

One of the main quality parameter is colour for dried figs because its lighter colour is important in world market (Sen *et al*., 2010). The colour of figs changes during drying. This colour change was made by many reactions such

Table 5. Sensory quality of fresh dehydrated figs

Treatments	Colour and appearance	Taste	Texture	Overall acceptability
O_1S_1	7.30	7.00	7.00	7.10
O_1S_2	8.00	6.12	8.00	7.33
O_1S_3	7.00	5.00	6.00	6.00
O_2S_1	7.20	7.00	7.00	7.07
O_2S_2	8.10	8.00	8.51	8.20
O_2S_3	6.60	6.00	6.80	6.46
SEm(±)	0.050	0.037	0.095	0.026
CD at 5%	NS	0.106	NS	0.074

as phenolics polymerization and maillard reactions which may cause an increase in darker colour.

Similarly average score for taste, texture and overall acceptability were higher for figs treated with 38 ppm dipping oil and dipped in 60°Brix sugar syrup solution.

Conclusion

Moisture reduction and drying rate decreases with increase in concentration of dipping oil as well as sugar syrup solution. Drying of fig occurs in falling rate period. Acceptable dried figs can be prepared by using 38 ppm dipping oil, sulphitation, osmosis at 60°Brix sugar syrup solution followed by cabinet drying at 55°C.

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Studies on Packaging and Storage of Green Capsicum (Cv. Indra) at Different Storage Conditions

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Abstract

The effect of different packaging materials along with two storage conditions i.e. Zero Energy Cool Chamber (ZECC) and Cold Storage (CS) were assessed for maintaining quality attributes and extending shelf life of green capsicum. The qualities of capsicums were assessed by physiological loss in weight, firmness, rotting, ascorbic acid and moisture content. The green capsicum fruits in all the treatments showed increasing trends of physiological loss in weight (%), TSS (°B) and rotting (%) while in moisture content, ascorbic acid (mg 100^{-1} g) and firmness (N) showed decreasing trend during the advancement of storage period in ZECC and CS. The quality of capsicum fruits of green varieties under CS and ZECC were found to be best when packed in cellulose acetate (CA) film followed by breathing bags. The shelf life of green capsicum fruits was extended up to 40 days in CS, 24 days in ZECC when packed in CA film followed by breathing bags and was found to be beneficial in extending the shelf life of capsicum fruits. The green capsicum packed in CA films was found to be best packaging material for extending the shelf life followed by breathing bags and without vent polythene bags of 100 micron, 50 micron and 25 micron, in CS and ZECC storage in respect of quality parameters.

Key words : Capsicum, Cv. indra (green), shelf life, cold storage, zero energy cool chamber, chemical properties.

Capsicum (*Capsicum annum* L.) is one of the important high value vegetable crop in India and successfully grown in the temperate and subtropical regions including North Eastern States. Capsicum is the second important crop among family Solanaceae. It is known by other names such as Shimlamirch, and sweet pepper. The fruit of most species of Capsicum contains capsaicin (methyl vanillylnonenamide), a lipophilic chemical that can produce a strong burning sensation (pungency or spiciness) in the mouth of the unaccustomed eater. Capsicums are used as culinary ingredients for their colour, flavour and pungency. Capsicums are perishable products and are susceptible to chilling injuries. They are not suitable for long term cold storage. Water loss has a great impact on green bell pepper quality and it is a major cause of deterioration. For a maximum shelf life, to reduce water loss and desiccation, it is recommended to keep green bell peppers at 7.5oC and 90-95 per cent relative humidity (RH). Vegetables are highly perishable in nature due to high moisture, action of enzymes, chemicals reactions, structural changes and conditions of storage, most of vegetables are wasted. This is chief hurdle for marketing of fresh produce. Fruits and vegetables are living products undergoing a ripening and at the end ageing process, in which the plant tissue is broken down. One major constraint confronting capsicum production in developing countries is post-harvest losses as a result of unavailability of storage facilities (Anon, 2003).

This necessitates the development of special packaging techniques to extend post-harvest life of capsicum. The main aim of storage is to limit water loss from the crops due to transpiration

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which in turn causes shrivelling, tissue softening, physiological disorders. Controlled atmospheres or modified atmospheres are designed to slow down respiration and thus senescence by reducing oxygen or increasing carbon dioxide concentration (Kader, 1985). To avoid shrivelling and increase shelf-life, proper packaging and storage condition are of paramount importance. Adequate and proper packaging protects the fruit from physical, physiological and pathological deterioration (Zagory and Kader, 1998 and Dhemre *et al*., 2017). Packaging is a very important to glamorize the product in order to attract the consumer's attention.

Materials and methods

Materials and experimental design

Capsicum : Fresh and healthy fruits of capsicums Cv. Indra (green) were procured from a local progressive farmer of Tal- Rahuri, Dist. Ahmednagar for the research work. Freshly harvested fruits were cleaned and sorted manually to remove diseased and unhealthy fruits.

Packaging : The capsicum samples were packed in cellulose acetate (CA) film bags, breathing bags and polythene bags of 25, 50 and 100 micron with 2 and 4 per cent vents and without vents.

Storage : The capsicums of Cv. Indra (green) were stored at two different storage conditions viz., zero energy cool chamber (ZECC) and cold storage (CS) for further storage study.

Zero energy cool chambers (ZECC) : Based on the principles of direct evaporative cooling, low cost, zero energy input, zero energy cool chamber has been developed. The structure is made out of cheap, locally available raw material such as bricks, sand, bamboo, coconut leaves etc. with a source of water supply. The floor of this storage place is made with a single layer of bricks and the side walls with a double layer of bricks. The space between double walled bricks (3) is filled up with riverbed sieved sand. It is installed under temporary shed (thatch). Once the zero energy cool chamber is saturated with water, sprinkling of water once in the morning and once in the evening is enough to maintain the temperature and relative humidity. The temperature and relative humidity in zero energy cool chamber during research work was varied between 16-22oC and 72-88 per cent, respectively. The packed and unpacked fruits of capsicum were kept in zero energy cool chamber for storage.

Cold storage : The packed and unpacked fruits of capsicums were stored in cold storage. The storage atmosphere in cold storage was maintained at 7 ± 2°C and 85-90 per cent relative humidity.

Experimental details

1. Crop : Capsicum
2. Design : Factorial Completely Randomized Design (FCRD)
3. Treatments details :

   Factor- A : Variety - V_1- Indra (Green)

   Facor - B : Storage conditions. S_1 - Cold storage (CS) (at 7 ± 2°C and 85-90 % RH) and S_2 - Zero Energy Cool Chamber (ZECC)

   Factor - C : Packaging materials

   T_1- Capsicum stored in CA film bags, T_2 - Capsicum stored in Breathing bags, T_3 - Capsicum stored in Polythene bags of 25 micron with 2% vent, T_4 - Capsicum stored in Polythene bags of 25 micron with 4% vent, T_5 - Capsicum stored in Polythene bags of 25 micron without vent, T_6 - Capsicum

stored in Polythene bags of 50 micron with 2 % vent, T_7 - Capsicum stored in Polythene bags of 50 micron with 4% vent, T_8 - Capsicum stored in Polythene bags of 50 micron withoy vent, T_9 - Capsicum stored in Polythene bags of 100 micron with 2% vent, T_{10} - Capsicum stored in Polythene bags of 100 micron with 4% vent, T_{11} - Capsicum stored in Polythene bags of 100 micron without vent, T_{12} - Capsicum stored in open condition (Control).

Details of observations : The observations on physical and chemical parameters were recorded initially and at four days interval for fruits stored at zero energy cool chamber and in cold storage.

Physical parameters (during storage)

Physiological loss in weight (PLW) : The weight of fruits was recorded at four days interval and PLW was calculated by noting the difference between initial and subsequent weights and it was expressed in per cent (Singh *et al*., 2014).

$$\text{PLW (\%)} = \frac{\text{Initial weight - Final weight}}{\text{Initial weight}} \times 100$$

Firmness : Firmness is an important factor which affects the quality of fruit and vegetable. It was determined by using Universal Testing Machine (UTM).

Penetration test was carried out at two different positions on the fruit. After running the test, the force required to penetrate into the fruit for given distance was directly obtained from the data recorder (computer). Finally, the averages of fruits from each treatment and replicate and at two different positions were taken as the firmness of capsicum in that treatment.

Rotting : The rotted percentage of stored samples was calculated by using equation,

$$\text{Rotting, \%} = \frac{\text{Wt. of rotted fruit bag}^{-1}\text{ (g)}}{\text{Wt. of total fruit bag}^{-1}\text{ (g)}} \times 100$$

Moisture content : Moisture content of sample was determined by standard oven drying method. The samples were dried in oven at 70°C till constant weight (15 h) (AOAC, 1990). The bone dried samples were removed from oven and cooled in desiccators for 10 min. The per cent moisture content on wet basis was calculated by using following equation (Nambiar and Seshadri, 2001).

$$\text{M.C. \% (w.b.)} = \frac{W_1 - W_2}{W_1} \times 100$$

where, M.C. (w.b.) = Moisture content, % Weight basis W_1= Weight of wet sample, g and W_2 = Weight of dry sample, g

Chemical Parameters : Chemical parameters such as total soluble solids (TSS) (°B), ascorbic acid (mg 100^{-1} g) were determined at 4 days interval as follows.

Total soluble solids (TSS)(°B) : The content of total soluble solids in the fruits was measured by using Erma Hand Refractometer (0–32 °Brix).

Ascorbic acid (mg 100^{-1} g) : Ascorbic acid was estimated by 2, 6-dichlorophenol indophenols-dye method given by AOAC (1990) and Ranganna (2005). Ascorbic acid is expressed in mg of ascorbic acid per 100 g of sample. The equation is,

$$\text{Ascorbic acid, mg } 100^{-1}\text{ g} = \frac{\text{Titre value (burette vale) x dye factor}}{\text{Volume of extract taken for titration}} \times \frac{\text{Volume of extract (ml)}}{\text{Weight of sample}} \times 100$$

Results and discussion

Chemical composition of fresh capsicum fruits : Fresh green capsicum had 92.61 per cent moisture content on wet basis, 4.52°B total soluble solids and 86.68 mg 100^{-1} g ascorbic acid. The results obtained in the present investigation are similar to earlier values recorded by Castro *et al*. (2008) and Antoniali *et al*. (2007) for yellow bell pepper; Manolopoulou *et al*. (2010) for green bell pepper; Rao *et al*. (2011) for sweet pepper; Renu and Chidanand (2013) for bell pepper and Singh *et al*. (2014) for green bell pepper .

Physico-chemical composition of green capsicums during storage

Ascorbic acid : The data regarding changes in ascorbic acid content of capsicum is presented in Table 1. The ascorbic acid was decreased significantly during the storage period in all the treatment combinations. The decline in ascorbic acid might be due to oxidation during storage since the oxygen present in the air. Less weight loss was observed due to less respiration rate, had more retention of ascorbic acid which is concluded by Manolopoulou *et al*. (2010).

Effect of varieties, storage and packaging material : The interaction effect of varieties, storage and packaging materials were significantly decreased with advancement of storage period for all the treatment

Table 1. Effect of varieties, storage conditions and packaging materials on ascorbic acid content of green capsicum along with their treatment combinations

Treatment combinations	Days after storage										
	0	4	8	12	16	20	24	28	32	36	40
V1S1T1	86.68	85.50	84.35	83.15	82.03	81.36	80.63	79.88	78.99	77.97	76.03
V1S1T2	86.68	85.29	84.14	82.93	81.80	81.19	80.41	79.68	78.76	77.79	75.86
V1S1T3	86.68	83.09	81.92	80.69	79.63	78.96	78.21	77.45	76.56	75.51	73.66
V1S1T4	86.68	82.05	80.86	79.65	78.63	77.90	77.21	76.40	75.51	74.49	72.63
V1S1T5	86.68	84.34	83.15	81.95	80.86	80.23	79.45	78.71	77.80	76.78	74.90
V1S1T6	86.68	83.44	82.26	81.05	79.97	79.32	78.56	77.81	76.90	75.87	74.01
V1S1T7	86.68	82.22	81.04	79.84	78.89	78.09	77.38	76.58	75.70	74.65	72.80
V1S1T8	86.68	84.59	83.41	82.20	81.10	80.47	79.70	78.95	78.06	77.05	75.14
V1S1T9	86.68	84.00	82.80	81.59	80.52	79.88	79.10	78.36	77.44	76.43	74.56
V1S1T10	86.68	82.73	81.57	80.37	79.30	78.61	77.89	77.11	76.22	75.18	73.32
V1S1T11	86.68	85.04	83.87	82.67	81.55	80.93	80.15	79.41	78.51	77.52	75.60
V1S1T12	86.68	81.70	80.67	79.53	78.49	77.82	76.38	75.22	74.35	73.30	71.46
V1S2T1	86.68	84.62	82.65	80.43	78.44	76.28	74.18	-	-	-	-
V1S2T2	86.68	84.42	82.50	80.24	78.25	76.10	74.01	-	-	-	-
V1S2T3	86.68	82.29	80.40	78.09	76.05	73.96	71.83	-	-	-	-
V1S2T4	86.68	81.28	79.42	77.01	75.03	72.92	70.81	-	-	-	-
V1S2T5	86.68	83.48	81.56	79.32	77.26	75.17	73.06	-	-	-	-
V1S2T6	86.68	82.60	80.72	78.43	76.41	74.30	72.17	-	-	-	-
V1S2T7	86.68	81.46	79.58	77.20	75.21	73.10	70.99	-	-	-	-
V1S2T8	86.68	83.71	81.79	79.55	77.51	75.40	73.31	-	-	-	-
V1S2T9	86.68	83.16	81.23	78.97	76.94	74.84	72.73	-	-	-	-
V1S2T10	86.68	81.99	80.08	77.73	75.75	73.61	71.50	-	-	-	-
V1S2T11	86.68	84.14	82.23	80.00	77.98	75.85	73.76	-	-	-	-
V1S2T12	86.68	80.10	78.26	75.83	73.85	72.76	69.65	-	-	-	-

combinations. The green capsicum on 40th day at CS, the highest retention of ascorbic acid was found in treatment V1S1T1 as 76.03 mg 100^{-1} g followed by V1S1T2 (75.86 mg 100^{-1} g) and V1S1T11 (75.60 mg 100^{-1} g), V1S1T12 showed the lowest value of ascorbic acid content (71.46 mg 100^{-1} g). At ZECC on 24th day of storage, V1S2T1 showed highest ascorbic acid content (74.18 mg 100^{-1} g) followed by V1S2T2 (74.01 mg 100^{-1} g) and V1S2T11 (73.76 mg 100^{-1} g). Lowest ascorbic acid was recorded in V1S2T12 (69.65 mg 100^{-1} g).

The results obtained in case of ascorbic acid content are similarly reported by Kadam and Singh (2006) for studying the effect of packaging materials and ethylene absorbent on shelf life of bell pepper; Manolopoulou *et al*. (2010) and Singh *et al*. (2014) for green bell pepper.

Total soluble solids (TSS) (°B) : The data regarding changes in TSS content of green capsicum is presented in Table 2. The TSS (°B) was increased significantly during storage in all treatment combinations. The increase in the TSS contents might be due reduction of moisture content, starch was being converted into sugars, increase of respiration and metabolic activity reported by Kad and Dhemre (2017) that the higher respiration rate increases the synthesis and use of metabolites result in higher TSS due to the higher change from carbohydrates to sugars.

Table 2. Effect of varieties, storage conditions and packaging materials on TSS (°B) of green capsicum along with their treatment combinations

Treatment combinations	Days after storage										
	0	**4**	**8**	**12**	**16**	**20**	**24**	**28**	**32**	**36**	**40**
V1S1T1	4.52	4.54	4.57	4.60	4.62	4.65	4.68	4.70	4.73	4.75	4.78
V1S1T2	4.52	4.61	4.64	4.66	4.69	4.71	4.75	4.76	4.80	4.81	4.85
V1S1T3	4.52	5.36	5.40	5.42	5.46	5.50	5.53	5.55	5.58	5.62	5.65
V1S1T4	4.52	5.67	5.69	5.73	5.77	5.80	5.82	5.84	5.89	5.93	5.96
V1S1T5	4.52	4.85	4.88	4.90	4.94	4.97	5.01	5.03	5.06	5.10	5.12
V1S1T6	4.52	5.14	5.17	5.20	5.23	5.26	5.30	5.32	5.34	5.39	5.42
V1S1T7	4.52	5.56	5.58	5.62	5.66	5.69	5.72	5.74	5.78	5.82	5.85
V1S1T8	4.52	4.76	4.79	4.82	4.85	4.87	4.91	4.93	4.95	4.99	5.02
V1S1T9	4.52	5.10	5.14	5.16	5.19	5.23	5.26	5.29	5.31	5.35	5.38
V1S1T10	4.52	5.51	5.54	5.57	5.61	5.65	5.67	5.70	5.73	5.77	5.80
V1S1T11	4.52	4.73	4.76	4.78	4.82	4.84	4.87	4.90	4.92	4.96	4.98
V1S1T12	4.52	5.83	5.86	5.89	5.94	5.96	5.98	6.01	6.05	6.09	6.12
V1S2T1	4.52	4.58	4.62	4.67	4.73	4.77	4.82	-	-	-	-
V1S2T2	4.52	4.66	4.69	4.75	4.81	4.85	4.90	-	-	-	-
V1S2T3	4.52	5.45	5.47	5.53	5.59	5.63	5.69	-	-	-	-
V1S2T4	4.52	5.78	5.80	5.86	5.92	5.67	6.02	-	-	-	-
V1S2T5	4.52	4.91	4.94	5.01	5.05	5.10	5.15	-	-	-	-
V1S2T6	4.52	5.26	5.28	5.34	5.40	5.45	5.50	-	-	-	-
V1S2T7	4.52	5.68	5.70	5.76	5.82	5.56	5.92	-	-	-	-
V1S2T8	4.52	4.85	4.88	4.94	5.00	5.04	5.09	-	-	-	-
V1S2T9	4.52	5.17	5.19	5.26	5.31	5.36	5.41	-	-	-	-
V1S2T10	4.52	5.61	5.63	5.69	5.75	5.48	5.85	-	-	-	-
V1S2T11	4.52	4.81	4.84	4.89	4.96	5.00	5.05	-	-	-	-
V1S2T12	4.52	5.97	6.00	6.05	6.12	5.87	6.22	-	-	-	-

Effect of varieties, storage and packaging material : For green capsicum at CS on 40th day of storage, V1S1T12 showed highest TSS (6.12°B) and lowest TSS was found in V1S1T1 as 4.78°B. At ZECC on 24th day, V1S2T12 recorded highest TSS (6.22°B) and lowest TSS was found in V1S2T1 (4.82°B).

The results obtained in the present study are in conformity with the observations recorded by Kadam and Singh (2006) for bell peppers; Rao *et al*. (2011) and Samira (2013) for capsicum ; Renu and Chidanand (2013) for bell peppers.

Moisture content : The data on effect of various factors like varieties, storage conditions and packaging materials on changes in moisture content of capsicum are presented in Table 3. The moisture content was found to be decreased statistically significantly during advancement of storage in all the treatment combinations. The per cent decrease in moisture content was pronounced in fruits might be due to the ripening process that undergo throughout the storage period of pepper fruit causes changes in the permeability of cell membranes, making them more sensitive to loss of water (Suslow, 2000 and Antoniali *et al*., 2007).

The moisture content was decreased with increase in storage period in all treatment combinations. The Green capsicum on 40th day of storage in CS, V1S1T1 showed the highest moisture content as 86.46 per cent followed by

Table 3. Effect of varieties, storage conditions and packaging materials on moisture content (%) of green capsicums along with their treatment combinations

Treatment combinations	Days after storage										
	0	4	8	12	16	20	24	28	32	36	40
V1S1T1	92.61	92.29	91.69	91.35	90.76	89.91	89.43	88.77	87.91	87.05	86.46
V1S1T2	92.61	92.02	91.47	91.00	90.15	89.51	88.85	88.16	87.50	86.63	85.79
V1S1T3	92.61	89.87	88.97	88.70	88.09	86.49	85.39	84.66	84.01	83.20	82.69
V1S1T4	92.61	87.85	86.88	85.97	85.31	84.20	83.52	82.69	81.58	80.17	79.29
V1S1T5	92.61	90.78	90.33	89.70	88.89	87.15	86.82	85.60	85.09	83.89	83.29
V1S1T6	92.61	90.08	89.23	88.82	88.21	86.65	85.61	84.82	84.12	83.33	82.81
V1S1T7	92.61	88.55	87.17	86.29	85.68	84.61	83.86	83.20	81.78	80.64	79.74
V1S1T8	92.61	91.24	90.69	90.11	89.34	87.69	87.27	86.18	85.22	84.40	83.77
V1S1T9	92.61	90.27	89.74	89.13	88.57	86.99	85.70	84.99	84.60	83.75	83.21
V1S1T10	92.61	89.28	87.79	86.76	85.94	84.90	84.43	83.51	82.17	81.11	80.22
V1S1T11	92.61	91.56	90.87	90.31	89.58	87.87	87.53	86.32	85.41	84.65	84.16
V1S1T12	92.61	87.25	85.70	84.07	83.05	82.13	80.69	79.73	78.84	78.01	76.80
V1S2T1	92.61	91.24	90.33	89.52	88.71	87.34	85.79	-	-	-	-
V1S2T2	92.61	90.71	89.84	89.02	88.10	86.78	85.60	-	-	-	-
V1S2T3	92.61	87.77	86.22	85.13	83.15	82.10	81.44	-	-	-	-
V1S2T4	92.61	86.29	84.23	82.36	81.54	80.49	79.61	-	-	-	-
V1S2T5	92.61	89.58	87.76	86.50	85.60	83.81	82.70	-	-	-	-
V1S2T6	92.61	88.10	86.58	85.53	83.51	82.56	81.78	-	-	-	-
V1S2T7	92.61	86.71	84.83	82.65	81.87	80.75	80.01	-	-	-	-
V1S2T8	92.61	89.88	88.08	86.77	86.18	84.19	83.11	-	-	-	-
V1S2T9	92.61	88.41	86.89	85.80	83.68	82.89	82.10	-	-	-	-
V1S2T10	92.61	86.94	85.24	83.06	82.19	81.08	80.31	-	-	-	-
V1S2T11	92.61	90.23	88.39	86.99	86.51	84.52	83.45	-	-	-	-
V1S2T12	92.61	86.18	83.84	81.08	79.93	76.80	72.10	-	-	-	-

V1S1T2 85.79 per cent, V1S1T11 as 84.16 per cent and V1S1T12 showed the lowest 76.80 per cent. At ZECC on 24th day of storage, V1S2T1 showed highest moisture content 85.79 per cent followed by V1S2T2 85.60 per cent, V1S2T11 83.45 per cent and lowest was recorded in V1S2T12 72.10 per cent.

The results obtained in this study are in agreement with Kadam and Singh (2006) for bell pepper and Samira (2013) for capsicum.

Firmness : The data on changes in firmness of capsicum are presented in Table 4. The firmness of capsicum was significantly decreased in all treatment combinations by increasing storage period. Cantwell (2004) reported that firmness is directly related to water loss.

At the end of 40th day storage in CS for green capsicum, V1S1T1 recorded highest firmness as 9.84N followed by V1S1T2 as 9.83N, V1S1T11 as 9.80N and lowest in V1S1T12 (9.55N). At the end of 24th day storage in ZECC, V1S2T1 recorded highest firmness as 9.50N followed by V1S2T2 as 9.49N which is at par, V1S2T11 as 9.48N and lowest in V1S2T12 (9.01N).

Singh *et al*. (2014) reported continuous decline in fruit firmness in all packaging material by the passage of storage period and also reported that fruit stored in refrigerated MAP

Table 4. Effect of varieties, storage conditions and packaging materials on firmness (N) of green capsicums along with their treatment combinations

Treatment combinations	Days after storage										
	0	4	8	12	16	20	24	28	32	36	40
V1S1T1	11.80	11.59	11.38	11.19	10.97	10.79	10.59	10.40	10.19	9.97	9.84
V1S1T2	11.80	11.59	11.37	11.18	10.96	10.78	10.58	10.39	10.18	9.96	9.83
V1S1T3	11.80	11.47	11.26	11.07	11.86	10.68	10.47	10.28	9.90	9.87	9.73
V1S1T4	11.80	11.36	11.16	10.96	11.46	10.57	10.39	10.18	9.80	9.76	9.62
V1S1T5	11.80	11.52	11.31	11.12	11.91	10.73	10.52	10.33	10.13	9.91	9.77
V1S1T6	11.80	11.48	11.27	11.07	11.87	10.69	10.48	10.29	9.91	9.87	9.73
V1S1T7	11.80	11.38	11.17	10.98	11.48	10.59	10.40	10.20	9.82	9.78	9.64
V1S1T8	11.80	11.53	11.32	11.13	11.92	10.74	10.54	10.35	10.14	9.92	9.78
V1S1T9	11.80	11.50	11.29	11.09	11.89	10.70	10.50	10.31	10.11	9.89	9.75
V1S1T10	11.80	11.41	11.20	11.02	11.51	10.62	10.43	10.23	9.85	9.81	9.67
V1S1T11	11.80	11.55	11.34	11.16	10.94	10.76	10.55	10.36	10.15	9.93	9.80
V1S1T12	11.80	11.59	11.32	11.17	10.95	10.75	10.53	10.28	10.05	9.79	9.55
V1S2T1	11.80	11.50	11.14	10.78	10.39	10.00	9.50	-	-	-	-
V1S2T2	11.80	11.50	11.13	10.77	10.39	9.99	9.49	-	-	-	-
V1S2T3	11.80	11.39	11.03	10.67	10.28	9.88	9.39	-	-	-	-
V1S2T4	11.80	11.33	10.97	10.61	10.22	9.83	9.33	-	-	-	-
V1S2T5	11.80	11.45	11.08	10.73	10.34	9.94	9.44	-	-	-	-
V1S2T6	11.80	11.40	11.04	10.68	10.29	9.89	9.40	-	-	-	-
V1S2T7	11.80	11.34	10.98	10.62	10.23	9.84	9.34	-	-	-	-
V1S2T8	11.80	11.46	11.10	10.74	10.35	9.95	9.46	-	-	-	-
V1S2T9	11.80	11.42	11.06	10.70	10.31	9.91	9.42	-	-	-	-
V1S2T10	11.80	11.36	11.00	10.64	10.25	9.86	9.36	-	-	-	-
V1S2T11	11.80	11.48	11.12	10.76	10.37	9.97	9.48	-	-	-	-
V1S2T12	11.80	11.22	10.68	10.19	9.85	9.44	9.01	-	-	-	-

has more firmness than other storage conditions. The results obtained in this study are similar with Cantwell *et al*. (2009) for sweet pepper.

Physiological loss in weight (PLW) : The data on changes in physiological loss in weight of capsicum are presented in Table 5. The physiological loss in weight was found to be increased during storage period and the rate was more under zero energy cool chamber as compared to cold storage.

The interaction effect of varieties, different storage conditions and packaging materials on PLW of capsicum was significantly increased during storage period in all treatment combinations. At the end of 40th day storage of green capsicum in CS, V1S1T1 recorded the lowest PLW as 6.18per cent followed by V1S1T2 as 6.86 per cent, V1S1T11 as 8.48 per cent and highest in V1S1T12 15.83 per cent. In ZECC on 24th day of storage, the lowest PLW was observed in V1S2T1 6.86 per cent followed by V1S2T2 7.05 per cent, V1S2T11 as 9.20 per cent and highest in V1S2T12 20.52 per cent.

The results obtained in present study are in agreement with Nyanjage *et al*. (2005) for sweet pepper; Kadam and Singh (2006) for bell pepper; Kablan *et al*. (2008) for bell pepper; Nath *et al*. (2010) for capsicum and Singh *et al*. (2014) for shelf life enhancement under active modified atmosphere storage of capsicum.

Table 5. Effect of varieties, storage conditions and packaging materials on physiological loss in weight (PLW %) of green capsicums along with their treatment combinations

Treatment combinations	Days after storage										
	0	**4**	**8**	**12**	**16**	**20**	**24**	**28**	**32**	**36**	**40**
V1S1T1	-	0.35	0.96	1.29	1.88	2.72	3.20	3.87	4.73	5.59	6.18
V1S1T2	-	0.62	1.17	1.64	2.50	3.12	3.79	4.48	5.13	6.01	6.86
V1S1T3	-	2.76	3.67	3.94	4.56	6.15	7.27	7.98	8.62	9.43	9.97
V1S1T4	-	4.80	5.79	6.66	7.32	8.44	9.12	9.96	11.02	12.43	13.35
V1S1T5	-	1.85	2.32	2.95	3.77	5.49	5.81	7.06	7.58	8.74	9.26
V1S1T6	-	2.57	3.41	3.82	4.43	5.99	7.02	7.78	8.50	9.30	9.84
V1S1T7	-	4.10	5.47	6.35	6.98	8.02	8.80	9.45	10.87	11.96	12.89
V1S1T8	-	1.39	1.96	2.53	3.30	4.96	5.37	6.46	7.38	8.27	8.83
V1S1T9	-	2.41	2.92	3.50	4.04	5.67	6.95	7.64	8.05	8.89	9.40
V1S1T10	-	3.40	4.87	5.90	6.70	7.73	8.20	9.13	10.46	11.55	12.40
V1S1T11	-	1.08	1.77	2.32	3.07	4.80	5.10	6.30	7.22	7.98	8.48
V1S1T12	-	5.33	6.90	8.56	9.57	10.47	11.90	12.87	13.76	14.60	15.83
V1S2T1	-	1.40	2.32	3.13	4.02	5.30	6.86	-	-	-	-
V1S2T2	-	1.92	2.78	3.62	4.53	5.85	7.05	-	-	-	-
V1S2T3	-	4.86	6.42	7.51	9.48	10.53	11.20	-	-	-	-
V1S2T4	-	6.34	8.41	10.28	11.09	12.15	13.04	-	-	-	-
V1S2T5	-	3.07	4.88	6.13	7.04	8.82	9.93	-	-	-	-
V1S2T6	-	4.53	6.07	7.10	9.12	10.07	10.86	-	-	-	-
V1S2T7	-	5.93	7.82	9.98	10.77	11.89	12.63	-	-	-	-
V1S2T8	-	2.75	4.57	5.86	6.45	8.46	9.52	-	-	-	-
V1S2T9	-	4.21	5.77	6.83	8.97	9.76	10.55	-	-	-	-
V1S2T10	-	5.69	7.40	9.57	10.46	11.57	12.33	-	-	-	-
V1S2T11	-	2.39	4.24	5.65	6.14	8.12	9.20	-	-	-	-
V1S2T12	-	6.42	8.76	11.52	12.67	15.83	20.52	-	-	-	-

Rotting : The data regarding changes in rotting of capsicums are presented in Table 6. The rotting was found to be increased during storage period and the rate was more under zero energy cool chamber as compared to cold storage.

At the end of 40th day of storage of green capsicums in CS, V1S1T1 recorded the lowest rotting as (9.38 %) followed by V1S1T2 as 9.47 per cent and highest in V1S1T11 (10.57 %). In ZECC on 24th day of storage, the lowest rotting was observed in V1S2T1 (11.86 %) followed by V1S2T2 (11.94 %) and the highest rotting was recorded in V1S2T11 (13.02 %).

The results obtained are similar with Nyanjage *et al*. (2005) for sweet pepper; Kablan *et al*. (2008) for bell pepper and Nath *et al*. (2010) for capsicum.

Summary and conclusion

The green capsicum fruits in all the treatments showed increasing trends of physiological loss in weight (%), TSS (°B) and rotting (%) while in moisture content, ascorbic acid (mg 100^{-1} g), and firmness (N) showed decreasing trend during the advancement of storage period in ZECC and CS. The quality of capsicum fruits of green and varieties under CS and ZECC were found to be best when packed in CA film followed by breathing bags. The shelf life of green capsicum fruits was extended up to

Table 6. Effect of varieties, storage conditions and packaging materials on rotting (%) of green capsicums along with their treatment combinations

Treatment combinations	Days after storage									
	4	8	12	16	20	24	28	32	36	40
V1S1T1	-	-	0.25	0.70	1.80	2.68	3.86	5.10	7.12	9.38
V1S1T2	-	-	0.32	0.79	1.86	2.76	3.93	5.16	7.19	9.47
V1S1T3	-	-	0.95	1.38	2.43	3.34	4.53	5.73	7.77	10.07
V1S1T4	-	-	0.65	1.07	2.13	3.04	4.22	5.43	7.46	9.76
V1S1T5	-	-	1.20	1.60	2.65	3.58	4.78	5.95	7.99	10.29
V1S1T6	-	-	1.02	1.45	2.49	3.43	4.63	5.79	7.84	10.13
V1S1T7	-	-	0.72	1.17	2.19	3.15	4.33	5.50	7.54	9.83
V1S1T8	-	-	1.34	1.78	2.80	3.76	4.95	6.11	8.16	10.44
V1S1T9	-	-	1.13	1.56	2.60	3.55	4.75	5.92	7.96	10.24
V1S1T10	-	-	0.89	1.35	2.41	3.32	4.51	5.70	7.73	10.05
V1S1T11	-	-	1.44	1.88	2.93	3.84	5.03	6.23	8.25	10.57
V1S1T12	-	-	0.53	1.05	2.10	3.01	4.18	5.40	7.43	9.72
V1S2T1	0.34	1.60	3.67	6.73	8.40	11.86	-	-	- -	
V1S2T2	0.43	1.68	3.75	6.81	8.48	11.94	-	-	- -	
V1S2T3	1.03	2.30	4.37	7.43	9.10	12.55	-	-	- -	
V1S2T4	0.70	1.97	4.04	7.10	8.77	12.21	-	-	- -	
V1S2T5	1.27	2.53	4.60	7.66	9.33	12.78	-	-	- -	
V1S2T6	1.08	2.36	4.43	7.49	9.16	12.60	-	-	- -	
V1S2T7	0.76	2.04	4.11	7.17	8.84	12.28	-	-	- -	
V1S2T8	1.38	2.66	4.73	7.79	9.46	12.91	-	-	- -	
V1S2T9	1.16	2.45	4.52	7.58	9.25	12.70	-	-	- -	
V1S2T10	0.93	2.21	4.28	7.34	9.01	12.47	-	-	- -	
V1S2T11	1.48	2.77	4.84	7.90	9.57	13.02	-	-	- -	
V1S2T12	0.61	1.92	3.99	7.05	8.72	12.16	-	-	- -	

40 days in CS, 24 days in ZECC when packed in CA film followed by breathing bags and was found to be beneficial in extending the shelf life of capsicum fruits.

The green capsicum packed in CA films was found to be best packaging material for extending the shelf life followed by breathing bags, 100 micron, 50 micron and 25 micron without vent polythene bags, in CS and ZECC storage in respect of quality parameters.

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Studies on Sowing Windows for Sustainable Production of *Rabi* Sorghum (*Sorghum bicolour* L.) Under Changing Climatic Condition in Scarcity Zone of Maharashtra.

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Abstract

The field experiment was conducted at research farm, Zonal Agriculture Research Station, Solapur Mahatma Phule Krishi Vidyapeeth,Rahuri for five years (2016-17 to 2020-21) in *rabi* on sorghum entitled as "Studies on Sowing windows for Sustainable Production of Rabi Sorghum (*Sorghum bicolour* L.) Under Changing Climatic Condition in Scarcity Zone of Maharashtra." to find out most optimum meteorological week for sowing sorghum in *rabi* season, to study the relationship between meteorological parameters and yield by using four different sowing windows. The results were obtained from the experiment; it was found that rabi sorghum sown at MW 40 (01-07 Oct) produced maximum pooled grain yield (808.28 kg ha^{-1}), fodder (1494.11 kg ha^{-1}) and total monetary returns (Rs. 26633 ha^{-1}). Among the varieties, M-35-1 was produced significantly higher grain yield (717.94 kg ha^{-1}), fodder yield (1559.03 kg ha^{-1}) and total monetary returns (Rs. 24968 ha^{-1}) over the other variety. The meteorological studies showed that the mean CUM and MUE recorded by sorghum crop was 240 mm and 2.7 kg ha^{-1} mm. The highest CUM was recorded by S_1 sown crop (282 mm) however the MUE was recorded by S_3 sown crop (3.5 kg ha^{-1} mm). This indicated that S_3 sown crop (*Chitra Nakshtras*) utilized moisture more efficiently than other dates of sowing. Among the variety M-35-1 recorded maximum mean CUM (266 mm) and MUE (3.1 kg ha^{-1} mm) than other varieties. The number of days required to attain physiological maturity and growing degree days were higher in S_3 sown crop. Among the varieties it is higher in M 35-1 than Mauli and Yashoda. In case of RUE initially values were low, it increases up to 70 DAS (i.e. up to 50 percent flowering to soft dough stage) further it decreases in all most all the sowing dates.

Key words : Sowing windows, varieties, yield, GDD, MUE, CUE, RUE.

Sorghum (*Sorghum bicolor* L.,) plays an important role as grain and fodder crop for both arid and semi-arid regions of the world. This importance is due to its higher water use efficiency, relatively good tolerance to drought and salt stresses and good competitiveness with weeds in advanced growth stages. Sorghum growth, development and yield depend on environmental conditions such as temperature and precipitation. The extent of effect of these environmental parameters may vary depending on planting time. The effect of stress due to environmental factors on final yield may depend upon the growth stage in which it occurs and the genotype. Deciding on early or late planting depends on a farmer's ability to deal with the risk of poor crop establishment with early planting or the effect of water or heat stress at reproductive stages with late planting. Since sorghum is cultivated majorly as a rainfed crop, its productivity is significantly influenced by climatic elements (Srivastava *et al*., 2010). Sorghum yield response to location, time of planting and soil water storage were associated with difference in leaf area development. Sowing time has an impact on sorghum growth stages. Decline in sorghum productivity in future climate change scenarios at different locations of India was primarily attributed to reduction in crop growth period with increase in temperature (Boomiraj *et al*., 2012). Pramod *et al*. (2017) used various adaptation strategies *viz*., change

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in sowing dates to minimize the yield reduction in wheat in India. In India, sorghum is extensively produced and both hybrid and improved varieties are taken on large scale. India is the third largest producer in the world. Among the cereals in India, sorghum ranks third, next to rice and wheat. Sorghum is a rich source of carbohydrates, proteins, minerals and vitamin B1 and B2. By keeping in view, this experiment was conducted to study suitable variety under suitable weather condition for optimum production and to identify the suitable sowing date and variety for better growth and yield of sorghum crop. Planting date affects not only the time from sowing to flowering but time from flowering to physiological maturity of grain sorghum (Clark, 1997).

Materials and Method

The experiment was carried out for five years during the *rabi* season from 2016-17 to 2020-21 at Dry Farming Research Station, Solapur (17.65° N 75° 90' E and 483.6 m MSL) on medium black soil (60 cm soil depth). The experiment was laid out in split plot design with four replications. Treatments were comprised of four sowing dates i.e. S_1: MW 36 (Sept.03-09) *Purva nakshtra*, S_2: MW 38 (Sept.17-23) *Uttara nakshtr*a, S_3: MW 40 (Oct.01-07) *Hasta nakshtr*a, S_4: MW 40 (Oct.15-21) *Chitra nakshtra*. Three sorghum genotypes i.e. V_1: M-35-1, V_2: Mauli and V_3: Yashoda were sown at spacing 45 cm x 15cm. The sowing of seed was done by dibbling method on respective date of sowing. Recommended packages of practices like thinning, weeding, application of recommended dose of fertilizer and pesticide were uniformly followed. Observations were recorded on five plants randomly selected per treatment. The soil of the experimental site was low in organic carbon (0.35%), medium in phosphorus (18.7 kg ha^{-1}) and high in potash content (540 kg ha^{-1}) with neutral pH (7.2). The crop was fertilized with 50:25:0 kg NPK ha^{-1}.

Results and Discussion

Growth and development of crop is influenced by environmental conditions such as temperature, radiation and photoperiod. The significant difference was recorded with different

Table 1. Pooled grain yield (kg ha^{-1}) of *rabi* sorghum as influenced by sowing dates and varieties 2016 to 2020

Treatment	2016-17	2017-18	2018-19	2019-20	2020-21	Pooled	SYI
Main = Sowing dates							
S_1 = MW 36 (Sept.03-09) *Purva nakshtra*	793.9	508.1	516.0	579.1	846.67	648.77	0.57
S_2 = MW 38 (Sept.17-23) *Uttara nakshtra*	897.4	618.2	583.3	701.6	926.92	745.46	0.63
S_3 = MW 40 (Oct. 01-07) *Hasta nakshtra*	1042.4	844.4	677.6	503.5	973.42	808.28	0.56
S_4 = MW 42 (Oct.15-21) *Chitra nakshtra*	480.9	434.0	379.9	357.2	424.24	415.25	0.76
Mean	803.7	601.2	539.2	535.4	792.81	654.44	0.63
Sub = Varieties							
V_1 = Maldandi (M-35-1)	884.3	659.1	594.3	588.5	863.56	717.94	0.64
V_2 = Mauli	770.2	573.2	514.8	534.3	801.44	638.79	0.62
V_3 = Yashoda	756.4	571.2	508.6	483.3	713.43	606.59	0.64
Mean	803.7	601.2	539.2	535.4	792.81	654.44	0.63
S.E.± (Sowing dates)	57.1	44.4	37.02	25.2	27.2	44.5	
C.D. at 5%	182.6	142.1	118.45	80.7	87.1	137.1	
S.E.± (Varieties)	33.3	23.9	22.16	19.6	23.3	10.3	
C.D. at 5%	97.1	69.6	64.69	57.3	68.1	29.7	
S.E.± (SD X V)	66.5	47.7	44.32	39.3	46.7	20.6	
C.D. at 5%	NS	NS	NS	NS	NS	NS	

interval of sowing in respect of grain yield, monetary returns, CUM, MUE, Tmax, Tmin etc.

Agronomical studies : Among all the sowing dates the crop sown at MW 40 (01-07th Oct) was produced maximum grain yield (808.29 kg ha^{-1}) and total monetary returns (Rs. 26633 ha^{-1}) over rest of the treatment (Table 1 and 3). These results are in concurrence with the findings of Hulihalli *et al* (2016). This indicates the hasta sown sorghum gets sufficient period for its biological development than the

Table 2. Pooled fodder yield (kg ha^{-1}) of *rabi* sorghum as influenced by sowing dates and varieties 2016 to 20

Treatment	2016-17	2017-18	2018-19	2019-20	2020-21	Pooled	SYI
Main = Sowing dates							
S_1 = MW 36 (Sept.03-09) *Purva nakshtra*	1500.3	1200.3	975.2	1125.86	1655.26	1291.40	0.61
S_2 = MW 38 (Sept.17-23) *Uttara nakshtra*	1642.9	1363.6	1126.0	1313.04	1894.91	1468.10	0.61
S_3 = MW 40 (Oct. 01-07) *Hasta nakshtra*	1711.3	1540.2	1145.1	975.35	2098.54	1494.11	0.49
S_4 = MW 42 (Oct.15-21) *Chitra nakshtra*	1116.0	1060.2	881.7	883.95	929.61	974.29	0.77
Mean	1492.7	1291.1	1032.0	1074.55	1644.58	1306.97	0.62
Sub=Varieties							
V_1 = Maldandi	1811.9	1572.2	1298.9	1298.71	1813.47	1559.03	0.71
V_2 = Mauli	1471.1	1275.1	995.2	1030.05	1634.07	1281.11	0.61
V_3 = Yashoda	1195.0	1026.0	801.9	894.89	1486.20	1080.79	0.54
Mean	1492.7	1291.1	1032.0	1074.55	1644.58	1306.97	0.62
S.E.± (Sowing dates)	106.6	94.6	61.8	46.3	68.0	83.2	
C.D. at 5%	341.2	302.7	197.8	148.2	217.6	256.2	
S.E.± (Varieties)	69.6	61.7	44.2	45.8	58.3	27.1	
C.D. at 5%	203.1	180.0	128.9	133.8	170.3	78.0	
S.E.± (SD x V)	139.2	123.3	88.3	91.7	116.7	54.2	
C.D. at 5%	NS	NS	NS	NS	NS	NS	

Table 3. Pooled total monetary returns (Rs. ha^{-1}) of *rabi* sorghum by sowing dates and varieties 2016 to 20

Treatment	2016-17	2017-18	2018-19	2019-20	2020-21	Pooled	SYI
Main = Sowing dates							
S_1 = MW 36 (Sept.03-09) Purva nakshtra	27349	18704	17777	23003	23706	22108	0.66
S_2 = MW 38 (Sept.17-23) Uttara nakshtra	30649	22273	19922	27611	25953	25281	0.68
S_3 = MW 40 (Oct. 01-07) Hasta nakshtra	34617	28810	22501	19982	27255	26633	0.60
S_4 = MW 42 (Oct.15-21) Chitra nakshtra	17603	16152	13906	15135	11878	14935	0.72
Mean	27555	21485	18527	21433	22198	22239	0.68
Sub = Varieties							
V_1 = Maldandi	31167	24338	21010	24147	24179	24968	0.68
V_2 = Mauli	26611	20706	17845	21179	22440	21756	0.69
V_3 = Yashoda	24886	19410	16725	18973	19975	19994	0.68
Mean	27555	21485	18527	21433	22198	22239	0.68
S.E.± (Sowing dates)	1665.7	1329.7	1084.5	937.9	7619	1352.9	
C.D. at 5%	5328.9	4254.0	3469.5	3000.5	2437.5	4168.7	
S.E.± (Varieties)	914.7	667.5	599.1	762.9	653.3	248.9	
C.D. at 5%	2669.7	1948.3	1748.6	2226.8	1906.9	716.9	
S.E.± (SD x V)	1829.3	1335.0	1198.1	1525.9	1306.6	497.7	
C.D. at 5%	NS	NS	NS	NS	NS	NS	

reproductive development, this might be due to uneven and inadequate distribution of rainfall and moisture during vegetative growth period of crops. It is also seen that as there was delay in sowing increase in consistency in grain yield production than the earlier sowing. This might be due to delayed sown crops were get uniform sufficient moisture for their development.

Among the varieties, M-35-1 was produced significantly higher grain yield (717.94 kg ha^{-1}) and total monetary returns (Rs.24968 ha^{-1}) over

Table 4. CUM and MUE as influenced by sowing time in *rabi* sorghum (2016 to 20)

Sowing time	CUM (mm)				MUE (kg ha^{-1} mm)			
	M-35-1	Mauli	Yashoda	Mean	M-35-1	Mauli	Yashoda	Mean
S_1	270	285	290	282	2.7	2.2	2.0	2.3
S_2	240	268	270	259	3.4	2.7	2.6	2.9
S_3	210	240	250	233	4.1	3.3	3.1	3.5
S_4	185	189	192	189	2.5	2.1	2.0	2.2
Mean	226	245	250	240	3.1	2.6	2.4	2.7

Table 5. Mean Growing degree days (GDD) required to attain phenological stages as influenced by sowing dates in *rabi* sorghum (2016 to 20)

Sowing time	Phenological stage						
	Emer.	3 leaf	Flag leaf	50 % flowering	Soft dough	Hard dough	Phy. maturity
S_1V_1	183	499	753	386	438	344	358
Cumulative	682	1252	1139	824	782	702	2963
S_1V_2	198	496	777	312	416	357	361
Cumulative	694	1273	1089	728	773	718	2920
S_1V_3	151	450	751	350	379	330	467
Cumulative	601	1201	1101	729	709	797	2893
S_2V_1	197	490	830	340	457	385	340
Cumulative	687	1320	1170	797	842	725	3041
S_2V_2	170	469	782	363	393	313	453
Cumulative	639	1251	1145	756	706	1066	2944
S_2V_3	198	440	730	365	419	335	380
Cumulative	638	1170	1095	784	754	715	2871
S_3V_1	168	463	833	393	433	337	432
Cumulative	631	1296	1226	826	770	769	3062
S_3V_2	197	434	778	395	461	361	367
Cumulative	631	1212	1173	856	822	728	2996
S_3V_3	161	450	751	350	379	330	467
Cumulative	611	1201	1101	729	709	797	2893
S_4V_1	187	477	747	302	402	382	369
Cumulative	664	1224	1049	704	784	751	2869
S_4V_2	187	398	706	358	399	351	392
Cumulative	585	1104	1064	757	750	743	2793
S_4V_3	183	506	799	335	435	367	332
Cumulative	689	1305	1134	770	802	699	2627

Table 6. Periodical radiation use efficiency (g MJ^{-1}) as influenced by varieties and sowing dates in sorghum (2016- to 2020)

MW	DAS	S_1			S_2			S_3			S_4		
		M.35-1	MAU	YESH	M.35-1	MAU	YESH	M.35-1	MAU	YESH	M.35-1	MAU	YESH
36	SO	SOW	SOW	SOW	-	-	-	-	-	-	-	-	-
38	14	0.42	0.34	0.28	-	-	-	-	-	-	-	-	-
40	28	0.78	0.62	0.66	0.45	0.31	0.27	-	-	-	-	-	-
42	42	1.55	1.42	1.40	0.72	0.55	0.58	0.54	0.43	0.34	-	-	-
44	56	2.41	2.33	2.11	1.38	1.25	1.26	0.95	0.88	0.88	0.39	0.18	0.15
46	70	2.65	2.60	2.58	2.38	2.09	2.26	1.90	1.83	1.80	0.60	0.41	0.46
48	84	2.60	2.44	2.56	2.60	2.62	2.45	2.18	2.37	2.22	1.27	1.10	1.10
50	98	2.16	2.04	2.05	2.70	2.60	2.50	2.72	2.61	2.60	2.32	1.86	2.08
51	105	2.07	1.86	1.75	2.48	2.38	1.90	2.60	2.11	2.03	2.39	2.38	2.28
1	119	1.82	1.57	1.67	2.39	2.11	1.71	2.53	1.93	1.69	2.50	2.10	2.08
3	133	0.42	-	-	2.16	1.67	1.52	2.24	1.61	1.87	2.40	2.00	1.80
5	147	-	-	-	1.85	-	1.38	2.10	1.36	1.51	1.76	1.65	1.56
6	154	-	-	-	-	-	-	1.44	-	0.34	1.35	1.44	1.39
7	161	-	-	-	-	-	-	-	-	-	1.30	-	1.40

the other variety. This might be due to M.35-1 was more effective in utilizing available moisture and weather for its growth and development than other varieties. Similar results were reported by Jadhav *et al.* (2010) and Mokashi *et al* (2008). This indicates that M.35-1 was more consistent in production of grain, biomass and total monetary returns than other variety (Table 3).

Meteorological studies : Growth and development of crop is influenced by environmental conditions such as temperature, radiation and photoperiod (Friend, 1966). The consumptive use of moisture (CUM) and moisture use efficiency (MUE) were presented in Table 4. Changing planting date could effluence on growth process with changing environment temperature (Dehghan, 2007). The mean CUM and MUE recorded by sorghum crop was 240 mm and 2.7 kg ha^{-1} mm. The highest CUM was recorded by S_1 sown crop (258 mm) however the MUE was recorded by S_3 sown crop (3.5 kg ha^{-1} mm). This indicated that S_3 sown crop (*Hasta Nakshtras*) utilized moisture more efficiently than other dates of sowing.

The number of days required to attain physiological maturity and growing degree days were higher in S_3 (2984) sown crop. Among the varieties it is higher in M35-1 (2983) than Mauli and Yashoda. This is due to more duration required by S_3 sown crop and M-35-1 variety.

The consumptive use of moisture (CUM) during total growth period of *Rabi* sorghum Fig. 1 showed a polynomial relationship with grain yield ($y=-0.0373 x^2 +15.477x - 737.45 R^2 = 0.8693$). The CUM of 240 mm was found to be optimum for getting higher grain yield. The RUE studies depicted in Fig. 2 showed linear relationship with grain yield. This indicated that radiation interception is directly related with grain yield ($y=1243.5x-5234.8x+5898.6$ R^2 =

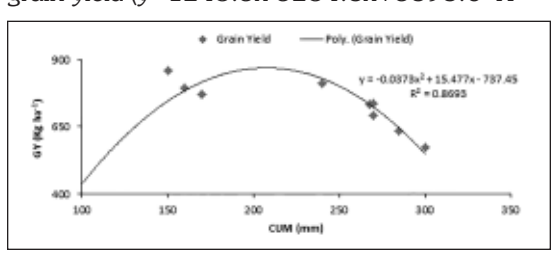

Fig. 1. Grain yield with CUM in Sorghum

0.8159). The figure showed that if RUE increases from 2.08 to 2.72 g mj^{-1}.

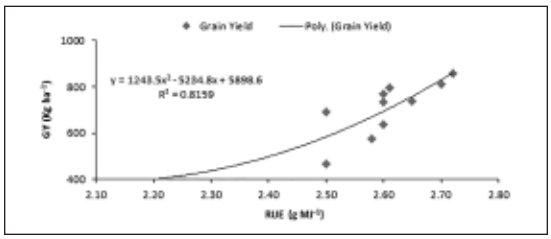

Fig. 2. Grain yield with RUE in Sorghum

The GDD was correlated with the grain yield of rabi sorghum and depicted in **Fig. 3.** It showed a linear relationship with grain yield (y=-0.0013 x^2 -6.3088 x-7826.8 R^2 = 0.7702). This indicated that with increase of GDD there was increase in grain yield upto 3082 GDD. The Tmax was correlated with the grain yield of rabi sorghum and depicted in **Fig. 4.** It showed a polynomial relationship with grain yield (y=31254 x^2 -2E+06+3E+07 R^2 = 0.8657). This indicated that with increase of T_{max} there was increase in grain yield upto 31.8°C and later on yield decrease with increase in T_{max}. The

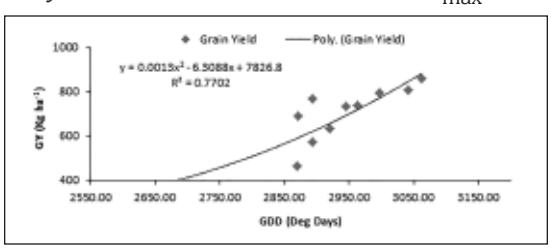

Fig. 3. Grain yield with GDD in Sorghum

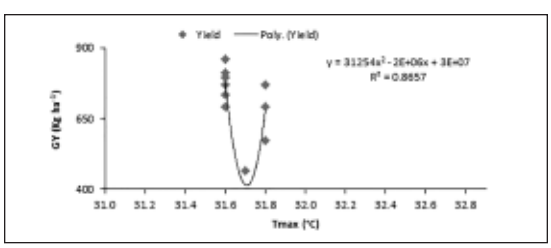

Fig. 4. Grain yield with Tmax in Sorghum

T_{min} was correlated with the grain yield of *rabi* sorghum and depicted in **Fig. 5.** It showed a polynomial relationship with grain yield (y=-191.12 x^2 + 6612x- 56367 R^2 = 0.7686). This indicated that with increase of T min there was increase in grain yield upto 17.5°C later on yield decrease with increase in T_{min}.

Initially the RUE values were low it increases

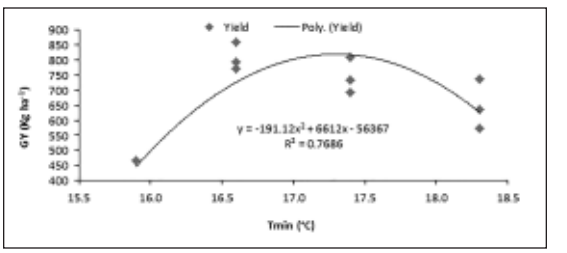

Fig. 5. Grain yield with Tmin in Sorghum

up to 70 DAS i.e. up to 50 percent flowering to soft dough stage further it decreases in all most all the sowing dates and varieties.

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Yield Prediction of Sunflower Using Regression Equation Under Changing Rainfall Situation in Scarcity Zone of Maharashtra

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Abstract

Present investigation entitled "Yield Prediction of sunflower using regression equation under changing rainfall situation in scarcity zone of Maharashtra." was carried out during 2016-20 at Zonal Agricultural Research Station, Solapur, Mahatma Phule Krishi Vidyapeeth, Rahuri Maharashtra State (India). The experiment was conducted in split plot design with three replications. Nine treatment combinations were formed considering different cultivars *viz*., V_1 Bhanu, V_2 MSFH-17 and V_3 Phule Bhaskar and sowing windows *viz*., (S_1) 2nd fortnight of June (25th - June), (S_2) - 2nd fortnight of July (27th - July), (S_3) - 2nd fortnight of August (24th - August). Among the three sunflower sowing window crop sown in second fortnight of July (S_2) produced significantly highest grain yield (1377.9 kg ha^{-1}) and total monetary returns (52,154/- kg ha^{-1}), CUM (326 mm), MUE (4.33 Kg ha^{-1} mm), GDD (19170 days), RUE July (1.79 g MJ^{-1}) than other dates of sowing. Among the genotypes Phule Bhaskar produced significantly higher grain yield (1200.0 kg ha^{-1}), total monetary returns (Rs. 44675/- ha^{-1}), CUM (314.8 mm), MUE (4.23 Kg ha^{-1} mm), mean number of days to attain physiological stages (92 days), GDD (18150 days).The correlation study revealed that the wind speed had significant positive correlation at emergence phase (P_1) and 3 leaf stage (P_2). Tmax had significant positive influence and RH-I, RH-II and RF has significant negative influence at button phase (P_3).Under changing rainfall situation sowing of *Kharif* sunflower contingent crop in second fortnight of July i.e. 16th July to 29th July (MW 30-31) in medium deep soil of scarcity zone of Maharashtra is recommended. Following regression equation based on weather parameters for predicting the yield (prior to 2 weeks) is recommended. Yield=-86.802-3.860 x Tmin + 2.332 x RH-1-0.182 x RH-2 -0.076 x RF +0.370 x Epan

Key words : *Kharif* sunflower, sowing windows, yield attributes, cultivars.

Oil seed crops play an important position next to food grains in Indian economy. The oil not only forms an essential part in human diet but also serves as an important raw material for manufacture of various products like flavour enhancers, lubricants etc. Sunflower (*Helianthus annuus* L.) is one of the most popular members of the family Asteraceae and is one of the world's most important sources of vegetable oil and It is a rich source of edible oil (40-52%) having anticholesterol properties (Joksimovic *et al*., 2006). The native of the sunflower is reported to be Southern parts of USA and Mexico. Sunflower (*Helianthus annuus*, L), is an important oil crop worldwide. Moreover, it's hardy and superior to sorghum (*Sorghum bicolar* L) in drought tolerance (Rachid *et al*., 1993). Under dryland conditions, sunflower extracts water from deeper soil profile to enable the crop tolerate prolonged dry periods (Unger *et al*., 1976; Meinke *et al*., 1993). Also, crop is well adopted by the farming community because of its desirable attributes such as short duration, photoperiod insensitivity, adaptability to wide range of soil and climatic conditions, drought tolerance, lower seed rate, higher seed multiplication ratio and high quality of edible oil (45-50%) (Reddy *et al*., 2007).

Materials and Methods

The study was conducted at research farm of Zonal Agricultural Research Station, Solapur,

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Mahatma Phule Krishi Vidyapeeth, Rahuri, Maharashtra State (India) during in year 2016-2020 in the *Kharif* season. The area is positioned at 75° 65' N latitude 75° 90'E longitude and at the altitude of 483.6 meters above the sea level. The experiment was conducted in split plot design with three replications. Nine treatment combinations were formed considering different cultivars *viz*., V_1 Bhanu, V_2 MSFH-1 and V_3 Phule Bhaskar and sowing windows *viz*., (S_1) 2nd fortnight of June (25th - June), (S_2) - 2nd fortnight of July (27th -July) S_3 - 2nd fortnight of August (24th - August). The soil comes under the vertisol (medium black) clayey loam in texture and slightly alkaline (pH-7.4) in nature and having the depth up to 90 cm. The monsoon lasts from June to the end of September, with moderate rainfall. It has an average rainfall of about of 545 mm year^{-1}. The annual maximum and minimum temperature ranged between 25.0 to 43.2°C and 7.3 to 27.1°C, respectively. The gross and net plot sizes were 6.0 x 4.5 m^2 and 4.2 x 3.6 m^2, respectively. All the cultivars were dibbled as per different sowing windows at a spacing of 45 cm x 20 cm.

Results and Discussion

Agronomical studies : The crop sown in second fortnight of July (S_2) produced

Table 1. Mean grain yield (kg ha^{-1}) of *Kharif* Sunflower as influenced by various sowing dates and varieties (2015 to 2020)

Treatment	2015	2016	2017	2018	2020	Mean	Sur/def (%)	SYI
Main=3 Sowing dates								
S_1 = MW 26 (June 26-July 01) 2nd fortnight of June	491.1	1467.4	880.4	1270.4	1153.9	1052.6	1.6% less over mean	0.39
S_2 = MW 30 (July 23-29 July) 2nd fortnight of July	827.7	1978.9	1187.3	1469.9	1426.0	1377.9	28.7% high over mean	0.52
S_3 = MW 35 (August 27-Sept 2) 2nd fortnight of Aug	543.7	849.1	509.5	977.4	1020.4	780.0	27.1% less over mean	0.48
Mean	620.8	1431.8	859.1	1239.2	1200.1	1070.2		0.46
Sub=3 Varieties								
V_1 = Bhanu	605.9	1159.9	696.0	1063.4	1038.0	912.6	14.7% less over mean	0.46
V_2 = MSFH-17	576.8	1559.3	935.6	1201.9	1216.2	1098.0	2.6% high over mean	0.46
V_3 = Phule Bhaskar	679.7	1576.1	945.7	1452.3	1346.0	1200.0	12.1% high over mean	0.47
Mean	620.8	1431.8	859.1	1239.2	1200.1	1070.2		0.46
Sub-Sub= 2 Treatments								
T_1 = Protected	718.3	1600.6	960.3	1422.7	1362.90	1213.1	13.3% high over mean	0.48
T_2 = Unprotected	523.3	1263.0	757.8	1055.7	1037.30	927.4	13.3% less over mean	0.44
Mean	620.8	1431.8	859.1	1239.2	1200.1	1070.2		0.46
S.E.± (Sowing dates)	14.8	36.8	22.1	33.2	43.20	118.9		
C.D. at 5%	58.1	144.5	86.7	130.4	169.6	387.8		
S.E.± (Varieties)	26.4	35.6	21.4	42.3	42.00	37.4		
C.D. at 5%	81.3	109.6	65.8	130.4	129.40	109.1		
S.E.± (SD x V)	45.7	61.6	37.0	73.3	72.7	64.7		
C.D. at 5%	NS	189.9	113.9	225.8	NS	NS		
S.E.± (Treatment)	18.4	45.6	27.4	26.2	25.7	18.0		
C.D. at 5 %	54.7	135.6	81.3	77.8	76.2	51.6		
S.E.± (SD x Treatment)	31.9	79.0	47.4	45.3	44.4	31.2		
C.D. at 5%	94.8	NS	NS	134.7	NS	NS		
S.E.± (Treatment x Variety)	31.9	79.0	47.4	45.3	77.0	31.2		
C.D. at 5%	NS	NS	NS	NS	NS	NS		

significantly highest grain yield (1377.9 kg ha^{-1}) and total monetary returns (52154/- kg ha^{-1}) than other dates of sowing. These findings are in confirmative with those reported by Keshta *et al*., (2006), Dhanasekar *et al*., (2012) and Khan *et al*., (2016). In general pearl millet can be sown up to second fortnight of August (S_3). It was revealed from that the crop sown at second fortnight of July (S_2) produced significantly higher grain yield and total monetary returns with high degree of sustainability. These results are in close agreement to the findings of Kawade *et al.* (2018). It might be due to crop sown at second fortnight of July (S_2) gets sufficient period for its biological and reproductive development and ultimately resulted into higher grain yield and total monetary returns. It also indicates that crop sown at second fortnight of June (S_1) get sufficient uniform availability of moisture during its life span helps for better yield and monetary benefits. However among the genotypes Phule Bhaskar produced significantly higher grain yield (1200.0 kg ha^{-1}) and total monetary returns (Rs. 44675/- ha^{-1}). This indicates sustainability of Phule Bhaskar variety over other varieties. This might be due to short duration life span of Phule Bhaskar than other varieties and at reproductive stage MSFH-17 and Bhanu might be faced moisture stress condition.

Meteorological studies : The mean

Table 2. Mean total monetary returns of Kharif Sunflower as influenced by various sowing dates and varieties (2015 to 2020)

Treatment	2015	2016	2017	2018	2020	Mean	SYI
Main = 3 Sowing dates							
S_1 = MW 26 (June 26-July01) 2nd fortnight of June	21925	47686	33457	48275	37294	40753	0.55
S_2 = MW 30 (July. 23-29) 2nd fortnight of July	33216	58450	45118	55855	45615	52154	0.64
S_3 = MW 35 (August 27-Sept 2) 2nd fortnight of August	20650	23059	19360	37140	26864	25436	0.49
Mean	25263	43065	32645	47090	36591	39447	0.56
Sub=3 Varieties							
V_1 = Bhanu	25061	37076	26446	40410	30200	33486	0.56
V_2 = MSFH-17	23357	43305	35553	45672	35003	40181	0.56
V_3 = Phule Bhaskar	27372	48813	35936	55188	44567	44675	0.57
Mean	25263	43065	32645	47090	36591	39447	0.56
Sub-Sub = 2 Treatments							
T_1 = Protected	29039	48476.3	36493	54062	42920	44483	0.57
T_2 = Unprotected	21487	37653.3	28797	40118	30261	34412	0.55
Mean	25263	43065	32645	47090	36591	39447	0.56
S.E.± (Sowing dates)	559.3	3727.0	839.0	1262.2	1043.3	3038.1	
C.D. at 5%	2195.9	12154.5	3294.5	4955.8	4096.5	9907.9	
S.E.± (Varieties)	1009.5	1272.8	811.3	1607.9	1346.5	1271.1	
C.D. at 5 %	3110.5	3715.2	2499.9	4954.6	4149.0	3710.0	
S.E.± (SD x V)	1748. 5	2204.6	1405.2	2785.0	2332.2	2201.6	
C.D. at 5%	NS	NS	4330.0	8581.6	7186.2	NS	
S.E.± (Treatment)	681.6	772.5	1040.2	994.5	878.0	643.5	
C.D. at 5%	2025.2	2215.5	3090.7	2954.7	2608.8	1845.6	
S.E.± (SD x Treatment)	1180.6	1337.9	1801.7	1722.5	1520.8	1114.6	
C.D. at 5%	3507.7	NS	NS	5117.8	4518.6	NS	
S.E.± (Treatment x Variety)	1180.6	1337.9	1801.7	1722.5	2634.1	1114.6	
C.D. at 5%	NS	NS	NS	NS	NS	NS	

Table 3. CUM and MUE as influenced by different treatments in *Kharif* sunflower (2015 to 2020)

Treatment	GY (kg ha^{-1})	CUM (mm)	MUE (kg ha^{-1} mm)
$S_1V_1T_1$	1208	300.0	4.0
$S_1V_1T_2$	776	280.0	2.8
$S_1V_2T_1$	1228	320.0	3.8
$S_1V_2T_2$	1122	300.0	3.7
$S_1V_3T_1$	1385	329.0	4.2
$S_1V_3T_2$	1204	300.0	4.0
$S_2V_1T_1$	1564	330.0	4.7
$S_2V_1T_2$	959	270.0	3.6
$S_2V_2T_1$	1640	340.0	4.8
$S_2V_2T_2$	1213	320.0	3.8
$S_2V_3T_1$	1729	360.0	4.8
$S_2V_3T_2$	1451	340.0	4.3
$S_3V_1T_1$	1027	250.0	4.1
$S_3V_1T_2$	693	230.0	3.0
$S_3V_2T_1$	1151	280.0	4.1
$S_3V_2T_2$	944	260.0	3.6
$S_3V_3T_1$	1333	300.0	4.4
$S_3V_3T_2$	974	260.0	3.7

consumptive use of moisture CUM (326.6 mm) and mean moisture use efficiency MUE (4.33 Kg ha^{-1} mm) was significantly higher recorded by crop sown in second fortnight of July (S_2) over rest of the sowing windows. It indicates that early and delay in sowing of crops results in recording low value of CUM and MUE. This might be due to July sown crop gets sufficient period to utilize available soil moisture along with good weather for grain production. Being thermo-sensitive and short day plant, sowing time affect phenology of the crop from adoption to the time of maturity (Kumar and Badiyala, 2005). Phule Bhaskar recorded highest mean value of CUM (314.8 mm) and MUE (4.23 Kg ha^{-1} mm). This indicates that the Phule Bhaskar variety utilized the moisture most efficiently for productions of grains. The mean number of days required to attain the physiological maturity stages recorded higher in July sown crop (S_2) (Table 4). This might be due to more favorable conditions prevailed in case early sown crop and

Table 4. Number days required to attain phenological stages as influenced by sowing dates in sunflower (2015 to 2020)

Sowing time	Phenological stage						
	Emer.	4 leaf	Button	50 % flowering	Soft dough	Hard dough	Phy. maturity
S_1V_1	8	6	25	11	8	8	7
Cumulative	8	14	39	50	58	66	73
S_1V_2	7	8	26	10	8	7	6
Cumulative	7	15	41	51	59	66	72
S_1V_3	6	7	24	11	7	6	6
Cumulative	6	13	37	48	55	61	67
S_2V_1	7	7	28	12	8	7	7
Cumulative	7	14	42	54	62	69	76
S_2V_2	8	7	30	13	8	10	8
Cumulative	8	15	45	58	66	76	84
S_2V_3	8	8	32	13	11	12	8
Cumulative	8	16	48	61	72	84	92
S_3V_1	7	6	27	11	7	10	7
Cumulative	7	13	40	51	58	68	75
S_3V_2	6	7	29	12	8	8	8
Cumulative	6	13	42	54	62	70	78
S_3V_3	7	10	30	11	9	8	7
Cumulative	7	17	47	58	67	75	82

Table 5. Growing degree days required to attain phenological stages as influenced by sowing dates in sunflower (2015 to 2020)

Sowing time	Phenological stage						
	Emer.	4 leaf	Button	50 % flowering	Soft dough	Hard dough	Phy. maturity
S_1V_1	174	150	604.48	242	202	206	160
Cumulative	325	475	1080	1323	1525	1731	1892
S_1V_2	174	171	626	220	223	268	214
Cumulative	345	517	1143	1363	1587	1855	2070
S_1V_3	174	150	583	223	203	206	162
Cumulative	325	475	1059	1282	1485	1691	1854
S_2V_1	165	166	591	242	199	203	162
Cumulative	332	499	1090	1332	1532	1735	1898
S_2V_2	145	166	653	258	181	245	239
Cumulative	311	477	1131	1390	1572	1817	2057
S_2V_3	165	145	591	225	155	205	163
Cumulative	311	456	1048	1273	1428	1633	1797
S_3V_1	184	144	625	278	187	179	147
Cumulative	328	472	1097	1376	1563	1742	1890
S_3V_2	163	165	645	258	169	216	214
Cumulative	328	493	1138	1397	1566	1782	1997
S_3V_3	162	144	582	239	194	183	143
Cumulative	307	452	1034	1274	1469	1652	1796

vice versa. Phule Bhaskar required more mean number of days to attain physiological stages (92 days) than MSFH-17 (84 days) and Bhanu (78 days). This indicates Phule Bhaskar variety required more number of days to attain physiological maturity than other varieties during *kharif* season under dryland conditions.

The growing degree days (GDD), the function of maximum, minimum and base temperature were presented in Table 5. The crop sown in second fortnight of July (S_2) recorded highest mean value of growing degree days (GDD) (19170 days) than other windows of sowing. It indicates that as a GDD is a function of temperature, during July (S_2) sown crop might be grown under high temperature condition and hence recorded highest values of GDD. Further, it is seen that S_2 sown crop required more growing degree days to attain physiological maturity. Sattar *et al.*, 2017 revealed that variation in phenophase duration caused by changes of sowing dates, which led to early or delayed fulfillment of thermal requirements to attain a particular phenological

Table 6. Periodical dry matter (g m^{-2}) and its partitioning into different parts of sunflower (2015 to 2020)

Sowing time	Growth stage					
	4 leaf	Button	50 % flowering	Soft dough	Hard dough	Phy. maturity
S_1V_1	1.8	62.3	111.0	166.4	217.2	285.2
S_1V_2	1.6	73.3	116.2	186.0	229.0	318.9
S_1V_3	1.9	83.8	134.1	211.0	276.5	357.2
S_2V_1	1.9	88.5	149.1	235.7	315.6	369.4
S_2V_2	2.3	93.5	156.3	260.8	334.9	398.6
S_2V_3	2.0	106.7	174.6	295.0	373.3	434.4
S_3V_1	1.6	73.5	142.3	223.9	317.7	356.4
S_3V_2	1.7	91.8	150.3	254.9	337.7	387.5
S_3V_3	2.0	99.8	168.4	279.3	364.5	420.8

Table 7. Radiation use efficiency (g MJ^{-1}) by sowing dates in sunflower (2015 to 2020)

Sowing time	Growth stage					
	4 leaf	Button	50 % flowering	Soft dough	Hard dough	Phy. maturity
S_1V_1	0.11	0.51	1.40	1.22	0.94	0.36
S_1V_2	0.13	0.59	1.55	1.37	1.28	0.47
S_1V_3	0.14	0.63	1.64	1.55	1.40	0.61
S_2V_1	0.12	0.51	1.74	1.54	1.33	0.69
S_2V_2	0.09	0.55	1.80	1.66	1.45	0.89
S_2V_3	0.12	0.61	1.84	1.71	1.51	0.95
S_3V_1	0.08	0.48	1.20	0.91	1.02	0.48
S_3V_2	0.09	0.51	1.20	0.94	1.11	0.51
S_3V_3	0.11	0.55	1.60	0.98	1.23	0.55

stage in soybean crop. However, among the varieties the values of mean GDD were higher in Phule Bhaskar (18150 days) followed by MSFH-17 and Bhanu variety. This is due to more duration required by S_2 sown crop and Phule Bhaskar variety. Further, it was also noticed that the early sown crop not received fairly good amount of rainfall during its growth period due to which soil moisture available was less, however, late sown crop favours due to moisture availability during flowering and grain filling stage which resulted in more duration required for maturity and good yield. In short the second fortnight of July (S_2) sown crop required more number of days to attain various growth stages. This is due to existence of favorable condition for crop growth and development. This is because the GDD which is function of temperature which in turn is a function of bright sunshine hours.

The mean maximum values of total dry matter were recorded by S_2 sown crop i.e. 400.8 g m^{-2} over rest of the sowing windows. Data revealed that as the delay in sowing of *kharif* sunflower there is considerable reduction in mean total dry matter. Among the genotype Phule Bhaskar variety recorded highest values of mean total dry matter (404.1 g m^{-2}) in almost all the growth stage than the other varieties (Table 6). This indicates that the Phule Bhaskar utilized more efficiently moisture, light and temperature and produced maximum total dry matter by maximum solar radiation interception.

The highest mean values of RUE recorded by the crop sown in second fortnight of July (1.79 g MJ^{-1}) (Table 6) at 50 per cent flowering stage in almost all the sowing dates and genotypes. It was also revealed that with delayed sowing recorded low mean values of LAI and RUE. This indicated that the rate of conversion of light i.e. photosynthetically active radiation (PAR) was considerably high at 50 per cent flowering stage, thereafter the conversion rate was declined due to ageing of leaves. Among the sowing windows maximum mean RUE values were higher in July sown crop than late sown crop. Further, it was seen that Phule Bhaskar showed higher values

Table 8. Correlation coefficient between grain yield and different weather parameters during different phenophases of kharif sunflower

Phenophase	MAXT (°C)	MINT (°C)	RH1 (%)	RH2 (%)	WS (kmph)	RF (mm day^{-1})	SS (hrs day^{-1})	EVP (mm day^{-1})
P_1	-0.260	0.184	-0.221	0.342	0.694**	-0.071	-0.464	0.331
P_2	-0.233	0.207	-0.428	-0.157	0.512*	-0.044	-0.326	0.216
P_3	0.626**	0.334	-0.732**	-0.560*	0.400	-0.704**	-0.020	0.428
P_4	-0.453	0.508*	0.544*	0.623**	0.336	0.248	-0.519*	0.544*
P_5	-0.509*	0.592**	0.710**	0.657**	0.154	0.754**	-0.450	0.576*
P_6	0.342	0.377	0.311	0.146	0.042	0.281	0.074	0.763**
P_7	0.353	0.268	0.094	0.182	-0.041	-0.040	-0.049	0.246

of RUE (1.69 g MJ^{-1}) than MSFH-17 and Bhanu variety for conversion of light into dry matter in all the dates of sowing (Table 6). The July (S_2) sown crop has taken maximum number of days than late sown crops to attain the different growth stages during the crop growth period. This is due to better amount of moisture available and low values of temperature during the crop growth period of July sown crops. The same trend was obtained in case of GDD this indicates that GDD is a function of bright sunshine hours which reflected into a better grain yield.

Correlation Regression Studies : The weather parameter influence their contribution and performance in *Kharif* sunflower crop sown in different sowing windows were assessed.

The influences of weather parameter and agrometeorological indices on performance of *kharif* sunflower crop sown at different windows with different varieties were assured in terms of phase-wise correlation of grain yield with mentioned weather parameters. It is revealed that the wind speed had significant positive correlation at emergence phase (P_1) and 3 leaf stage (P_2). Tmax had significant positive influence and RH-1, RH-2 and RF has significant negative influence at button phase (P_3). Significant positive correlation was found with Tmin, RH-1, RH-2 and Epan while BSS has significant negative correlation at 50 % flowering stage (P_4). Tmax had significant negative influence and Tmin, RH-I, RH-II, RF and Epan has significant positive influence at soft dough phase (P_5) while at hard dough stage (P_6) Epan had significant positive association with grain yield.

Significant negative association with grain yield by Tmin, RH-I, RH-II and RF at button phase (P_3) indicates that at early growth stages *Kharif* sunflower not favour moisture stress condition. Significant positive association with grain yield at 50 % flowering stage by Tmin, RH-I, RH-II, RF and Epan indicates *Kharif* sunflower responds well to available moisture and low temperature conditions. It is revealed that button phase (P_3) and 50% flowering stage (P4) are more crucial growth stages to contribute grain production.

It is observed that the significantly positive correlation (Table 9) of weather parameters namely Tmin, RH-I, RH-II and RF with grain yield at soft dough phase. The predicted grain yield and actual pooled grain yield is presented in Table 10. The regression equation is developed by using this weather parameters i.e. Yield=-86.802-3.860 x Tmin+2.332 x RH-1-0.182 x RH-2 -0.076 x RF +0.370 x Epan. This equation is helpful to predict grain yield after completion of soft dough phase (P_5).

The consumptive use of moisture (CUM) during total growth period of *kharif* Sunflower Fig. 1 showed a linear relationship with grain yield (y=7.2534 x -963.44 R^2 = 0.8279). The CUM of 326.6 mm was found to be optimum for getting higher grain yield. The moisture use efficiency (MUE) during total growth period of *kharif* sunflower Fig. 2 showed a linear relationship with grain yield y = 477.1 x -698.48 R^2 = 0.8665). The MUE of 4.33 kg ha mm^{-1} was found to be optimum for getting higher grain yield.

The RUE studies depicted in **Fig. 3** showed

Table 9. Stepwise multiple regression of different weather parameters with yield of kharif sunflower at soft dough stage (2012 to 2017)

Weather parameter	Regression coefficient	R^2
Intercept	-87.801	0.70
Minimum Temperature (T_{min})	-3.864	
Relative Humidity (RH-1)	2.338	
Relative Humidity (RH-2)	-0.185	
Rainfall (RF)	-0.077	
Epan	0.372	

Table 10. Observed and predicted yield by using linear regression equations.
√Yield=-86.802 - 3.860 x Tmin + 2.332 x RH-1 - 0.182 x RH-2 - 0.076 x RF + 0.370 x Epan

Treatment	Actual yield	Predicted yield	Residuals	Standardized residual
Main treatment - Sowing time				
S_1 = MW 26 (June 26-July 01) 2nd fortnight of June	1481.8	1473.0	8.8	-0.248
S_2 = MW 30 (July 23-29) 2nd fortnight of July	1763.5	1744.8	18.7	1.101
S_3 = MW 35 (August 27-Sept 2) 2nd fortnight of August	995.1	990.8	4.3	-0.853
Sub treatment - variety				
V_1 = Bhanu	1228.1	1298.4	-70.3	-1.007
V_2 = MSFH-17	1425.6	1335.2	90.4	0.993
V_3 = Phule Bhaskar	1586.7	1575.0	11.7	0.014
Sub-Sub = 2 Treatments				
T_1 = Protected	1601.3	1402.9	198.4	0.707
T_2 = Unprotected	1225.7	1402.9	-177.2	-0.707

Standard Residual > 3 and < -3 is outleter, T_{min} = Min. Temperature (°C), RH-I = Morning relative humidity (%), RH-II = Evening relative humidity (%), RF = Rainfall (mm)

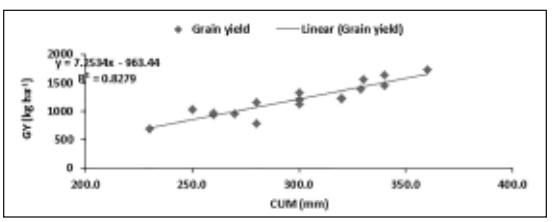

Fig. 1. Grain yield with CUM in Sunflower

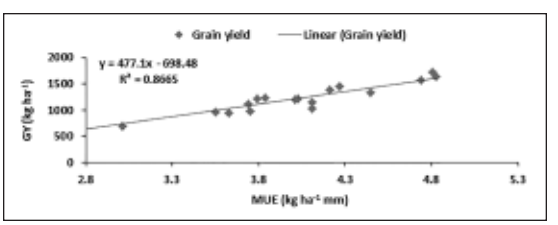

Fig. 2. Grain yield with MUE in sunflower

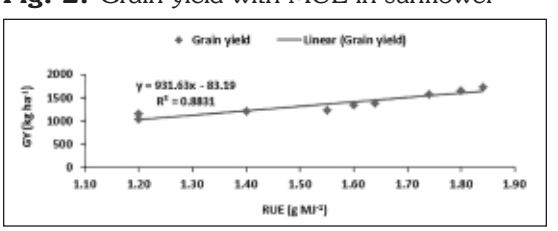

Fig. 3. Grain yield with RUE in Sunflower

linear relationship with grain yield. This indicated that radiation interception is directly related with grain yield (y = 931.63 x –83.19 R^2 = 0.8831). The figure showed that if RUE increases from 1.7 to 1.8 g mJ^{-1} it increases the yield .

The GDD was correlated with the grain yield of sunflower and depicted in Fig. 4. It showed a linear relationship with grain yield (y= 2.2611 x -2971.9 R^2 = 0.9521). This indicated that with increase of GDD there was increase in grain yield.

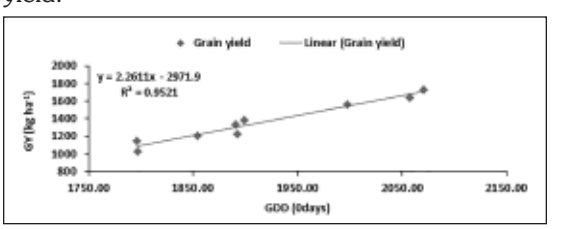

Fig. 4. Grain yield with GDD in Sunflower

The Tmax was correlated with the grain yield of sunflower and depicted in Fig. 5. It showed a polynomial relationship with grain yield (y = -4347.3 x 2 -284109 x + 5E + 06 R^2 = 0.7854). This indicated that with increase of T_{max} there was increase in grain yield up to 32.3°C. The T_{min} was correlated with the grain yield of sunflower and depicted in Fig. 6 It

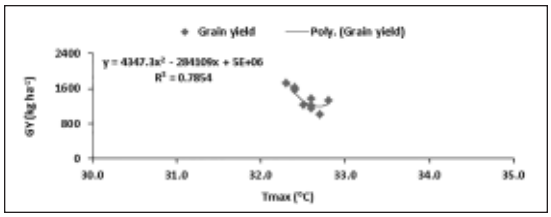

Fig. 5. Grain yield with T_{max} in sunflower

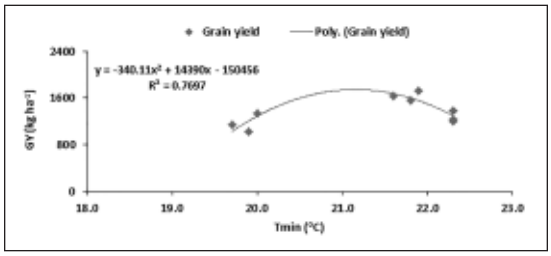

Fig. 6. Grain yield with T_{min} in sunflower

showed a polynomial relationship with grain yield (y=-340.11 x^2 + 14390 x-150456 R^2 = 0.7697). This indicated that with increase of Tmin there was increase in grain yield upto 21.3°C.

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Effect of Seasonal Variations and Different Organic Wastes on Growth Parameters and Fecundity of *E. fetida*

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Abstract

Earthworms are major contributors to soil biodiversity; they are the basic driver of abiotic and biotic soil properties, also known as important ecosystem engineers in terrestrial soils. Their feeding, damming and casting affects pedogenesis, soil structure, water regulation, bioremediation of toxins, distribution of organic matter and soil structure. *E. fetida*, an exotic species also known as the red wriggler, has been shown to have wide international potential for converting organic waste into high-value compost useful for plant growth media called vermicomposts. These red worms are active year-round and can tolerate a wide range of temperature and humidity fluctuations. These worms have strong capacity to survive due to its regenerative capacities and this capacity depends on the amputation site, ambient conditions and developmental stages involved. Worm growth patterns in different types of organic wastes have been investigated by various authors in laboratory studies. Animal manure is used as the main substrate for *E. fetida*. They can easily multiply on a variety of organic wastes in a short generation time and are therefore a standard test organism used in terrestrial ecotoxicology.

Key words : Bioremediation, E. fetida, ecotoxicology, pedogenesis, vermicomposts.

Earthworms are categorized into 23 families, representing more than 700 genera and more than 7,000 species worldwide, however the actual number of earthworm species is significantly larger than what is reported. Earthworms are members of the phylum annelida, and they are assigned to the class oligachaeta. Exotic earthworms drastically alter the composition of the soil's microbial community by reducing the amount of fungal growth and increasing the amount of bacteria, according to Dempsey *et al*. (2011). In soil, earthworms and microbes work together in harmony. Vermicomposting refers to the ability of earthworms to transform organic wastes into useful compost, which is advantageous for environmentally friendly farming methods. Many nutrients in vermicompost are available to be used by earthworms, such as exchangeable phosphorous, nitrate, and soluble potassium, magnesium, and calcium. By considerably increasing the amount of minerals like nitrogen, phosphorus, and potassium and lowering the pH, electrical conductivity, and carbon to nitrogen ratio, earthworms increase biofertility. Utilizing *Eisenia fetida* reduces the pollution risk brought on by the degradation of organic wastes. It serves as the standard earthworm in tests for global toxicity (Nahmani *et al*. 2007). At higher temperatures, temperate species are frequently more susceptible than tropical ones, and conversely at lower temperatures (Lee, 1985). A temperature beyond 40 °C will entirely halt the development of juvenile earthworms and also diminish the formation of cocoons. Below 10 °C, earthworm feeding activities have been found to decrease (Edwards and Bohlen 1996., Satchell 1967) The activity of earthworms may be restricted at temperatures of 5°C or below, depending on the species. However, after reaching reproductive maturity, Presley *et al*. (1996) found that *E. fetida*'s

maximum growth and survival rates occurred at moderate/high humidity and low temperatures. At higher temperatures of more than 40 °C, temperate species are frequently more susceptible than tropical ones, and conversely at lower temperatures (Lee.1985).

Materials and Methods

Collection of the test animal : Earthworm culture of *E. fetida* was maintained for use of third generation earthworms to avoid pre-exposure or residual effects of agrochemicals at vermicomposting unit of Institute of Zoology, CCSHAU, Hisar. Mature and fully clitelate earthworms were used for experiments to evaluate the effect of herbicides on growth and reproductive potential.

Collection of Substrate : The dung used as substrate was obtained from the Biogas Station of the Department of Microbiology, CCS HAU, Hisar. To exclude the harmful effect of noxious gases and temperature rise during vermicomposting, cow dung was pre-decomposed for 15 days prior to the study.

A total of three organic wastes viz. cow dung, buffalo dung and a mixture of both were used as substrates after pre-decomposition for 15 days. Three replicates of each treatment were maintained in 90 liter containers at the Vermicompost Unit of the Department of Zoology and Aquaculture, CCSHAU Hisar. Tubs with different finishes have been marked for recording.

Twenty healthy clitellated earthworms (*E. fetida*) were randomly selected and released into each bath after washing and weighing. Moisture content in all treatments was maintained regularly by sprinkling water as needed.

The experiment took place in the summer and winter seasons. Earthworms were sampled after 30 days and regularly up to 90 days. Length, total number of adults/cocoons and total weight of earthworms were recorded.

Results

Survivability of earthworms : Current research has revealed the effect of seasonal changes and different organic wastes on the growth and reproduction of earthworms. The substrate mixture of cow and buffalo dung showed maximum growth in both seasons as shown in Table 1 and Fig. 1. Relatively maximum numbers of adult earthworms, 48 and 19.3 were recorded in summer season and winter season, respectively on day 90. Individually, buffalo dung showed better growth in summer season with 39.3 earthworms on day 90 and cow dung in winter with 13.6 earthworms. The correlation effect of temperature and humidity on earthworm survival was found to be insignificant in both seasons. (Table 2)

Number of cocoons : Maximum numbers of cocoons were found in combined substrate of cow and buffalo dung during summer season than winter. *E. fetida* produced 69.6 and 24 cocoons during the summer season and 24 cocoons. Individually, *E. fetida* produced 48.6 and 36 cocoons in buffalo and cow dung, respectively, during the summer season. But the reproduction rate decreased to 18 and 20.3 cocoons during the winter season in buffalo and cow dung, respectively, on the 90th day of the experiment.

Length of earthworm : Maximum increase in worm length was observed with buffalo + cow dung combination in summer season as compared to winter. A low increase in length (7.2 cm) was recorded in cow dung during the summer season and 5.9 cm in buffalo dung during the winter season on day 90 of the experiment.

Body weight of Earthworm : Maximum

Table 1. Effect of different seasons and substrate on adult earthworms, *E. fetida*

Treatments	Season							
	Summer				Winter			
	Time Interval							
	30 days	60 days	90 days	Mean	30 days	60 days	90 days	Mean
Cow + buffalo dung	19.6	36.6	48	34.7	12.6	18	19.3	16.6
Buffalo dung	18.6	28.6	39.3	30.6	5.6	10.3	9.0	7.2
Cow dung	17.6	20.6	27.6	21.9	8.6	10.3	13.6	10.8
Mean	18.6	28.6.	36.3		8.9	11.7	18.6	
Overall Mean	28.5	11.5						

Factors	C.D.
Season	1.571
Time interval	1.924
Interaction (Season x Time interval)	2.72
Substrate	1.924
Interaction (Season x Substrate)	NS
Interaction (Time interval x Substrate)	3.332
Interaction(Season x Time interval x Substrate	4.712

mean body weight was achieved by the adult earthworms in combination of cow + buffalo dung in both seasons but comparatively maximum (0.82 gms) gain was recorded in summer season and (0.52 gms) in winters on 90th day of experiment. Individually, gain in body weight was 0.61gms and 0.54gms in buffalo dung and cow dung respectively, in summer season and it was 0.37 gms and 0.44 gms respectively on 90th day of experiment in winter season.

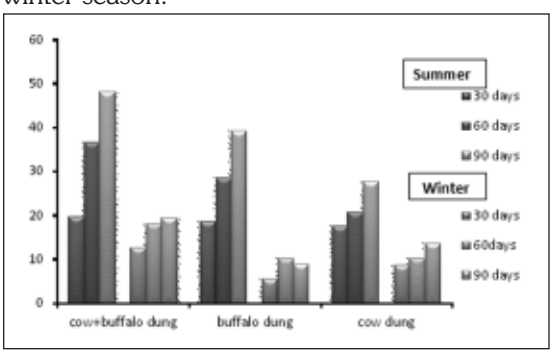

Fig. 1. Effect of different seasons and substrate on adult earthworms, *E. fetida*.

Discussion

E. fetida showed a significant increase in the mixture of buffalo and cow dung during the present research and this mixture initiated pupa production, clitellum development, length and weight gain during summer and winter season, but our observations showed that summer

Table 2. Correlative effects of temperature and humidity on survival of earthworms, *E. fetida*

Treatments	Season			
	Summer		Winter	
	Climatic factors		Climatic factors	
	Humidity	Tempe-rature	Humidity	Tempe-rature
Cow+buffalo dung	0.968^{NS}	-0.937^{NS}	0.938^{NS}	-0.743^{NS}
Buffalo dung	0.958^{NS}	-0.924^{NS}	0.992^{NS}	-0.874^{NS}
Cow dung	0.970^{NS}	-0.940^{NS}	0.999^{*}	-0.911^{NS}

Cow dung is significant at (P = 0.05) with respect to humidity in winters

Table 3. Effect of different seasons and substrate on reproductive potential of earthworms, *E. fetida*

Treatments	Season							
	Summer				Winter			
	Time Interval							
	30 days	60 days	90 days	Mean	30 days	60 days	90 days	Mean
Cow + buffalo dung	33.6	54.6	69.6	52.6	18	20.3	24	20.7
Buffalo dung	27.3	41	48.6	38.9	9.6	12.3	18	13.3
Cow dung	19.3	29	36	28.1	14.3	16.3	20.3	16.9
Mean	26.7	41.5	51.4		13.9	16.3	20.7	
Overall Mean	39.8	16.9						

Factors	C.D.
Season	1.501
Time interval	1.838
Substrate	1.838
Interaction (Season x Time interval)	2.599
Interaction (Season x Substrate)	2.599
Interaction (Time interval x Substrate)	3.184
Interaction(Season x Time interval x Substrate)	4.502

season was more favorable for all growth parameters. Binary combination of cow and buffalo dung showed superior performance in all aspects of growth parameters and fertility compared to individual cow and buffalo dung. When comparing the effect of the season, the summer season showed a significant growth of earthworms compared to winters and non. cocoons were produced by 69.6 and 24 on the 90th day of the experiment. Season and substrate therefore have a significant effect on earthworm growth and survival. A mixed substrate (cow + buffalo dung) among the three was found to be the most suitable for rearing earthworms. Although seasonal variations in temperature and humidity during this study had a negligible effect on worm growth and survival, the cumulative effect of season can affect earthworm growth and survival. Presley *et al* in

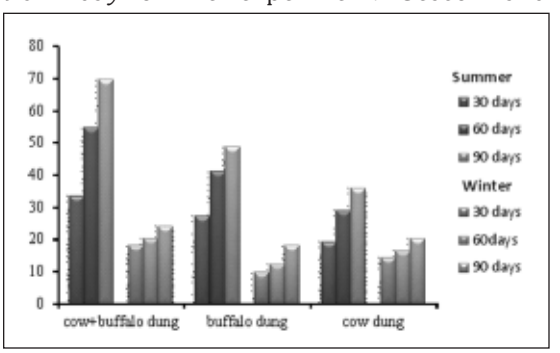

Fig. 2. Effect of different seasons and substrate on reproductive potential of earthworms, *E. fetida*

Table 4. Correlative effects of different seasons and substrate on reproductive potential of earthworms, *E. fetida*

Treatments	Season			
	Summer		Winter	
	Climatic factors		Climatic factors	
	Humidity	Temperature	Humidity	Temperature
Cow+buffalo dung	0.989^{NS}	-0.968^{NS}	0.979^{NS}	-0.834^{NS}
Buffalo dung	0.974^{NS}	-0.945^{NS}	0.996^{NS}	-0.957^{NS}
Cow dung	0.981^{NS}	-0.957^{NS}	0.956^{NS}	-0.780^{NS}

Table 5. Effect of different seasons and substrate on the body length (cm)of earthworms, *E. fetida*

Treatments	**Season**							
	Summer				**Winter**			
	Time Interval							
	30 days	**60 days**	**90 days**	**Mean**	**30 days**	**60 days**	**90 days**	**Mean**
Cow + buffalo dung	7.0	7.6	7.9	7.5	6.7	6.9	7.2	6.9
Buffalo dung	6.8	7.3	7.5	7.2	5.8	6.0	5.9	5.9
Cow dung	6.3	6.8	7.2	6.7	6.4	6.5	6.7	6.5
Mean	6.7	7.2	7.5		6.3	6.5	6.6	
Overall Mean	7.1	6.4						

Factors	**C.D.**
Season	0.092
Time interval	0.113
Substrate	0.113
Interaction (Season x Time interval)	0.159
Interaction (Season x Substrate)	0.159
Interaction (Time interval x Substrate)	N/A
Interaction (Season x Time interval x Substrate	N/A

1996 also observed the effects of various climatic factors on earthworm growth and reported that the reproductive fitness and growth of *E. fetida* is affected by changes in temperature and humidity conditions. The observations of Chauhan and Singh 2012 also matched our findings that the binary combination of buffalo dung with wheat bran showed significantly better results for the growth and development of *E. fetida* earthworm.

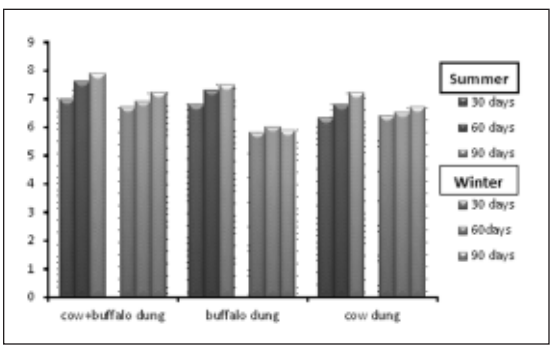

Fig. 3. Effect of different seasons and substrate on the body length of earthworms, *E. fetida.*

Beyginiya *et al*. in 2013 reported that the best growth of *E. fetida* was observed in 80% sheep manure + wheat straw 20% in spring season. Their results evaluated that the maximum activity, biomass increase and greater number of cocoons were produced during the spring season and the reproductive ability of *E. fetida* varies in different seasons. Biradar *et al*, 2015 evaluated the effect of seasonal environmental factors and different organic

Table 6. Correlative effects of different seasons and substrate on the body length of earthworms, *E. fetida*

Treatments	**Season**			
	Summer		**Winter**	
	Climatic factors		**Climatic factors**	
	Humidity	**Tempe-rature**	**Humidity**	**Tempe-rature**
Cow+buffalo dung	0.993^{NS}	-0.975^{NS}	0.967^{NS}	-0.803^{NS}
Buffalo dung	0.998^{*}	-0.986^{NS}	0.619^{NS}	-0.866^{NS}
Cow dung	0.970^{NS}	-0.940^{NS}	0.945^{NS}	-0.756^{NS}

Table 7. Effect of different seasons and substrate on weight (gms) of earthworms, *E. fetida*

Treatments	Season							
	Summer				Winter			
	Time Interval							
	30 days	60 days	90 days	Mean	30 days	60 days	90 days	Mean
Cow + buffalo dung	0.58	0.69	0.82	0.69	0.41	0.45	0.52	0.46
Buffalo dung	0.47	0.56	0.61	0.54	0.32	0.38	0.37	0.35
Cow dung	0.42	0.46	0.54	0.47	0.35	0.40	0.44	0.39
Mean	0.49	0.57	0.65		0.36	0.41	0.44	
Overall Mean	0.57	0.40						

Factors	C.D.
Season	0.015
Time interval	0.018
Substrate	0.018
Interaction (Season x Time interval)	0.025
Interaction (Season x Substrate)	0.025
Interaction (Time interval x Substrate)	0.031
Interaction (Season x Time interval x Substrate	NS

waste on life activities of Perionyx excavations. The study revealed that environmental factors had a significant effect on the growth, maturity and reproduction of Perionyx digs.Maximum growth was recorded in monsoon season for all wastes. Mixed organic waste and soft (straw-based) wastes were found to be more favorable to the overall life activity of the Perionyx excavation than hard (pod-based) wastes. Findings Vodounnou *et al*., 2016 on the effect of plant compost and various organic wastes on the growth and survival of *E. fetida* support our observations and the highest growth rate was observed in cow dung among all organic wastes, *viz*., pig, cattle, rabbit, sheep, poultry and vegetable compost). They observed all physico-chemical parameters of growth and survival for 90 days. To promote vermiculture biotechnology as an approach for ecological livestock

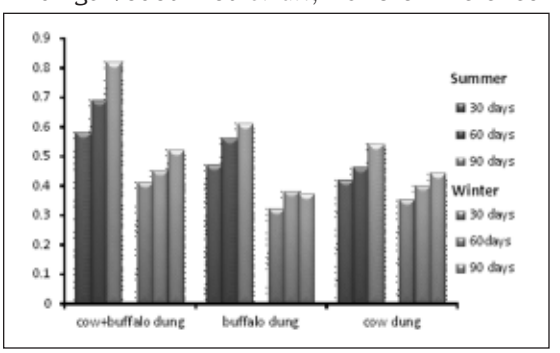

Fig. 4. Effect of different seasons and substrate on weight (gms) of earthworms, *E. fetida.*

Table 8. Correlative effects of different seasons and substrate on weight (gms) of earthworms, *E. fetida*

Treatments	Season			
	Summer		Winter	
	Climatic factors		Climatic factors	
	Humidity	Temperature	Humidity	Temperature
Cow+buffalo dung	0.936^{NS}	-0.896^{NS}	0.955^{NS}	-0.778^{NS}
Buffalo dung	0.989^{NS}	-0.969^{NS}	0.997^{NS}	-0.896^{NS}
Cow dung	0.877^{NS}	-0.824^{NS}	0.860^{NS}	-0.988^{NS}

enhancement and sustainable production of earthworm biomass as a source of protein and vermicompost, Kabi *et al*., 2020 attempted to understand fecundity, survival and growth patterns of earthworms using four organic substrates including cattle manure (CM), slaughterhouse waste (AW), soybean post-harvest residue (SBCR) and a binary mixture of manure and soybean crop residue (CM + SBCR) for 2 weeks. They reported that the fecundity, growth and survival of *E. eugeniae* were affected by the different type of organic substrate and the rate of cocoon production (0.41 cocoons/ worm/day) was highest in earthworms fed CM + SBCR. A study by Esmaeili *et al.* (2020) on a combined (composting - vermicomposting) process with *E. fetida* for the treatment of pistachio waste (PW) mixed with cow dung (CD) in different proportions (100% CD (T1), 25% PW (T2), 50% PW (T3), 75% PW (T4) and 100% PW (T5)) support our results. Their results showed that the combined process significantly increased the quality of the final product and the fertilizer produced. Physico-chemical analysis showed a significant decrease in the C:N ratio, total organic carbon and total potassium and an increase in total nitrogen, available phosphorus and pH. The number of adult worms during the procedure also increased in all treatments, and the net weight and growth rate of worms in T2 and T5 were higher than in other treatments.

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Appraisal of Quantitative Losses in Different Wheat Varieties Due to *Sitotroga cerealella*

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Abstract

An experiment was conducted using five different wheat genotypes to determine their resistance to *Sitotroga cerealella* (L.) at Chaudhary Charan Singh Haryana Agricultural University, Hisar during the year 2018-2020. The experiment was carried out in Completely Randomized Design (CRD) with three replications in a control temperature of 29±2°C with 65±5% relative humidity. The cultures were maintained in glass jars of 1 kg capacity containing the wheat grains and 25 adults of *S. cerealella* were released in these jars, separately. The results were evaluated by calculation of susceptibility index, percent grains damaged and percent weight loss of wheat grains against the infestation of *S. cerealella*. Among all the genotypes percent grains damaged (52.91%), percent weight loss (21.75%) and was found to be 'highly susceptible' genotype, while the lowest percent damaged grains (25.25%) and weight loss (8.64%) were recorded in genotype HPBW 1 and was found the 'susceptible' genotype against the infestation of pest, while all the remaining genotypes were intermediary to the pest attack.

Key words :

According to the Food and Agriculture Organization (FAO) "Food security exists when all people, at all times, have physical and economic access to sufficient, safe and nutritious food that meets their dietary needs and food preferences for an active and healthy life" (FAO, 1996). Still, food security remains major goal to accomplish in the developing countries. In spite of lots of improvement and numerous government policies, the problem of food security pose a major challenge around the world and deterioration of grains in storage conditions due to the activity of pests, contributes the issue. Stored grain insects can cause post-harvest losses, estimated from 9 percent in developed countries to 20 percent or more in developing countries (Phillips and Thorne, 2009). The quantitative and qualitative losses vary among different zones of the world ranging from 5 to 30 percent; highest in tropical zone (20-30%) and lowest in temperate zone (5-10%) (Jadhav, 2006).

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Wheat (*Triticum aestivum* L.) plays a major role for hunger mitigation of the World. India is the second largest producer of wheat in the world with production of 99.70 million tons which constitutes 13.58 percent of total wheat grain production of the world (FAO, 2018). Wheat contributes about 31.32 percent of total food grain production of country (FAO, 2018).

Wheat crop is less vulnerable to insect-pest in field but suffer relatively higher losses during storage. Abnormal grain moisture, temperature and storage conditions create conducive conditions for the attack of various agents such as insects, mites and rodents resulting in quantitative and qualitative loss. Besides rendering the grain unfit for human consumption, infestation may even downgrade the physical and nutritional value of grains. Infestation enhances the cost and efforts to transport, grow, harvest and store food grains. Stored grain pest encourages the incidence of different type of moulds, hence increases the

chances of toxic residues accumulation in the grains. In postharvest conditions, wheat grains are prone to attacked by many insect pests. Among these, lesser grain borer Rhyzopertha dominica (Fabricius), grain weevils complex Sitophlilus spp., Angoumois grain moth Sitotroga cerealella (Olivier), Khapra beetle Trogoderma granarium Everts and red flour beetle Tribolium castaneum (Herbst) are the important insect pests (Ebeling, 1971).

In storage, cereal grains are also infested by Angoumois grain moth, *S. cerealella* (Olivier). This pest was first reported in Angoumois Province of France in 1736, but now it is cosmopolitan pest (Cotton 1960). This moth cause serious damage in many cereals like rice, wheat, maize, barley, and sorghum (Ghosh and Durbey, 2003). It developed as serious pest due to its ability to feed inside grains at larval stage. Therefore, it is difficult to control at larval stage by the application of contact insecticides (Boshra, 2007). However, S. cerealella can be controlled by changing the physical properties and nutrition contents of cereal grains (Gomez and Santos 1992) like ferulic, amylose content, coumaric acids, kernel hardness, phenolic contents and texture (Arnason *et al*., 1994). Changes in protein and carbohydrate content can also alter the body weight, developmental time, fecundity and viability of the pest (Slansky, 1985).

Materials and methods

Procurement of wheat seed : The experimental material consisted of 5 genotypes, namely HD 2967, WB 2, HD 3086, HPBW 1 and WHD 948 (Table 1). The clean, disease and insect free seeds were procured from godown of wheat section, Department of Genetics and Plant Breeding, CCS HAU, Hisar to initiate stock culture. The seeds of various genotypes were stored separately in individual plastic container (6.5 x 6.5 x 10 cm^3) at Storage Laboratory, Department of Entomology.

Maintenance of stock culture : In case of *S. cerealella*, freshly emerged adults were collected from stock culture and caged in inverted glass funnel covered with mosquito net. They mated in the net and laid eggs. Then the eggs were kept in glass beaker and newly hatched 1^{st}, 3^{rd} and 5^{th} instar larvae were used for conducting the experiments. The stock culture was maintained under laboratory conditions throughout the experimental period. The adults were emerged from the stock culture were used for further experiments.

Plastic jars of about 250 g capacity were filled with 50 g wheat seeds of each genotype i.e. (HD 2967, WB 2, HD 3086, HPBW 1 and WHD 948) and tightly covered with rubber band and muslin cloth. Ten pairs of test insects male and female of *S. cerealella* were released separately in each container for oviposition. After thirty days adults were removed and wheat grains were retained in the containers. The wheat genotypes were compared by the observations taken on number of adult produced and mean development period. The data was used to calculate the index of susceptibility:

Index of susceptibility (S.I.) : It is a ratio of the log of F1 progeny completing development x 100 divided by the mean of the development period. The higher ratio indicates greater resistance relative to other cultivars or varieties under evaluation (Dobie, 1974). The resistance was classified according to the susceptibility index rating (Table 1).

Table 1. Classification of susceptibility index (rating 0-11)

Susceptibility index rating	Classification
0-3	Resistant
4-7	Moderately resistant
8-10	Susceptible
11	Highly susceptible

$$I = (\ln F/M.D) \times 100$$

Where, I= Index of susceptibility, ln= Natural log, F= Total number of F1 adult and M.D = Mean development period

Quantitative losses : 50 g wheat grains of each genotype was kept separately in plastic containers and newly emerged 10 pairs of test insects of S. cerealella was released. The number based damage estimation was done by randomly selecting 100 grains from infested sample of each genotype. On the basis of damage symptoms the healthy and infested grains were separated from randomly selected 100 grains at intervals of 30, 60 and 90 days after infestation. These containers were kept at standard laboratory temperature conditions. The healthy and damaged grains were counted from each container at 30, 60 and 90 days after storage, then percent grain damage and weight loses was worked out from following formula.

$$\text{Percent grain damage} = \frac{\text{No. of damaged grains}}{\text{Total no. of grains used}} \times 100$$

$$\text{Percent loss in weight} = \frac{(Wu \times Nd) - (Wd \times Nu)}{Wu\,(Nd + Nu)} \times 100$$

Where, Wu = Weight of undamaged grains, Wd = Weight of damaged grains, Nu = Number of undamaged grains and Nd = Number of damaged grains.

Results and Discussion

Appraisal of Susceptibility Index (S.I.) of different insect-pest on various wheat genotypes : The data presented in Table 2 revealed that maximum F1 emergence (65.33) of angoumois grain moth was found in HD 2967 followed by WHD 948 (59.00) and HD 3086 (52.33) whereas minimum F1 emergence (41.00) was recorded for genotype HPBW 1. The susceptibility index of various genotypes varied from 9.36 to 13.93. The minimum (9.36) susceptibility index was recorded in HPBW 1 and it was followed by WB 2 (10.00) whereas maximum (13.93) susceptibility index was recorded for HD 2967 and WHD 948 (12.36) during 2019.

Table 2. Appraisal of the susceptibility index of different varieties of wheat against Sitotroga cerealella

Genotypes	Susceptibility Index									Category
	2019			2020			Pooled Mean			
	F1 adult emergence (no.)	M.D	S. I.	F1 adult emergence (no.)	M.D	S. I.	F1 adult emergence (no.)	M.D	S. I.	
HD 2967	65.33 (08.08)	30.00	13.93	67.00 (08.18)	31.33	13.42	66.17 (08.13)	30.67	13.67	Highly Susceptible
WHD 948	59.00 (07.68)	33.00	12.36	65.00 (08.06)	35.00	10.16	62.00 (07.87)	34.00	11.26	Highly Susceptible
HD 3086	52.33 (07.23)	32.67	12.11	47.00 (06.85)	37.37	10.30	49.67 (07.05)	35.17	11.20	Highly Susceptible
WB 2	46.33 (06.81)	38.33	10.00	44.00 (06.63)	43.67	8.67	45.17 (06.72)	41.00	9.33	Susceptible
HPBW 1	41.00 (06.40)	39.67	9.36	38.00 (06.16)	47.00	07.74	39.50 (06.28)	43.33	8.55	Susceptible
C.D. (0.05%)	(03.30)	(02.97)	-	(03.59)	(03.08)	-	(07.50)	N.S	-	-
S.E (m)	01.03	00.93	-	01.12	00.33	-	02.02	02.38	-	-

Figure in parentheses are square root transformed values. M.D. = Mean development period in days, S.I. = Susceptibility index

The genotypes having minimum susceptibility index (HPBW 1 and WB 2) showed maximum median development period (M.D.) of 39.67 and 38.33 days, respectively during 2018-19. In 2019-2020 similar observations were recorded with maximum (67.00) F1 emergence for HD 2967 followed by WHD 948 (65.00) whereas minimum F1 emergence (38.00) was recorded for HPBW 1. Similarly, maximum susceptibility index was recorded in HD 2967 (13.42) and minimum in HPBW 1 (7.74).

On the basis of pooled susceptibility index data of both years the various genotypes were categorized as resistant, moderately resistant, susceptible and highly susceptible. HD 2967, WHD 948 and HD 3086 were found to be 'highly susceptible' whereas all other genotypes were found 'susceptible'.

Extent of grain damage (%) of major insect-pest on various wheat genotypes : During 2018-19, maximum grain damage (36.33%) was observed in HD 2967 followed by WHD 948 (28.67%) at 30 DAR against angoumois grain moth (Table 3). Minimum grain damage was observed in HPBW 1 (10.33%) followed by HD 3086 (18.00%). At 60 DAR, maximum (48.00%) grain damage was recorded in HD 2967 followed by WHD 948 (36.00%) whereas minimum (19.00%) grain damage was recorded in HPBW 1 followed by HD 3086 (25.00%). At 90 DAR, the maximum (54.67%) grain damage was recorded in genotype HD 2967 followed by WHD 948 (43.33%), WB 2 (36.67%) and HD 3086 (31.00%) whereas minimum (25.33%) grain damage was recorded for HPBW 1. All the genotypes varied significantly from each other at 90 DAR. Similar trend was followed at 120 DAR in case of grain damage. The mean percent grain damage for 2018-19 showed that HPBW 1 has minimum (21.58%) grain damage followed by HD 3086 (27.67 %) and WB 2 (33.58%). The mean grain damage during 2018-19 was highest in HD 2967 (49.58%) followed by WHD 948 (39.92%) which were at par with each other.

During 2019-20 the maximum grain damage was observed in HD 2967 (43.33%) followed by HD 3086 (25.67%) at 30 DAR. Minimum grain damage was observed in HPBW 1 (16.33%) and that was at par with WB 2

Table 3. Extent of grain damage (%) by Sitotroga cerealella in different varieties of wheat

Genotypes	Grain damage (%)										Pooled mean
	2019					2020					
	30 DAR	60 DAR	90 DAR	120 DAR	Mean	30 DAR	60 DAR	90 DAR	120 DAR	Mean	
HD 2967	36.33 (37.05)	48.00 (43.84)	54.67 (47.66)	59.33 (50.36)	49.58 (44.73)	43.33 (41.15)	52.67 (46.51)	61.33 (51.53)	67.67 (55.32)	56.25 (48.63)	52.91 (46.67)
WHD 948	28.67 (32.36)	36.00 (36.85)	43.33 (41.15)	51.67 (45.94)	39.92 (39.08)	22.00 (27.96)	31.00 (33.81)	40.00 (39.21)	47.33 (43.45)	35.08 (36.11)	37.50 (37.61)
HD 3086	18.00 (25.07)	25.00 (29.97)	31.00 (33.81)	36.67 (37.25)	27.67 (31.54)	25.67 (30.42)	30.33 (33.40)	37.67 (37.84)	43.00 (40.96)	34.17 (35.66)	30.91 (33.63)
WB 2	23.67 (29.08)	31.67 (34.21)	36.67 (37.25)	42.33 (40.57)	33.58 (35.29)	15.67 (23.28)	24.00 (29.31)	29.33 (32.78)	37.00 (37.45)	26.50 (30.71)	30.04 (33.05)
HPBW 1	10.33 (18.71)	19.00 (25.80)	25.33 (30.18)	31.67 (34.23)	21.58 (27.25)	16.33 (23.81)	25.33 (30.20)	33.67 (35.45)	40.33 (39.41)	28.92 (32.33)	25.25 (29.81)
C.D. (0.05%)	(03.43)	(04.83)	(04.46)	(01.06)	(13.72)	(02.89)	(02.97)	(01.51)	(01.43)	(14.91)	(14.29)
SE(m)	01.07	01.51	01.4	00.33	04.51	00.91	00.93	00.47	00.45	04.90	04.70

Figure in parentheses are angular transformed values. DAR= days after release of insects

(15.67%). All other genotypes varied significantly from each other. At 60 DAR, maximum grain damage was observed in HD 2967 (52.67%) followed by WHD 948 (31.00%) and it was significantly at par with HD 3086 (30.33%) in percent grain damage. Minimum grain damage was observed in WB 2 followed by HPBW 1 (25.33%) which was at par with each other. At 90 DAR, minimum grain damage was observed in WB 2 (29.33%) followed by HPBW 1 (33.67%). Maximum grain damage was observed in HD 2967 (61.33%) followed by WHD 948 (40.00%). All the genotypes varied significantly from each other. Similar trend was followed at 120 DAR. The mean grain damage recorded at different stages was highest in case of HD 2967 (56.25%) followed by WHD 948 (35.08%). The genotype HD 2967 varied significantly from all other genotypes. Minimum mean percent grain damage was observed in WB 2 (26.50%) followed by HPBW 1 (28.92%), HD 3086 (34.17%) and WHD 948 (35.08%) which were at par with each other.

The pooled mean grain damage was highest in case of HD 2967 (52.91%) followed by WHD 948 (37.50%). Minimum mean grain damage was observed in HPBW 1 (25.25%) followed by WB 2 (30.04%), HD 3086 (30.91%) and WHD 948 (37.50%) which were at par with each other. These results were in line with Upadhyaya *et al*. (1979) and Arve *et al*. (2014). Uttam *et al*. (2002) found a significant positive correlation with percentage of damaged grains and loss in grain weight, from the incidence of *R. dominica* and *S. cerealella* on different rice varieties. Similarly Meghwal and Bajpai (2010), also reported that varieties with minimum percent weight loss were found resistant and the varieties having maximum percent weight loss were susceptible.

Extent of weight damage (%) of major insect–pest on various wheat genotypes : The percent weight loss by angoumois grain moth was presented in Table 4 for years 2018-19 and 2019-20. During 2018-19, the minimum 4.24 percent weight loss was recorded for HPBW 1 which was followed by WB 2 (6.07%) and HD 3086 (7.63%) while maximum 17.46 percent weight loss was recorded in HD 2967 followed by WHD 948 (10.21%) at 30 DAR. All the genotypes varied

Table 4. Extent of percent weight loss by Sitotroga cerealella in different varieties of wheat

Genotypes	Weight damage (%)										Pooled mean
	2019					2020					
	30 DAR	60 DAR	90 DAR	120 DAR	Mean	30 DAR	60 DAR	90 DAR	120 DAR	Mean	
HD 2967	17.46 (24.69)	19.73 (26.36)	22.07 (28.00)	25.70 (30.45)	21.24 (27.28)	18.77 (25.66)	19.51 (26.20)	23.16 (28.76)	27.59 (31.67)	22.26 (28.07)	21.75 (27.73)
WHD 948	10.21 (18.63)	11.78 (20.06)	14.49 (22.36)	17.44 (24.67)	13.48 (21.43)	06.43 (14.68)	10.55 (18.95)	12.98 (21.11)	16.19 (23.72)	11.5 (19.61)	12.51 (20.56)
HD 3086	07.63 (16.03)	08.69 (17.14)	12.41 (20.62)	13.75 (21.75)	10.62 (18.89)	07.69 (16.10)	09.37 (17.82)	12.21 (20.44)	14.94 (22.73)	11.05 (19.27)	10.84 (19.08)
WB 2	06.07 (14.26)	10.49 (18.89)	11.82 (20.10)	18.92 (25.77)	11.82 (19.75)	05.14 (13.09)	08.17 (16.60)	10.57 (18.97)	12.25 (20.48)	09.03 (17.28)	10.43 (18.56)
HPBW 1	04.24 (11.87)	05.43 (13.47)	10.83 (19.21)	12.80 (20.95)	08.32 (16.68)	05.54 (13.61)	06.23 (14.44)	11.33 (19.67)	12.77 (20.93)	08.97 (17.16)	08.64 (16.78)
C.D. (0.05%)	(00.46)	(00.61)	(00.38)	(00.29)	(05.95)	(00.47)	(00.59)	(00.25)	(00.25)	(05.53)	(05.64)
SE(m)	00.15	00.19	00.12	00.09	01.96	00.15	00.18	00.08	00.08	01.83	01.85

significantly from each other. Minimum 5.43 percent weight loss was recorded in HPBW 1 , followed by HD 3086 (8.69%) whereas maximum 19.73 percent weight loss was recorded in HD 2967 which was followed by WHD 948 (11.78%). All the genotypes varied significantly from each other. Similar trend was followed at 90 and 120 DAR. The mean percent weight loss for 2018-19 showed that maximum (21.24%) weight loss was recorded in HD 2967 whereas minimum (8.32%) in HPBW 1. No significant difference was found among the genotypes.

During 2019-20, the maximum (18.77%) weight loss was recorded for HD 2967 and it was followed by HD 3086 (7.69%) and WHD 948 (6.43%) but minimum 5.14 percent weight loss was recorded for WB 2 which was followed by HPBW 1 (5.54%) at 30 DAR. At 60 DAR, maximum (19.51%) weight loss was recorded in HD 2967 which was followed by WHD 948 (10.55%) while minimum 6.23 percent weight loss was recorded for HPBW 1 followed by WB 2 (8.17%). Similar trend was followed at 90 and 120 DAR. The mean percent weight loss during the year 2019-20 was maximum (22.26%) in HD 2967 and minimum (8.97%) in HPBW 1.

The pooled mean percent weight loss data of both years (2018-19, 2019-20) showed that maximum (21.75%) of weight loss was in HD 2967 followed by WHD 948 (12.51%) whereas minimum (8.64%) in HPBW 1 followed by WB 2 (10.43%). The results were in confirmation of Shafique *et al*., (2006) who observed that twelve wheat varieties were resistant to angoumois grain moth, *S. cerealella* and observed that the resistance in different genotypes was based on the progeny of moths emerged and weight loss of grains.

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Evaluation of Genetic Variation in Indian mustard (*Brassica Juncea* L Czern and Coss) Using Multivariate Techniques

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Abstract

A set of 310 lines of Indian mustard (*Brassica juncea* L Czern and Coss) were analysed for cluster and principal component analysis (PCA). PCA identified four principal components which explained 65.13% of total variability among the 310 genotypes. Hierarchical cluster analysis grouped 310 genotypes into 3 clusters. Cluster1 included maximum number of 155 genotypes and clusters 3 had the lowest number of 43 genotypes. The grouping pattern of genotypes obtained by cluster analysis and PCA plots was almost similar.

Key words : Indian mustard genotypes, cluster analysis, principal component analysis.

Indian mustard (*Brassica juncea* L. Czern and Coss.) is the most important crop among the rapeseed-mustard grown in India. India is the fourth largest oilseed economy in the world. Among the seven oilseeds cultivated in India, rapeseed-mustard contributes 28.6% in the total oilseeds production Mustard seed is the second most important oil seed crop in India after soyabean. Haryana accounts for 11 per cent of the total area and 16 per cent of the total production in the country. Indian mustard accounts for nearly 21% of the total oilseeds produced in the country (http://www.religareonline.com /research/Disclaimer/Disclaimer_rcl.html) [1]. Total production of rapeseed mustard in India for the year 2013-14 was 72.82 lakh tonnes, which has increased by 9.5% as compared to previous year.

To boost up the productivity of Indian mustard, hybridization and exploitation of heterosis may play significant role. For developing better genotypes/hybrids, the choice of suitable parents is a matter of great concern to the plant breeders. For this purpose, breeders conduct experiments and record data on a number of variables. So, in general, breeders are to select the best genotypes by discarding those least useful for the final decision making and maintaining high performance.

Hamman (1972)[2] suggested that the use of multivariate techniques could reduce several phenotypic measurements in large populations into fewer, more interpretable, and easily visualized dimensions. Several other researchers have worked on similar lines regarding selection of diverse genotypes for breeding purpose. Acharya and Swain (2003)[3] have worked on genetic divergence in Indian mustard. Shathi *et al*. (2012) [4] conducted field experiment of 25 mustard (Brassica spp. L) genotypes with eleven quantitative characteristics to study the genetic diversity. Cluster analysis was used for grouping the 25 mustards (Brassica sp. L) genotypes into six clusters. Neeru *et al*. (2015)[5] used principal component analysis and hierarchical cluster analysis on 25 characters in 60 genotypes of Indian mustard (*Brassica juncea* L.) identified 11 principal components which explained about 75% variability. Using cluster analysis all the 60

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genotypes were categorized into 10 clusters. The results of cluster and principal factor analysis confirmed each other. Chaudhary *et al.* (2015)[6] analysed a set of 66 lines of pearl millet using cluster and principal component analysis. PCA identified six principal components which explained 77.7% of total variability among the 66 genotypes. Hierarchical cluster analysis grouped 66 genotypes into six clusters. The grouping pattern of genotypes obtained by cluster analysis and PCA plots was almost similar.

The multivariate analysis is an important tool for assessment of genetic divergence of the genotypes. Various first degree and second degree statistics are available for grouping of the genotypes to select for diverse types, but sometimes the recorded data become unmanageable and complicated to interpret. Often PCA and cluster analysis have been used to reduce large no of genotypes upto manageable level to identify the characters of significance to be used in a fresh breeding programme with a greater degree of reliance.

The present investigation was undertaken on 310 genotypes of Indian mustard for evaluation and grouping for similarity and degree of genetic diversity based on data recorded on 11 characters using PCA and cluster analysis.

Materials and Methods

In the present study, secondary data on Indian mustard genotypes was obtained from experiment conducted by the Oilseeds section of the department of Genetics and Plant Breeding, CCSHAU, Hisar. Data were recorded on 310 genotypes on 11 characters *viz*., plant height, 1000 seed wt, siliqua length, main shoot length, siliqua no, seed yield, days of maturity, oil content, primary branches, secondry branches, seeds/siliqua. Statistical tools like cluster analysis (CA) and principal component analysis (PCA) were used for groupig of genotypes into similar groups based on their agronomic traits and seed yield. Cluster analysis was performed using Ward's hierarchical clustering algorithm.

Methods

Principal Component Analysis : Principal component analysis is a statistical tool for data exploration and feature extraction in multivariate analysis. The procedure consists of finding the eigen roots and eigen vectors of the correlation matrix of explanatory variables. Interpretation of principal components is often facilitated by computing the components loadings. PC loadings are correlation coefficients between the PC scores and the original variables. PC loadings measure the importance of each variable in accounting for the variability in the PC. One of the most commonly used criteria for solving the number of components problem is the eigen value, also known as the Kaiser's (1960)[7] criterion.

Cluster Analysis : Cluster analysis is also one of the methods of data reduction technique. PCA reduces the number of variables whereas cluster analysis reduces the number of observations. Cluster analysis identifies homogeneous groups or clusters. It helps in grouping the materials in such a manner that similar types are grouped together while dissimilar ones belong to different groups.

Results and Discussion

Correlation matrix based principal component analysis was performed to extract the principal dimensions for agronomic traits and seed yield. The variance of each component and the percentage of cumulative variation explained by various principal components are presented in Table 1. Four PCs with eigen values greater than one were retained (Jeffers, 1967)[8].

Table 1. Total variance explained by various principal components

Components	PC1	PC2	PC3	PC4	PC5	PC6	PC7	PC8	PC9	PC10	PC11
Eigenvalue	2.66	1.89	1.52	1.10	0.99	0.89	0.61	0.53	0.40	0.21	0.20
Variability%	24.16	17.21	13.80	9.96	9.00	8.11	5.54	4.82	3.62	1.93	1.86
Cumulative%	24.16	41.37	55.17	65.13	74.13	82.24	87.78	92.60	96.22	98.14	100.00

The first four principal components were with eigen values more than one together explained 65.13% of the total variability. Only siliqua no. contributed positively to all the four PCs. The component loadings for the characters secondary branches, 1000 seed wt, siliqua length, primary branches contributed the maximum to the first principal component which accounted for 24.16% variation indicating that the Indian mustard genotypes were differentiated on the basis of these characters. Main shoot length and siliqua no. were the characters contributing to the second principal component, accounted for 17.21% of the total variability. The character seed yield and Days of maturity contributed to the third principal component which explained 13.80% variation. The fourth principal component accounting for 9.96% variability had high loading for the character seed siliqua. The character days of maturity had high loading for PC3 and PC4 while seed yield for PC1 and PC3.

The analysis without rotation of axes failed to load all the variables signifying that it could not offer much information regarding the idea of correlation between the variables and the principal components. The Varimax rotation thus, applied resulted in loading of all the variables on different principal components. Factor loading of different variables obtained through varimax rotation are presented in Table 2. All the 11 variables showed high loading on different PCs and none of them was left rotation of the factor axes. Moreover, it already grouped the similar type of variables by loading them together as a common PC. The principal components 1, 2 and 4 assigned for 5 variables secondary branches, 1000 seed wt, siliqua length, primary branches and seeds/siliqua in total related to yield can be designated as yield factor. The principal component 2 and 3 showing high loadings for main shoot length and seed yield are related to the growth rate at different stages and vegetative parameters. These together can be designated as growth rate. Such a clear grouping of similar type of variables having loaded on a common principal component elaborates the successful transformation of eleven interrelated variables into four independent principal components explaining 65.13% of the variability of the original set.

Two main components have been extracted having eigen value more than one. They account for 41.37% of the total variability. The first main component (PC1) explaining 24.16% of total variation and was positively correlated

Table 2. Loadings of different characters with respect to different PC's

Characters	Principal Components			
	1	2	3	4
Secondry branches	*0.787	-0.281	0.173	0.127
1000 seed wt	*-0.711	0.186	0.460	-0.093
Siliqua length	*-0.695	-0.073	0.470	0.214
Primary branches	*0.640	-0.304	0.093	0.170
Plant height	0.436	0.373	0.219	-0.363
Main shoot length	-0.007	*0.842	0.215	0.346
Siliqua no.	0.483	*0.757	0.078	0.243
Seed yield	0.420	-0.176	*0.686	0.179
Days of maturity	0.121	-0.145	*0.637	-0.551
Oil content	0.087	0.067	-0.217	-0.151
Seeds/siliqua	-0.136	-0.451	0.151	*0.572

with plant height, days to maturity, primary branches, secondary branches and seeds/siliqua whereas it was negatively correlated with siliqua no. main shoot length, 1000 seed wt, oil content and siliqua length (Fig. 1). This implies that, genotypes with high values of PC1 have lower oil content and vice versa. The second main component (PC2) accounted 17.21% of the total variation and was negatively associated with seed/siliqua, primary branches, secondary branches while positively associated with remaining characters (Fig. 1). This means that, genotypes with high values of PC2 have lower 1000 seed wt, siliqua length, plant height, main shoot length, siliqua no., seed yield, days of maturity, oil content. In this condition selecting the genotypes for higher yield is easy because in both main components positive coefficients with seed yield were obtained.

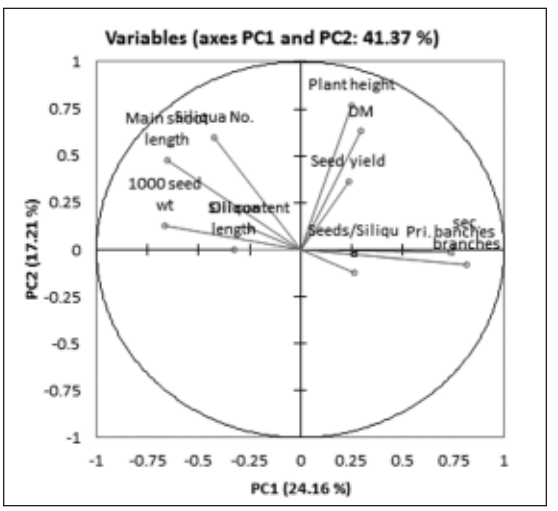

Fig. 1. Correlation between PC1 and PC2

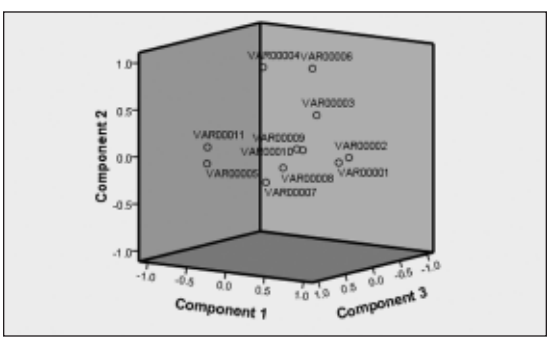

Fig. 2. 3D plot for first three principal component scores

Cluster analysis is an important statistical technique for the study of genetic diversity among genotypes which is of great practical significance for the plant breeders (Chaudhary *et al*., 2015)[6]. Cluster analysis using ward's method based on quantitative traits, all mustard genotypes were grouped into three clusters. Out of total 310 genotypes, the maximum of 155 genotypes formed cluster I. In second cluster there were 112 genotypes and third cluster contained 43 genotypes. To assess the diversity, inter and intra cluster distances were calculated and are presented in Table 3. The maximum inter cluster distance (52.018) was noted between cluster I and III, followed by (26.442) between cluster II and III, (25.759) between clusters I and II indicating that the lines grouped in these clusters were diverse and selected lines could be intercrossed to prepare a base population to combine the desirable characteristics. The clustering pattern further shows different genotypes were grouped in same cluster, this shows geographical diversity could not necessarily be an index of genetic variability, and the factors other than geographic diversity such as selection pressure and environment may be responsible for differential grouping of genotypes. The groupings obtained in 3-D plot of principal components (Figure 2) demonstrating the distribution in the first three principal components clearly showed the separation of 310 genotypes evaluated into four different groups. The results of PCA were closely in accordance with those of the cluster analysis.

Table 3. Average Inter and intra-cluster distances

Cluster No	I	II	III
I	0	25.759	52.018
II	25.759	0	26.442
III	52.018	26.442	0

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Role of Molecular Motors in Endosomal Dynamics: A review

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Abstract

Molecular motors are continually agitated by random Brownian motion, which provides both challenges and opportunities for energy conversion mechanisms. Molecular motors, an important class of molecular machines, harness various energy sources to generate unidirectional mechanical motion. In biological systems, molecular motors made of proteins and nucleic acids are ubiquitous, and commonly use the chemical energy of ATP or the electrochemical potential of protons across the cell membrane (the so-called proton-motive force) as an energy source. ATP synthase and V-ATPase also act as energy converters, in which ATP chemical energy and proton electrochemical potential are reversibly converted via mechanical rotation. In the cytoplasm of eukaryotic cells, three different classes of motors that generate linear movement are known to exist – myosin, kinesin and dynein. Most motors studied so far in some detail can generate a force that is sufficient to move even large objects through viscous cytoplasm.

Key words : ATP, brownian, dynein, kinesin, molecular motors, myosin.

Molecular motors are enzymes that transform chemical energy into mechanical work. Cytoskeletal motor proteins that move unidirectionally along an oriented polymer track either towards the plus end or the minus end of the track. These have the ability to use chemical energy to propel them along a linear track, with the direction of sliding dependent on the structural polarity of the track. All of them generate motion by coupling nucleoside

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triphosphate hydrolysis to a large-scale conformational change in a protein. In the cytoplasm of eukaryotic cells, three different classes of motors that generate linear movement are known to exist - myosin, kinesin and dynein.

Myosin : Skeletal muscle myosin, which is responsible for producing force during muscular contraction, was the first motor protein to be discovered. There are at least 24 distinct myosin families in higher species, according to the current boom of genetic information. Myosin II, the second isolating myosin, is a muscle protein that works with actin to generate contraction. The elongated protein known as myosin II (see below) is composed of two heavy chains and two copies of each of the two light chains. The force-generating mechanisms are located in a globular head domain at the N-terminus of each heavy chain, which is followed by a very lengthy amino acid sequence that creates an expanded helix and facilitates heavy chain dimerization.class-2 myosins which encompass the myosins involved in muscle contraction are referred to as 'conventional,' all other myosins as 'unconventional

Unconventional myosins : These unusual myosins are not involved in filament formation or contraction. They play a crucial role in a number of cellular processes, such as the transportation of organelles, organelles, and other cargo along actin filaments. Myosin I proteins are significantly smaller molecules (about 110 kD in mammalian cells) without the lengthy tail of myosin II, but they nonetheless include a globular head group that functions as a molecular motor, similar to that of myosin II. Their tails attach to other structures, including membrane vesicles or organelles, as opposed to dimerizing. The associated cargo can then be transported by the movement of myosin I along an actin filament.

Conventional myosins : Traditional myosin molecules are hexamers with two globular heads (each with one active site for ATP processing and one actin binding site), a long coiled-coil tail, and four sets of polypeptide chains: heavy chains (HCs), regulatory light chains (RLCs), and essential light chains (ELCs). At the intersection of the head and tail, the light chains are crucial in controlling the activity of this enzyme. The three cellular myosins, M2A, M2B, and M2C, which are nonsarcomeric, have a variety of roles in vesicle trafficking, endothelial cell migration, cell adhesion, polarity, fusion, and cytokinesis, as well as neuronal dynamics, axon guidance, and synaptic transmission. These three traditional myosins have distinct functional roles that are unique to each cell lineage during development and maturation; the precise roles depend on the developmental stage of the cell, the cellular location, the upstream regulatory controls, and the relative isoform expression (Fig.1).

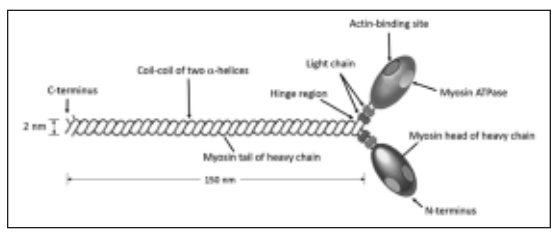

Fig. 1. Structure of myosin

There Are Two Types of Microtubule Motor Proteins:

- Kinesins
- Dyneins

Kinesin : Kinesin is a motor protein that moves along microtubules. Kinesins are ubiquitous in eukaryotic cells, in part because most members of the kinesin family have essential roles in cell division (Clancy and Block, 2012). It was first identified in the giant axon of the squid, where it carries membrane -enclosed organelles away from the neuronal cell body toward the axon terminal by walking toward the plus end of microtubules. Kinesin is similar

structurally to myosin II in having two heavy chains and two light chains per active motor, two globular head motor domains, and an elongated coiled coil responsible for heavy chain dimerization. Like myosin, kinesin is a member of a large protein superfamily, for which the motor domain is the only common element. These are a type of motor proteins that have been preserved throughout evolution. They use the energy produced by ATP hydrolysis to carry out work (Fig. 2). Kinesins interact with microtubules, which are dynamic polar -tubulin filaments that serve a variety of biological purposes. Transport kinesins can move cargo from one area of the cell to another by coupling ATP hydrolysis to translocation along microtubules (Ohi and Wordeman (2013). They are essential for mitosis and the movement of organelles and vesicles. Techniques for measuring the characteristics of certain proteins were created not long after the discovery of kinesin in 1985. These methods have been extensively used to study kinesin over the years, and it is fair to say that kinesin research has coincided with the development of single molecule approaches (Kapitein and Peterman, 2009).

A common, high-homology ATP-binding domain seen in members of the kinesin superfamily is abundant in both and secondary structure. This domain is frequently referred to as the motor domain (MD), sometimes even in the case of non-motor kinesins, because the majority of members of the kinesin superfamily-namely, conventional kinesin or Kinesin-1 as well as many kinesin-related proteins of the other kinesin classes-are involved in active transport and movement. The majority of other domains are class-specific and variable. The same is true of the motor domain's sequential position.

This enables the classification of the kinesin family into N-type kinesins (Kinesin-1 to 12), M-

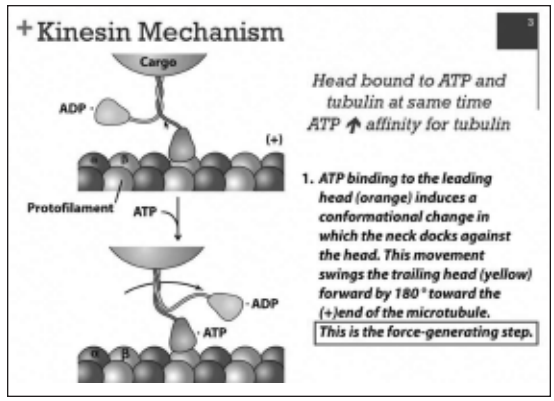

Fig. 2. Kinesin mechanism

type kinesins (Kinesin-13), and C-type kinesins (Kinesin-1 to 12), with the motor domain at or near the N-terminus and flanked on both sides by additional domains (Kinesin-14). Surprisingly, the functional classification of plus-end directed motors (N-type), minus-end directed motors (C-type), and non-motor kinesins matches this domain structure-based classification (I-type).

Myosin and kinesin MD's folds unexpectedly resemble one another, indicating that both motor proteins descended from a single ancestor (Kull *et* al. 1998; Vale and Milligan 2000). This led to theories that myosin and kinesin might share a mechanism. Four motifs seen in myosin, G-proteins, and other P-loop-containing proteins with a Walker fold (Walker *et* al., 1982) make up the ATP binding site in the kinesin motor domain. A phosphate binding loop (P-loop) is formed by the Walker A motif (GxxxxGKT/S) between helix 2 and -strand 3 of the central -sheet. This loop holds the nucleotide's phosphate firmly. The presence or absence of -phosphate affects the conformation and interaction of two additional motifs, the switch-1 (NxxSSR) and switch-2 (DxxGxE) motifs. Adjacent structural elements communicate and magnify these local changes, which ultimately have a large-scale impact.

Dynein : Dyneins are found in many

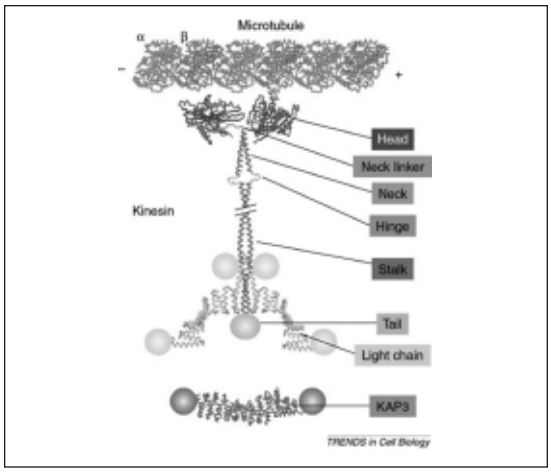

Fig. 3. Microtubule-kinesin interaction (Mandelkow and Mandelkow, 2002)

eukaryotes, including fungi, worms, insects, and vertebrates, but analysis of the Arabidopsis genome shows that they are absent in plants.These are found in many eukaryotes, including fungi, worms, insects, and vertebrates, but analysis of the Arabidopsis genome shows that they are absent in plants..

One, two, or three dynein heavy chains (DHCs) and a number of smaller subunits make up dynein complexes. An N-terminal tail and a

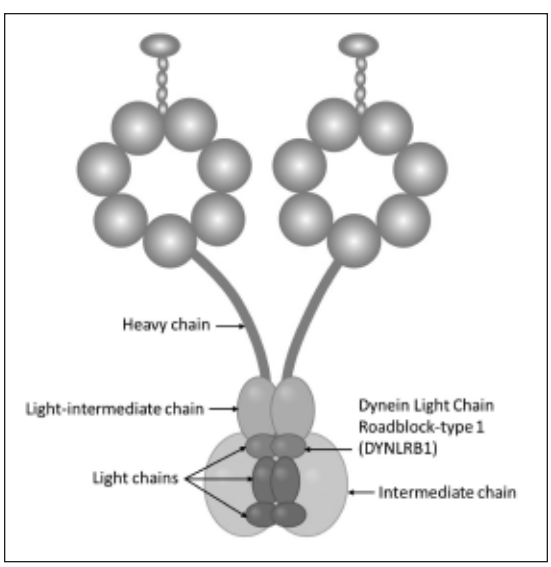

Fig. 4. Dynein structure

C-terminal motor domain make up the two domains of the big DHC, which has between 4,000 and 5,000 amino acids (Fig. 4). The conserved motor domain, which consists of six AAA+ domains and a C domain, transforms the energy of ATP hydrolysis into mechanical work while the tail domain binds the majority of the smaller subunits and promotes anchoring of the dynein complex to other payloads. The DHC motor domain is substantially responsible for each dynein complex's functional characteristics. Most species with motile cilia and flagella possess 15 or more DHC genes, according to recent whole-genome DNA sequencing of a variety of taxa.

Dynein is thought to be the main motor for microtubule-based retrograde axonal transport, and dynein has been shown to be associated with mitochondria. Cytoplasmic dynein 1 moves membrane organelles, kinetochores, and viruses along microtubules. It is also a motor for retrograde axonal transport and is involved in the assembly and function of the mitotic spindle. A second type of cytoplasmic dynein, cytoplasmic dynein 2, is responsible for a component of intraflagellar transport (IFT), namely the transport of protein complexes from the tips of cilia and flagella to their base, which occurs between axonemal microtubules and the flagellar membrane.

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Integrated Weed Management in *Bt*-Cotton Under Semi Arid Conditions – A Review

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Abstract

Cotton is one the major *Kharif* cash crop of India and is also known as '*White Gold*' or '*King of fibres*'. Being a rainy season, long duration, wide spaced and slow growing crop at initial stage, it is highly sensitive to weed competition. The critical period of crop-weed competition is 15 to 60 days after sowing and during this period the crop suffers from heavy losses in seed cotton yield. Weeds are the major constraints that reduce the crop yields since they compete for the nutrients, moisture, light and space. The losses caused by weeds in cotton ranges from 50 to 85 percent depending upon the nature and intensity of weeds in the field. The most common practices adopted by the farmers are manual weeding and inter-culture operation. But during critical period of crop-weed competition, the non-availability of labour, high wages of labour and wet field conditions, leads to ambiguous conditions for cotton growers. Due to delay in inter-culture operations in the crop, ineffectual results produced are clearly reflected in final yield. Thus, timely management of weeds through physical, mechanical, biological and chemical means needs to be ensured for achieving the higher cotton productivity. Physical and mechanical methods are widely used but in case of biological weed control, limited options are available. Chemical weed management is the better choice of the farmer being economical, quick responsive and suitable to the prevailing conditions. Chemical weed control in cotton by using suitable pre and post emergence herbicides during critical period of crop-weed competition gives a way out to handle the situation and to realise higher productivity. Further, the integration of all the weed management practices in the form of IWM needs to be explored more and more being economically viable, ecologically sustainable and locally available and user friendly techniques. Realization of higher cotton yield and fetching better remunerations mainly depends on an integrated weed management approach that also recognizes the adoption of location specific cultivar.

Key words : Bt-cotton, weeds flora, crop-weed competition, seed cotton yield, weed management

Bt-Cotton (*Gossypium* sp.) is the most important commercial crop in India known as "White Gold" or "King of fibres". Cotton crop is grown in about 70 countries across the world and grown in an area of 33.2 m ha. India ranks first in global occupying about 36% of the world cotton area but in production it ranks second, next to China. In India, cotton cultivation provides livelihood for over 4 million farming families. It occupies 12.95 m ha area with production 371 lakh bales and productivity 487 kg ha^{-1} (Anonymous, 2020-21). Gujarat, Maharashtra and Telangana were the leading cotton growing states covering around 71% (86.4 lakh ha) in area under cotton cultivation and 65% (246 lakh bales) of cotton production in India (Anonymous, 2019-20). It is major kharif cash crop of Haryana grown in area of 7.36 lakh ha with production 24 lakh bales and productivity 580 kg ha^{-1} (Anonymous, 2019-20). Cotton is essentially produced for its high quality fibre, which is commonly used in textile industry. It is the back bone of textile industry contributing nearly 80% of raw material. Hence, cotton is an important commodity in the world economy.

Weeds are major biological constraints that reduce the crop productivity since them highly competition with crop for the resources;

moisture, space, minerals nutrients and solar radiation. Weeds also tend to exhibit allelopathy, competition and parasitism. Cotton being long duration, wide spaced, slow growing habit initial stage which is turn invites multiple weed species infestation. Weed management in cotton concentrated on scientific manner to provide weed free environment to the crop. Brar and Brar (1992) reported that weed infestation in cotton offer severe competition for basic resources and causing yield reduction up to 74 percent in the crop. The infestation of weeds in cotton has to severe competition during its initial growth stages and causing yield reduction extended 40 to 85% (Sreenivas, 2000; and similar results found by Gnanavel and Babu, 2008). Weeds remove about 30-50% of applied fertilizers and 20-40% moisture (Jayakumar *et al.*, 2008). Due to the competition of weeds for nutrients, light, moisture and space the cotton yield was adversely affected. Raskar and Bhoi (2002) reported that competition with weeds caused 79.1% reduction in cotton yield. Productivity loss caused by weeds in cotton ranged from 50 to 85 percent mainly depending upon the nature, associated weeds flora and intensity of weeds in cotton field (Venugopalan *et al.*, 2009 and Prabhu *et al.*, 2012). Uncontrolled weed growth during crop growing season resulted in yield loss of up to 86 percent (Leela *et al.*, 2016). The suitable combination of different weed management practices would be a better option for controlling broad spectrum weeds, increasing the cotton productivity and bring to more sustainability in crop ecosystem. Thus, integrated weed management strategy has several aspects such as physical, mechanical, chemical and biologically methods. Integrated weed management approach totally based upon the critical period of crop weed competition, involving different direct and indirect control methods has been developed which has been commonly adopted by farmers to reducing the weed infestations in cotton field in a sustainable manner.

Keeping all these facts above view, the current review provides, extended overview of weeds associated with of *Bt* cotton and their cost effective suitable weeds management practices as well as future outcomes, needs to developments of weed science importance in Indian agriculture. It also includes weeds associated with *Bt* cotton in Haryana under irrigated conditions, their critical weed competition periods, productivity losses, cost benefit ratios and properly weeds management practices. The present scenarios, weed research findings, their adoptions, challenges and more opportunities for weed management.

Weed spectrum in *Bt*-cotton : To evolve a successful weed management programme, the proper knowledge about identification of weed species in the field, weed life cycle, detail of associated weeds, weed community and seed prolification ability of weeds, critical period of crop-weed completion, and characteristics of the variety along with the cross and multiple resistances to herbicides is essential. However, the weed community also depends upon climatic conditions and soil characteristics. Wide spectrums weeds have greater adaptability, to extreme climatic conditions and edaphic factors and cropping system advocated by Marnotte *et al.*, (1997). Cheema *et al.*, (2008) reported that *Bt* cotton fields were mainly infested with grassy weeds, broad leaf weeds (BLW) and sedges. Broad leaf weeds category mainly present six species viz., *Trianthema portulacastrum, Digera arvensis, Amaranthus viridis, Cucumis prophetarum, Portulaca oleracea* and *Tribulus terrestris*. Broad leaf weeds was the dominant group with 54% mean population followed by grassy weeds such as *Cynodon dactylon, Dactyloctenum aegyptium, Echinochloa colonum* occupying 31% area. Least infestation in cotton field was reported w.r.t. single species of sedges, i.e. *Cyperus rotundus* occupying the 15% area. In cotton experimental field, *Trianthema portulacastrum* was higher with

40 percent density among all weeds species and poses serious weed infestation problem throughout the crop season. Manikandan (2009) advocated that the predominant broad leaved weeds occurrence in the trial field of irrigated cotton grasses was *Chloris barbata* and *Cynodon dactylon* (L.) in sedges *Cyperus rotundus* (L.) and presence of broad leaved weeds were *Trianthema portulacastrum* (L.), *Digera arvensis* and *Parthenium hysterophorus* (L.). Bharathi *et al*., (2011) reveals that *Cyprus rotundus, Commalina bengalensis, Corchorus acutangulus, Amaranthus viridis, Abutilon indicum, Phyllanthus niruri, Celosia argentia, Parthenium hysterophorus* (L.) were the dominant weeds in experimental field of *Bt* cotton. Prabhu (2012) highlighted that predominant monocots weeds in the experiment field were *Cyperus rotundus* (L.), *Cynodon dactylon* (L.), *Dinebra retroflexa, Echinochloa colonum* (L.), *Echinochloa crusgalli* (L.). Beauv and Tragus Bifloris Schult (2012) reported that common dicotyledonous weeds were *Abutilon indicum* (L.), *Ageratum conyzoides* (L.), *Aristolochia bracteata* Retz, *Commelina benghalensis* L., *Cynaotis dactylon* (L.), *Digeria arvensis Forsk, Merremia emarginata* (L.). Cufod., *Mimosa pudica* (L.), *Parthenium hysterophorus* (L.), *Phyllanthus maderaspetensis, Phyllanthus fraternus, Tribulus terrestris* (L.), *Xanthium strumarium* (L.), *Coccinia indica* and *Sesbania aculeata* Pers. Similar weed population was also reported by Khan and Khan (2003) and Shahzad *et al*., (2012). Duraisamy *et al*., (2013) resulted that in transgenic maize and cotton crops experiment field in both season 2009 and 2010 the population broad leaved weeds were dominated over grasses and sedge. Among the weed community, *Trianthema portulacastrum, Cleome gynandra, Digera arvensis, Datura stramonium, Cynodon dactylon, Dactyloctenium aegyptium, Commelina bengalinsis* and *Cyperus rotundus* were predominant in maize field during both the seasons. Among broad leaved weeds, *Trianthema portulacastrum* was the dominant one during both the season. Werth *et al*., (2013) noted that in cotton based cropping systems a major species shift towards *Conyza bonariensis* and minor increase in *Sonchus oleraceus* at the end of the season is a major concern. Several species including *C. bonariensis, S. oleraceus, Hibiscus verdcourtii* and *Hibiscus tridactylites, Echinochloa colona, Convolvulus species, Ipomea lonchophylla, Chamaesyce drummondii, Cullen* sp., Amaranthus *macrocarpus* and *Chloris virgata* were still present full season. Ray *et al*., (2014) highlighted that south-western, Nimar region of Madhya Pradesh some exotic weeds species were early established as dominant in the *Bt* cotton. The 55 species of weeds were belonging to 21 families and 47 genera have been severing infestation in *Bt* cotton fields. Among them

Table 1. Major weeds of cotton in Haryana

Broad leaf weeds	**Grassy weeds**
Amaranthus viridis	*Cenchrus catharticus*
Cleome viscosa	*Digitaria sanguinalis*
Celosia argentia	*Dactyloctenium aegyptium*
Corchorus spp.	*Echinochloa colona*
Commelina spp.	*Echinochloa crusgalli*
Conaza canadhalensis	*Eragrostis tenella*
Digeria arvense	*Imperata cylindrical*
Eliptica alba	
Ipomoea pestigridis	
Portulaca spp.	
Phyllanthus niruri	
Trianthema portulacastrum	
Tribulus terrestris	
Xanthium strumarium	
Perennial weeds	
Convolvulus arvensis	
Cyperus iria	
Cyperus rotundus	
Cynodon dactylon	
Sorghum halepense	
Saccharum spontaneum	

eleven weed species have been observed to be changeable threatened of *Bt* cotton cultivation in this region.

Weed flora in different soil types

A. Sandy loam soils : Balasubramanian (1985) reported that predominant weed species of cotton fields in sandy loam soils of Coimbatore were Trianthema portulacastrum, Dactyloctenium aegyptium, Echinochloa colonum and Cyperus rotundus the weed ratio of broad leaved 60%, grasses 29% and sedges 11% respectively. Balasubramanian (1992) found that the mainly 14 common BLW namely; 1. *Digera arvensis* 2. *Trianthema portulacastrum* 3. *Amaranthus viridis* 4. *Amaranthus spinosus* 5. *Abutilon indicum* 6. *Cleome viscosa* 7. *Commelina benghalensis* 8. *Corchorus olitorius* 9. *Datura fastuosa* 10. *Euphorbia prostrata* 11. *Flaveria australasica* 12. *Parthenium hysterophorus* 13. *Portulaca oleracea* 14. *Boerhaavia diffusa*, five grass species *viz*., 1. *Cynodon dactylon* 2. *Echinochloa colonum* 3. *Dactyloctenium aegyptium* 4. *Panicum repens* 5. *Chloris barbata* and sedge weed *Cyperus rotundus* were very closely related with cotton crop. Brar *et al*. (1998) found that in Punjab, the dominate weeds in sandy loam soil cotton fields were *Cyperus rotundus, Trianthema portulacastrum, Tribulus terrestris, Eleusine indica, Xanthium strumarium* and *Cenchrus* species. But in Haryana conditions, *Trianthema portulacastrum* (L.) and *Echinochloa crusgalli* (L.) were the most dominant weeds in cotton under sandy-loam type soils (Panwar *et al*., 1998). Panwar *et al*. (2001) observed weeds in the sandy loam soils of Haryana, *Trianthema portulacastrum* (L.), *Cyperus rotundus* (L.), *Digera arvensis* and *Celosia argentia* (L.), were the dominant weeds in cotton field in Hisar condition.

B. Clayey loam soil : Jadhav *et al*., (1995) advocated that in clay loam soil of Maharashtra kharif season weed flora in cotton field were flashes *Digera arvensis, Abutilon indicum, Cynodon dactylon, Parthenium hysterphorus* and *Cyperus rotundus*. In clayey loam soil, cultivated irrigated hybrid cotton the predominant weeds were observed *Cyperus rotundus, Cynodon dactylon, Trianthema portulacastrum, Echinochloa colonum, Eclipta alba, Panicum repens* and *Cleome viscosa* (Gnanavel and Babu, 2008).

C. Black soil : Giri and Bhosle (1997) highlighted that cultivation of rainfed condition cotton in deep black soil of cotton research farm Parbhani (Maharashtra), the main dominant weeds in cotton field were *Trianthema portulacastrum, Digera arvensis, Eclipta alba, Euphorbia hirta, Abutilon indicum, Acalypha indica, Ischeemum pilosum, Cyperus rotundus, Cynodon dactylon, Vicoa indica, Amischophacelous cucullata, Phyllanthus medraspatensis, Corchrous acutangulus, Alleteropsis cimicina*.

Cotton (*kharif*) season - Dominate weed flora : The major weeds infesting the in crop season such as *Trianthema portulacastrum* (58.9%), *Echinochloa crusgalli* (16.9%), *Cyperus rotundus* (16.6%) and *Digera arvensis* (5.6%) were predominately weed species of cotton fields. The ratio of broad leaved weeds 58% grasses 16% and sedges 16% respectively as observed by Chander *et al*., (1997). Ali *et al*., (2005) reported *Euphorbia prostrata, Convolvulus arvensis, Cynodon dactylon, Cyperus rotundus, Portulaca oleracea, Sorghum halepense, Trianthema monogyna, Amaranthus viridis, Echinochloa colonum, Setaria viridis, Euphorbia helioscopia, Corchorus tridens, Digeria muricata* and *Tribulus terrestris* as the predominant weed flora in *kharif* season. Vivek *et al*., (2002) observed that the major weed flora occurrences in cotton-wheat cropping system

Bulandshar region of UP were *Cyperus rotundus, Cynodon dactylon, Cyperus iria, Panicum* spp. and *Trianthema monogyna.* According to Patil *et al*., (2003) major weed flora found in cotton fields of Akola area in Maharashtra such as *Cynodon dactylon, Cyperus rotundus, Poa annua, Parthenium hysterophorus, Digera arvensis* and *Euphorbia* sp. were dominate weeds community. The predominant broad leaved weed species were identified; *Trianthema portulacastrum, Acalypha indica, Cleome viscosa* and in grasses; *Dactyloctenium aegyptium, Echniochloa colona, Digitaria sanguinalis and in sedges Cyperus rotundus, Cyperus iria* weeds in Tamil Nadu noticed by Srinivasan (2003).

Critical period of crop-weed competition : The critical period crop weed competition is the period between early growth stage during which weeds can grow without affecting crop yield and the point after which weed growth does not affect the yield. The critical crop weed competition occurs in crop, when growth and development of crop and weeds are in the same growing period. The critical period of crop-weed competition is approximately 1/3rd of the duration of the crop. Weeds that germinate along with crop are more damaging than the later emerging weeds. This weed competition period in cotton crop varies from 3 to 9 weeks after sowing time and it's totally depends on climatic condition and edaphic factors that crop area.

The weed free condition up to three to five weeks after sowing was required to get desirable yield (Mohamed Ali and Bhanumurthy, 1985). Initial period of 30 to 50 days the most critical period for crop weed competition in cotton in Tamil Nadu condition Jayakumar *et al*., (1990). Panwar and Malik (1991) reported that competition of carpet weed (*Trianthema portulacastrum*) was more during initial 50 days after sowing, whereas the competition of barnyard grass (*Echinochloa crusgalli*) was during 50 and 100 days after sowing. They opined that initial 60 days were most critical for crop weed competition in cotton under sandy loam soils of Hisar condition. In American cotton, weed competition during the first 30 days after sowing resulted in an average yield loss of 10.5 percent in Punjab. Thind *et al*., (1995) observed that seed cotton yield increased from 1890 to 3021 kg ha^{-1} when the initial stage weed free period extended from 30 days to full growing season. Mishra (1997) revealed that critical period of crop-weed competition was 15-60 days and during this period weeds were not controlled caused yield losses from 40-50 percent. Papamichail *et al*., (2002) reported that cotton is very sensitive to weed competition in the first 60 days of crop growth. The occurrence of weeds for more than three weeks after crop emergence caused significant losses in crop growth and yields. Sivakumar and Subbian, (2002) observed 33-40% reduction in yield have been noted due to severe infestation of weed population field. They also found higher weed biomass per square meter than that recorded in weed free treatments. In cotton plant establishment, plant height, square

Table 2. Critical period of crop-weed competition in some major crops

Crop	Critical period of crop-weed competition (DAS)
Black gram	30-45
Bt-Cotton	30-60
Green gram	20-45
Groundnut	30-50
Maize	15-45
Paddy	15-45
Pearl-millet	25-45
Sorghum	15-45
Soyabean	30-45
Sugarcane	30-120
Sunflower	30-45
Wheat	30-45

formation, number of bolls and biomass were significantly affected by weed competition Mushtaq and Cheema (2008). Rajiv Sharma (2008) found that critical period of crop weed competition was 15 to 60 days during its growing period. Webster (2005) reported that the significant reduction in yield and yield attributes due to weed infestation over weed free treatments. Critical period of weed competition occurred between planting and the 3-5 leaf stage of cotton minimized yield loss to five percent (Webster, 2008). Spasova *et al.*, (2008) advocated the duration of weed presence with the crop and the time of weed emergence, generally affect crop-weed competition. Ayyadurai and Poonguzhalan (2013) pointed that critical period of weed competition was found to be 20 to 60 days after sowing. Cotton yield loss increased in during weed competition and maximum loss (96.5%) occurred due to full growing season competition. Seed cotton yield increased significantly with the increase in initial duration of weed free condition up to 80 days after sowing. Beyond 80 DAS, seed cotton yield was reduced considerably due to decrease no. of bolls percentage. Poonguzhalan *et al.*, (2013) found that cotton was very sensitive to weed competition in the first 60 days of crop growth. The period of weed interference, crop damage and the critical period of crop-weed competition were 30 to 60 days which occupied 50 percent of the whole cotton growing period. Seed cotton yield loss increased with the increase in the duration of competition and maximum loss was observed due to full season competition. Tursun *et al.*, (2015) noted that proper knowledge and understating power of crop weed competition period is very important for weed management strategies in any cropping systems. Indiscriminate use of fertiliser, the relative yield of cotton decreased with increasing duration of weed interference. Depending on the nitrogen application rate, weed free conditions need to be established as early as one week after crop emergence and maintained as late as eight weeks after crop emergence to avoid more than 5% loss in cotton yield. These findings could help cotton producers improve the cost effectiveness and efficacy of their weed management programme under different nitrogen application rates.

Weed interference in cotton : Weed infestation in crop field is main hindrance and limiting factors in crop production. Cotton being a long duration, wide spaced and slow growing habits in initial stages that caused severe weed infestation field. Weeds have always drastically competed with crops and pull down the seed cotton yield. Incompetent weed control at appropriate stage is considered as a major constraint for high production. Cotton was very sensitive to weed competition in the first 60 days of crop growth. The period of weed interference, crop damage and the critical period of crop weed competition were 30 to 60 days which occupied 50% of the whole cotton growing period. Seed cotton yield loss increased with the increase in the duration of competition and maximum loss was observed due to full season competition. Weeds also increased the infestations of insects-pest and diseases in cotton such as whitefly, jassid, aphid, thrips, green leaf hoppers and mealy bug (sucking insects) resultants decrease the yield, revealed by Zhang *et al.*, (2014). Weed infestation in cotton has been reported to offer severe competition and causing yield reduction to an extent of 40 to 85 percent. Due to their high competitive ability, weeds compete for resources like as nutrients, light, soil moisture and space thereby affecting productivity of cotton. Hence, the productivity of cotton is largely depends on a weed free condition particularly in their early growth periods. Broad spectrums of weeds with grater adaptability in adverse climatic conditions, edaphic factor and biotic or abiotic stresses are occurs in the cotton fields. So, mention views is presented on the nature of weed spectrum in

cotton, competition between crops and weeds effect the growth, yield attributes, yield and also impaired quality of cotton. Long persistence nature type of weeds has high ability seed production and its proliferation or induced more seed viability (Nadanassababady *et al*., 2001). The crop productivity totally depends upon the severity of weed interference in field. The losses of crop productivity causes by weed interference depends on many factors, such as environmental conditions, edaphic factor, fertility status of soil, nature of weed community and their intensity, density, distribution and duration of emergence of weeds community in relation to cotton crop (Papamichail *et al*., 2002).

Effect of weeds on cotton

A. Growth components : Cotton growth stage plant height, dry matter accumulation and in development phase flowers initiations, square formation and finally bolls developments and yield or yield attributes are significantly influenced the presence of weeds in the cotton field.

According to Sankaran and Rethinam, (1974) the dry matter production of cotton crop per unit area was the lowest under uncontrolled weeds field. Similar result was recorded by Snipes *et al*., (1982). Decrease in plant height was observed due to weed competition by Balasubramanian and Sankaran, 1976; Singh, 1983; Rushing *et al*., 1984. Based on research study Holt and Orcutt (1991), concluded that yellow nut sedge (*Cyperus esculentus*) and purple nut sedge (*Cyperus rotundus*) highly competition for light, soil moisture and space with cotton and takes very faster growth, accumulation more biomass by using resources rather than the cotton crop. Reduction in plant growth & development prolonged delays in weed removal in cotton field was observed by Bukun (2004). Balasubramanian (1992) found that weed free condition in cotton increased the plant height, dry matter production, number of bolls/plant, boll weight and seed cotton yield. The highest plant height was recorded by low weed growth in cotton field (Khan *et al*., 2001). According to Mahar *et al*., (2007) plant height of cotton was significantly decreased in uncontrolled weeds plots. Spasova *et al*., (2008) found that the presence of weeds for more than three weeks after crop emergency caused significant reductions in crop growth and seed cotton yields. However, weeds that emerged 11 weeks after crop emergence they did not much adversely affect cotton yields. A weed free period of eleven weeks after crop emergence was needed to prevent significant reductions in plant height, dry matter production, number of bolls and seed cotton yield. Veeramani *et al*., (2009) opined that the pre-emergence application of chemical herbicide paraquat @ 0.40 kg ha^{-1} fb cultural hoeing to check weed density significantly influenced the plant growth and development parameters like plant height, sympodial and monopodial fruiting branches, number of bolls and accumulation of biomass on per plant basis. Post sowing weed management practices on 20 DAS fb glyphosate @ 1.5 kg/ha (protective cultivation) increased the plant height, physiological parameters and dry matter production per plant over the control treatment. Cotton plant establishment, plant height and accumulation of biomass significantly influenced the presence of number of weeds per unit area, their growth and crop-weed competition in the cotton field (Mushtaq and Cheema, 2008). Leaf area index and crop growth rate were decreased in unweeded check plots (Prabhu *et al*., 2012). Muhammad *et al*. (2013) concluded that decreased plant population per unit area, small plant height and number of monopodial branches per plant was recorded in weedy check field. Scientific application of pre and post-emergence chemical herbicides viz; pendimethalin, pyrithiobac sodium and quizalofop ethyl which are not harmful to cotton

crop. Directed spray of glyphosate caused foliar injuries or leaf scorching may be occurs. All the herbicides application alone or tank mix according to their compatibility were significantly influenced the plant height, biomass accumulation, number of bolls per plant, boll size and weight, seed cotton yield and quality parameters (Hargilas *et al*., 2015). Leela *et al*., (2016) observed that plant establishment, plant height, dry matter production of plant significantly higher in unweeded check cotton field.

B. Yield components : Weeds have always harmful impact on yield and quality of cotton. Efficient weed management practices significantly influences the cotton yield. The growing season of crop weed control resulted in better crop growth and increased source availability which resulted in increased number of yield components of cotton. Balasubramanian and Sankaran (1976) reveal that significant reduction in number of sympodial branches, fruiting bodies and seed yield due to weeds infestation in cotton field. Similar result was found by Mohamed Ali and Bhanumurthy (1985). Loss in seed cotton yield varied from 40-85 percent due to crop weed competition (Jain *et al*., 1981; Bhan and Mishra, 1993). Bishnoi *et al*., (1993) reported that effective weed control at initial stage 20 days after sowing significantly higher seed cotton yield (2798 kg ha^{-1}) as compared to weedy check plots (1614 kg ha^{-1}). Mofett and Mcclosky, (1998) recorded that severe infestation of weeds yellow nut sedge (*Cyperus rotundus*) seed cotton yield was reduction upto 34 percent in field. Seed cotton yield reduction is mainly due to severe weed competition in the initial stages. Weeds accumulated higher concentration of mineral nutrients than crops, thereby depleting soil nutrients quickly and reducing the yield (Gupta, 1998). According to Srinivasulu and Rao, (2000) Being a long duration, wide spaced, very slow growth in early stages crop permitted more weed competition that causing seed cotton yields reductions extended upto 69 percent in unweeded check. Sreenivas (2000) observed higher number of bolls plant per plant with lower weed incidence. Khan *et al*., (2001) recorded the big size bolls with lesser weed interference in cotton crop. Maqbool *et al*. (2001) revealed that no control the weeds in cotton field significantly reduction in the seed cotton yield. According to Velayutham *et al*., (2002) uncontrolled weed growth reduced the number of bolls plant per plant and boll size and weight and ultimately yield of cotton. Significant reduction in no. of bolls plant and boll weight in unweeded check was similar result found by Srinivasan (2003). Khan and Khan (2003) reported that yield losses in cotton from broad leaved weeds infestations was nearly 15 to 30 percent and infestations of grassy weeds nearly15 to 40 percent. Kalaisundareson and Sundari (2004) concluded that the highest number of bolls plant per plant was observed when weeds were efficiently controlled. Sadangi *et al*., (2006) observed that lesser no. of sympodial branches, no. of bolls per plant and boll weight in unwed control treatments. Higher intensity per unit area of broad leaf weeds Trianthema portulacastrum significantly decrease the number of fruiting branches, number of bolls per plant and seed cotton yield reported Anjum *et al*. (2007). According to (Mahar *et al*., 2007) in cotton number of sympodial branches, no. of bolls per plant and yield were significantly reduction under untreated check plots. Mushtaq and Cheema, (2008) reveal that significant reduction in square formation, number of fruiting bodies and seed yield due to higher weeds infestation in cotton field. Prabhu *et al*., (2012) recorded that total number of bolls at harvested and boll weight were significantly affected in unweeded check compared to other treatments. In weedy check plots lesser number of sympodial branches and

number of bolls plant per plant assumed by Muhammad *et al*., (2013). Weeds can utilise more water than cotton plants and compete for sun light, space and nutrients with cotton plants and ultimately, significantly reduction in the cotton yields observed by Nalini *et al*., 2015). Leela *et al*., (2016) observed that number of bolls per plant, boll weight and seed cotton yield was significantly affected weedy check cotton field.

Cotton quality characteristics : Cotton yield is decreased due to severe weed competition in the initial stages. Often, noticeable that weeds causes mainly two types losses the in crop. The most important one is the direct yield loss due to competition of resources; second one is the indirect loss by destroyed crop productive quality. Nobrega *et al*., (1997) reported that chemical herbicide application not affected the seed weight, quality, fiber percentage and staple length of fiber. Dimitrova and Gueorgieva (1997) found that infestation of field bind weed (*Convolvulus arvensis*) by sticking or mixing with fiber impairs the quality of cotton. Weeds exhaust more mineral and nutrients from soil than crops and depleting soil nutrients quickly or decrease the soil fertility that causes significantly reduction in the seed cotton yield (Gupta, 1998). Sandhu *et al*., (1996) advocated that yield losses caused by weeds in cotton ranged from 45-75 percent depending upon weed flora and intensity of weeds. Prabhu (2010) state that weed infestation was no affected the quality parameter of cotton, but weeds were significantly reduction the yield of cotton. Highest weed control efficacy approximately 96% and seed cotton yield of kg ha^{-1} were recorded by Singh and Kokate (2010) from pre and post emergence application of pendimethalin @1.00 kg ha^{-1} fb by glyphosate @ 1.00 kg ha^{-1} with nearly 90% weed control and higher seed cotton yield as compared to unweeded check plots. Similar trend was noted in respect of physiological parameters such as growth and development, yield attributes and fibre quality characteristics. According to Soliman *et al*., (2013), unweeded check significantly reduced the seed cotton yield and quality parameters i.e. lint percent, staple length, micronaire value, fibre length and ginning percentage. Crop season competence uncontrolled weeds also reduced the crop yield and along with enhanced weed seed bank of soil which serious problem for cultivation. Hence, weeds play a significant greater role in decreasing the cotton yield and quality characteristics (Nithya and Chinnusamy, 2013). Highest dry matter accumulations of weeds were recorded at harvest time in the weedy check plots. Pre and post emergence herbicides application and cultural practices significantly reduced the weed density than in weedy check (Patel *et al*., 2013). From the above mentioned views, it is obvious that crop weed association and crop weed competition drastically pull down the seed cotton yield with the significantly affected the quality characters viz., lint percentage, ginning percentage, staple length and micronaire value.

Nutrient depletion by weeds : The nutrient removal by weeds showed a significant impact on the availability of nutrients to the crop and thus affecting its dry matter accumulation. Jain *et al*., (1981) reveals that the nutrients uptakes by cotton very slow as compare to weeds. Weeds 5-6 time more nitrogen uptake, phosphorus 5-12 times and potassium 2-5 times than the cotton crop. Singh *et al*., (1988) found that nutrients depletion by weeds range 10-90 percent that causes significantly losses of crop yield up to 67 to 78 percent particularly in northern India. Weeds absorbed present major plant nutrients from soil and caused significantly losses in crop production. Weeds reduced the availability of both major and micro nutrients to the crop (Shobana, 2002). Maximum nutrient depletion was recorded in cotton at early growth stages i.e. 60 days after sowing. The depletion

rate of major nutrients NPK was 61.8 kg, 5.6 kg and 57.6 kg per ha respectively reported Baldev *et al*. (2004). Excessive absorption of nutrient's by weeds resulting luxurious growth of weeds in cotton crop reported by Kumar *et al*., (2007).

Integrated weed management in *Bt*-cotton : Proper time and successful way weed control is essential for economic cultivation of cotton. Cotton being a wide spaced, slow growth habit crop at initial stages suffers severe weed competition that resulting more depleting of mineral & nutrients turn to substantial decreased soil fertility, reduction in seed cotton yields and quality parameters. Often it's seen that, weed control practices adopted in the field are time consuming and more expensive. Among the agronomic constraints of cotton production, weed infestations have been a major issue. Innovation of many advances technology in weed management, despite cotton farmers still faces significant challenges from weeds. Chemical herbicide applications at the time of sowing will not give season long control of weeds. Pre and post emergence application has the initial advantage to cotton over the weeds. Hence, the integration of different weed management practices would be a viable option for broad spectrum weed control and enhancement of cotton productivity and balancing crop ecosystems. Thus, weed management has several aspects such as physical, cultural, mechanical, chemical and biological integrated weed management methods.

Why IWM? : Integrated weed management approach is the simultaneous application of different strategies on successful weed control in a sustainable way. Integrative methods is based on critical period of crop weed competition, including different direct and indirect weeds control method has been developed time to time and adopted by farmers to reduced weed infestations in cotton in a best suitable manners. An integrated weed management approach to land management practices combined use of complementary weed control methods such as animals grazing, herbicide application, land fallowing, crop rotation, crop diversification and biological control. IWM is a method whereby all economically, ecologically and toxicologically justifiable methods are employed to keep the harmful organisms below the threshold level of economic damage, keeping in the foreground the conscious employment of natural limiting factors. Thus, use of IWM has been shown to be the most economical and sustainable way to weeds management. In this review to include the present scenario of weed research findings or researcher's outcomes and their adoptability among farmers, challenges, opportunities and future perspectives for weed management study.

- Highly sustainable in crop ecosystem
- Cost effectiveness
- Long term approach
- Broad spectrum weed control
- Prevent development of herbicide resistant
- Weed management practices may be flexible to accommodate
- Optimum utilization of natural resources & environmental safety
- Appropriate integration of synthetics organic & inorganic herbicides

Principles of weed management

1. Prevention
2. Eradication
3. Control

Types of Integrated Weed Management

A). Indirect Methods

1. Preventive Methods
2. Cultural Methods & Ecological Methods

B). Direct Methods

1. Physical/Manual Methods
2. Mechanical Methods
3. Biological control
4. Chemical control

A. Indirect Methods

1. Preventive Methods

- Use of clean seed
- Use of clean farm equipments
- Clean leaves, watercourses and irrigation canals
- Control grazing of livestock
- Ensure that farmyard manure and other soil materials are free of weed
- Prevent the formation of weed seeds or vegetative progules
- Legislation

2. Cultural Methods : Cultural practices are important after preventive measure as eco-friendly techniques. All over the globe several cultural practices are available for weed control in cotton crop. These practices are strong reliable, cheap or even costless and are easily adjustable in the weed management strategy for cotton. The most important of these may include crop rotation, intercropping, smoother crops, stale seedbed method, soil solarization, suitable sowing time, sowing method, use of appropriate variety, plant geometry (spacing), plant density, flooding and drainage, irrigation scheduling, cover crop, mulching and managerial skill or judicious uses of farm management practices for weed control in cotton.

B). Direct Methods

Physical/manual method of weed control : Manual weed control is the oldest, most practical, physical method of weed control that utilizes manual power and simple hand tools to control weeds and is followed by farmers widely. Hand weeding, hand pulling, hand hoeing (kasola, khurpa etc.) wheel hand hoeing, bullock drawn plough, bullock operated trifali is still a traditional and effective method of weed control to eliminate weeds which could not recover again. It's very effectiveness to control annual and perennial weed population in cotton by removing rhizhomes and stolons of weeds and suppressed weed species.

Hand weeding/hand hoeing : Singh and Varma (1988) reported that nutrient uptake and dry matter production in cotton was significantly highest by manual weed control. Tiwana and Brar (1991) state that two hoeing provided the best weed control and the highest seed cotton yield. According to Detroja *et al*., (1992) three hand weeding at 20, 40 and 60 days after sowing significantly increased seed cotton yield and nutrient uptake capacity of cotton crop. Two hand weeding carried out at 21 and 42 DAS significantly higher weed control efficiency, crop growth and higher seed cotton yield recorded by Gogai *et al*., (1992). Two hand weeding carried out at 30 and 60 DAS, similar result was observed by Singh *et al*., (1992). Patil *et al*., (1997) advocated that Vidarbha region in cotton crop 20, 40 and 60 DAS time interval hand hoeing and hand weeding showed significantly effect in reducing weed density. Growing full season of hand weeding in cotton significantly decreased the weed density (92%) and increased the plant height, sympodial branches and no. of bolls per plant or seed

cotton yield Mahar *et al*., (2007). Hand weeding at time interval 25 and 45 DAS significantly reduction number of total weed density and total dry weight in cotton highlighted Nithya and Chinnusamy (2013).

Mechanical methods of weed control in cotton : Mechanical weed control starts with the primary and secondary tillage practices. In this method included mowing, mulching different tillage operation such as dry hoeing, deep ploughing and disk harrowing etc. uprooting and shredding of weeds in a field during the early spring season in cotton. They also bury the weed seeds deep layer with in the soil where they will not be able to emerge. Mechanical weed control after the planting of cotton is more successful when the weeds are relatively small. Therefore, cultivating a cotton field early in the season when the weeds are young will give better results than waiting until later. Mechanical weed control is comparatively faster and requires less labour than hand weeding (Chivinge, 1990). Pagar *et al*., (1995) observed that weed free environment through mechanical weeding resulted in high weed control efficacy (WCE) and seed cotton yield as compared to all other treatments. Central Research Institute for Dry Land Agriculture (CRIDA) use the power weeder for control the weeds and saving in labour up to 80 to 87 percent reported Prasad (2006). By applying these techniques they save time and cost remove weeding. This technology gave more relief to the farmers who are facing labour shortage and higher cost of labour during the peak season. Yadav and Pond, (2007) state that mechanical weed control can be applied as an intervention within the crop rows kept the soil surface loose resultant more soil aeration and increased water holding capacity. Leela *et al*., (2016) noticed that mechanical weeding at 20, 40 and 60 days after sowing significantly increased the plant height, crop dry matter, number of bolls, seed yield per plant and of cotton seed yield.

Chemical method : Chemicals that are used to kill plants or weeds are called herbicides. Herbicides have an important role in management of weeds in cotton. Herbicides make the weed control in cotton easy, efficient and economical. Herbicides as an alternative to mechanical control reduce mechanical damage to crops. The sequential application of pre-emergence and post-emergence application of herbicides with kept the weeds under control and favoured to plant growth and development and also improvement in quality characteristics. Their use has been increasing rapidly since 1944 when 2; 4-D was first use as herbicide. In many instance, they offer most practical, effective and economic means for controlling weeds. Successfully weed management by the chemical method always applied recommended dose of herbicides with uniform application in correct way over the target area. Proper calibrations of sprayers with adequate precision tools are very important to increase the herbicides efficacy. Over dose application of herbicides injurious the crops and too low may not be adequate amount weed control in crop field. Hence, it is very important to use the herbicides applications timely and with suitable calibrations for better management of weeds. Most common application of chemical herbicide in agro ecosystem as under;

a) Pre plant incorpation (PPI) e.g. Fluchloralin 45 EC, Trifluralin 48 EC, Metham sodium

b) Pre-emergence application e.g. Pendimethalin 30 EC

c) Post-emergence application e.g. Glyphosate 41 SL, Paraquat Dichloride 24 SL, Pyrithiobac sodium 10 EC, Quizalofop Ethyl 5 EC, Fenoxaprop-p-ethyl 9 EC, Quizalofop Ethyl 4 EC + Pyrithiobac sodium 6 EC (Hitweed maxx)

Today's chemical weed control: Become first choice of farmers

- Due to increase agriculture wages
- Scarcity of labours
- Short duration - effective control
- Easy to handling
- Availability in market

Pre-emergence herbicides for cotton : Pre-emergence herbicides are usually applied before germination or immediately after the sowing the crop but generally prior to crop sowing. Pre-emergence application of soil active herbicides are commonly applied to surface of the soil and these herbicides should be able to move into upper 3.5 to 4 cm of soil under the influence of irrigation to kill the germinating weeds (Gupta, 1998). Their use would be appropriate not only for minimizing early weed competition, but also for reducing the labour requirement and control weeds in the inter row as well as within the row (Nadanasababady, 2001).

Pendimethalin : Nalini *et al*. (2019) observed that new formulation of pre-emergence herbicide pendimethalin 38.7% resulted on growth and development of cotton with effective weed management in a cost effective manner, under irrigated condition. Pendimethalin and trifluralin are the most common herbicides that are applied for a pre-emergence weed control in cotton (Keeling *et al*., 1996). Pendimethalin is pre emergence herbicide used to control grasses and broad leaved weeds in many field crops including cotton. It is selective herbicides belong to dinitroaniline group. Mode of action in plant from absorption by roots and leaves and inhibits cell division, cell elongation and that caused plants die shortly after germination (Tomlin, 1997). Vencill, W. K. (2002) reported that application of pendimethalin (38.7%) @ 2-4 kg ha^{-1} fb one hand weeding at time of 45 days after sowing resulted in effectively control of all broad leaved weeds, grasses weeds and sedges weeds due to its broad spectrum action. Pendimethalin applied at pre-emergence @ 690 g ha^{-1} significantly controlled annual grassy weed species and effective control of broad leaves weed particularly on Amaranthus hybridus and Chenopodium album weed species reported Richardson *et al*., (2007). According to Grey *et al*., (2008) pre-emergence application pendimethalin was applied gave the significantly result in cotton for the control of grasses and broad leaves weeds. Application of pendimethalin at lower dose fb one hand weeding provided significantly higher seed cotton yields than application of pendimethalin herbicides alone at higher doses Gnanavel and Babu (2008). Kumar *et al*. (2020) reported that among the weed management practices, lower weed density was recorded with pre-emergence application of pendimethalin at 1.0 kg/ha and hand weeding twice at 40 and 60 DAS during studied periods of cotton. Mushtaq and Cheema (2008) reported that pre emergence application of pendimethalin @ 1.0 kg ha^{-1} was very effective controlling of broad leaved weeds as well as narrow leaved weed in cotton. The combined practices of pendimethalin + mechanical weeding observed maximum crop growth, higher yield and yield attribute over sole application of chemical weed control reported by Muhammad *et al*., (2009). Rajanand *et al*., (2013) revealed that pre-emergence application of pendimethalin significantly decreased the weed density in cotton field. Pre-emergence application of pendimethalin @ 2.5 letters ha^{-1} significantly reduced weed dry biomass and higher the seed cotton yield (Ali *et al*., 2013).

Post-emergence herbicides for cotton : Post-emergence herbicides work to control weeds after they have already germinated. They work by travelling down the plant stalk and into

the root system to kill the weed. As a post-emergence weed control herbicide it has shown promise in controlling broad spectrum weeds in cotton at low application rates with no adverse effect on seed cotton yield.

Glyphosate : Direct application of glyphosate at 8-10 leaf stage of cotton (30-35 DAS) caused phytotoxicity on crop due to drift hazards observed by Patil *et al*., (2003). They concluded that direct two times application of glyphosate controlled 90-95% all types of weeds in cotton, three times was no advantage over glyphosate applied twice. They also recorded early post-emergence (3-4 weeks) application of glyphosate obtained higher seed cotton yield as compared to mid post-emergence (6-7 weeks). According to Deshpande *et al*., (2006) the combination of post-emergence application glyphosate + two hand weeding and two hoeing at 20 and 40 days after sowing recorded maximum weed control efficiency in cotton crop. Protected spray of glyphosate (0.5%) integrated with pendimethalin or paraquat (0.3%) with pyrithiobac sodium fb quizalofop-p-ethyl being at par with three mechanical weeding (at 20, 40 and 60 DAS) helped to significantly reduce the population and dry weight of weeds at 90 DAS over weedy check (Punia *et al*. 2019). Singh and Kakate (2010) reveals that that combined pre-emergence and post-emergence application of non-selective herbicides glyphosate @ 1.0 kg ha^{-1} provides maximum (96%) weeds control as compare this was followed by glyphosate alone with 90 percent weed control.

Pyrithiobac sodium : Pyrithiobac sodium is new herbicides for cotton crop, used as post-emergence in cotton. It has great capacity to control broad leaved weeds in cotton without any harmful effect on seed cotton yield. There was no yield loss in cotton using post-emergence application of pyrithiobac at 105 g ha^{-1} reported Allen *et al*., (1997). Chaudhari *et al*., (2017) observed that pre-emergence application of pendimethalin 1000 g ha^{-1} fb hand weeding twice at 20 and 50 DAS, and pyrithiobac-sodium + quizalofop-p-ethyl (62.5 + 50 g ha^{-1}) as post-emergence fb directed spray of glyphosate 2000 g ha^{-1} at 60 DAS recorded significantly lower weed dry biomass as well as higher seed cotton yield and benefit cost ratio as compared to rest of the treatments. The weed control efficiency of these treatments proved to be 90 and 86% during 2014 and 2015 respectively. According to Branson *et al*., (2005) cotton new herbicides pyrithiobac sodium and trifloxysulfuron tank mixed with glyphosate at post-emergence application to significantly increase the control of troublesome weeds in cotton. Herbicide mixture containing pyrithiobac sodium + quizalofop ethyl at @ 100-125 g ha^{-1} can be recommended for broad spectrum weed control in cotton without any phytotoxic effect on cotton and without any residual effect on succeeding crops reported by Madhavi *et al*., (2015).

Quizalofop ethyl : According to Rao (2011) tank mix application of pyrithiobac sodium and quizalofop ethyl gives higher seed cotton yield instead of singly applied in cotton, but in other hand tank mixtures of pyrithiobac sodium + fenoxaprop ethyl and clodinafop propargyl significantly higher controlled broad spectrum weeds and 98% higher seed cotton yield than weedy check treatments. Application of tank mixed post-emergence herbicides pyrithiobac sodium + quizalofop ethyl at rate of 100-125 g ha^{-1} significantly controlled grassy and broadleaf weeds in cotton and no any phytotoxicity effect on the crop or without any residual effect in soil reported by Madhavi and Ramprakash (2015). Punia *et al*. (2019) found that irrigated cotton in Haryana conditions, application of pendimethalin @ 1.0 kg ha^{-1} supplemented with other two hoeing at 20 and 50 DAS or one hoeing and post-emergence

application of quizalofop-p-ethyl at 60 g/ha or one hoeing and post-emergence application of propaquizafop-p-ethyl at 62.5 g ha^{-1} at 60 DAS caused significant reduction in density and dry weight of weeds as compared to weedy check up to harvest in both the (2014 & 15) years.

Biological control : Last several decades, the concept of biological control/bio-herbicides of weeds in cotton has received significant interest. A considerable diversity of biological agents has been used to control weeds, includes the insects, plant pathogens, fungi, snails, mites, intercrops, herbivores fish, birds like geese, duck, rabbits and nematodes etc. However, these biological methods have shown limited successes in effective control of weeds in agronomic crops. Biological control must be implemented with a combination of management practices in order to increase their efficacy.

Challenges faced by IWM in present scenario

- Emergence of feral (wild) crops
- Herbicide resistance
- Effect of climate change
- Evidence of weed developing

	Biological methods
Insects	*Mexican beetle, Crocidosema lantana, Dactylopius tomentosus, Agasicleshygrophyla*
Plant pathogen	*Mycoherbicides (Devine, Collego)*
Herbivores fish	*Carp fish, Chinese grass carp, Fresh water, carp fish, white amur*
Snails	*Merisa cornuoritis & fresh water snails*
Mites	*Teranychus sp. (control prickly pear)*
Fungi	*Rhizoctina blight (control water hyacinth)*
Plants	*Cowpea as intercrop in sorghum*
Rabbit and rodents	*Bio-fauna*

- Shifting in weed flora
- Production of higher yields while conversion environment
- Eco-friendly cotton production
- Biotechnological perspectives
- No available antidote
- Policy perspectives

Conclusion

Based on the critical study of the previous work on weed management in cotton crop, the present review conclude that, suitable time and appropriate weed management strategy is essential for economical cotton cultivation. The famers need to be aware about weed flora in *Bt* cotton their critical stage, productivity losses, impaired fiber quality and appropriate weed management practices. The greatest weed competition usually occurs at the initial stage of growing period of crop 30 to 60 days after sowing. Pre and post-emergence application of chemical herbicides has the initial advantage to cotton over the traditional method. To ensure high crop yield, weed management programme require holistic approach, rely on mechanical, chemical or biological control practices to keep weeds pressure below the threshold levels that reduce yields, qualities and quantities. Hence, successful cotton production depends on the integration of different weed management strategy (IWM) would be a better option for broad spectrum management of weeds and enhancement of cotton productivity with maintaining the sustainability in ecosystems.

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Herbage Yield and Quality of Ryegrass (*Lolium Multiflorum* Lam) as Influenced by Nitrogen and Phosphorus Management

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Abstract

A field experiment was carried out at Forage Section Research Farm of CCS Haryana Agricultural University, Hisar (Haryana), India during *Rabi* (winter) season to study the effect of different nitrogen and phosphorus levels on annual ryegrass (*Lolium multiflorum*). Among different N levels, significantly highest green fodder yield (GFY) was recorded at N3 (80 kg N ha^{-1} at sowing + 20 kg N ha^{-1} at three weeks after sowing + 40 kg ha^{-1} N after each cut). The total green fodder and dry matter yield recorded with 220 kg N ha^{-1} were 28.10, 10.40 and 35.51, 8.80 per cent higher over 120 and 170 kg N ha^{-1} respectively. Highest *in-vitro* dry matter digestibility (IVDMD) content (62.34%) was estimated with 220 kg N ha^{-1} which was on a par with 170 kg N ha^{-1}. However, maximum digestible dry matter yield (35.91 q ha^{-1}) was estimated with 220 kg N ha^{-1} which was significantly higher over the lower nitrogen levels. Among different phosphorus levels, highest GFY was recorded at P_3 (50 kg P_2O_5 ha^{-1}) which was on a par with P_2 (40 kg P_2O_5 ha^{-1}). The green fodder and dry matter yield recorded with 50 kg P_2O_5 ha^{-1} were 3.78, 22.79 and 4.72, 35.51 per cent higher over 40 and 30 kg P_2O_5 ha^{-1} respectively. Crude protein content and IVDMD content were not affected significantly. However, maximum crude protein yield (5.63 q ha^{-1}) digestible dry matter yield (34.90 q ha^{-1}) were estimated with 50 kg P_2O_5 ha^{-1} which were on a par with 40 kg P_2O_5 ha^{-1}. To realize the higher forage yield and better nutritive value of ryegrass, application 220 kg N (80 kg N ha^{-1} as basal + 20 kg N ha^{-1} as topdressing at 3 WAS + 40 kg ha^{-1} N just after each cut) and 40 kg P_2O_5 ha^{-1} is recommended for soils low in available nitrogen and medium in phosphorus.

Key words : Fodder yield, nitrogen management, phosphorus levels and ryegrass.

The Indian land mass has to generate nutritional support to a huge livestock (535.78 million), poultry (851.81 million) (Anonymous, 2020a), human beings (1,352.64 million) (Anonymous, 2019), populations besides an additional vast population of pet and stray canines, wild life and a vast populations of fauna. This raises a relevant, question as to how effective is our land use and how it will sustain such a large population in future. The three main sources of forage supply are crop residues, cultivated fodders and forage from common property resources like forests, permanent pastures and grazing lands which are presently contributing 54, 28 and 18 per cent, respectively. Currently, India faces a challenge to feed its livestock population (Anonymous, 2020b). Feeding the large livestock population of our country with quality fodder uniformly throughout the year is a major challenge for the farmers. Country faces a net deficit of 36% and 11% of green fodder and dry fodder, respectively (IGFRI Vision, 2050). Growth of the grasses is monsoon bound and winter months are considered as the lean period for supply of fodder. Ryegrass (genus *Lolium*) is a genus of about 10 species in the family Poaceae. Perennial ryegrass (*Lolium perenne*) and annual ryegrass (*L. multiflorum*) are important constituents of pasture and lawn-seed mixtures used around the world and particularly in temperate parts of Eurasia (Europe and Asia)

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and Africa (Anonymous, 2020c). *Lolium multiflorum* (Italian ryegrass/annual ryegrass/ westerwold ryegrass) hybridizes freely with *L. perenne* (*L. x hybridum*), *L. rigidum* (*L. x hubbardii*), *L. temulentum* and *L. remotum*. The variability of this species and its tendency to form tetraploids has resulted in the development of a number of tetraploid cultivars which are commercially available as high-yielding pasture grasses (Anonymous, 2020d). Annual ryegrass (*Lolium multiflorum* Lam) is a cool season annual bunchgrass native to Southern Europe. It is genetically diverse and displays a high degree of phenotypic plasticity which means the grass is highly adaptable. Although, this cereal fodder is recently introduced in India but area under this grass is increasing continuously because it is a fast germinating, quick growing and outstanding winter fodder crop with high palatability and nutritive value. The productivity and number of cuttings of annual ryegrass depends on fertilizer dose and proper time of its application. As the grass is highly responsive to nitrogen and phosphorus fertilization, the experiment was undertaken to study its effect on fodder yield and quality of ryegrass.

Materials and Methods

A field experiment was conducted during winter season of 2016-17 at Forage Section Research Farm of CCS Haryana Agricultural University, Hisar (Haryana), India situated at 29°10' N latitude, 75°46' E longitude, and altitude of 215.2 m above mean sea level. The site has semi-arid and sub-tropical climate with hot dry summer and severe cold winter. Average annual rainfall is about 450 mm, 75 per cent of which is received in three months, from July to September during south-west monsoon. Fig. 1 represents the weekly weather parameters i.e. temperature - minimum and maximum (°C), relative humidity of morning and evening (%) and rainfall (mm). The soil of the experimental field was sandy loam in texture, slightly alkaline in reaction (pH 8.0), low in available nitrogen (128.5 kg ha^{-1}), medium in available phosphorus (12.0 kg ha^{-1}) and potassium (212.0 kg ha^{-1}). The experiment was laid out in factorial randomized block design with three replications. The two factor trial comprised of three nitrogen (N_1 - 120, N_2 - 170 and N_3 - 220 kg N ha^{-1}) and three phosphorus levels (P_1 - 30, P_2 - 40 and P_3 - 50 kg P_2O_5 ha^{-1}). The schedule of N application in N_1 - 40 kg N ha^{-1} as basal +

Table 1. Yield attributes and yield of annual ryegrass at different N and P levels (Total 4 cuts)

Treatments	No. of tillers mrl^{-1}	Plant height (cm)	Total GFY (q ha^{-1})	Total DMY (q ha^{-1})
N level (kg N ha^{-1})				
N_1 - 120	239.43	47.51	313.70	42.50
N_2 - 170	260.09	51.05	363.98	52.93
N_3 - 220	278.10	54.89	401.85	57.59
SEm±	1.53	0.57	5.17	0.89
C.D. (P=0.05)	4.48	1.67	15.17	2.61
P Levels (kg P_2O_5 ha^{-1})				
P_1 - 30	248.74	47.84	316.48	41.93
P_2 - 40	262.30	52.00	374.44	54.26
P_3 - 50	266.58	53.60	388.61	56.82
SEm±	1.53	0.57	5.17	0.89
C.D. (P=0.05)	4.48	1.67	15.17	2.61
N x P				
SEm±	2.64	0.99	8.95	1.54
C.D. (P=0.05)	7.76	NS	NS	NS

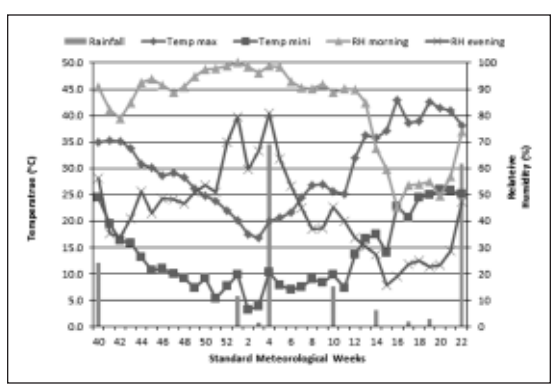

Fig. 1. Weekly weather parameters during the crop season (*Rabi* 2016-17)

20 kg N ha^{-1} as topdressing at 3 WAS (weeks after sowing) + 20 kg ha^{-1} N just after each cut, N_2 - 60 kg N ha^{-1} as basal + 20 kg N ha^{-1} as topdressing at 3 WAS + 30 kg ha^{-1} N just after each cut and N_3 - 80 kg N ha^{-1} as basal + 20 kg N ha^{-1} as topdressing at 3 WAS + 40 kg ha^{-1} N just after each cut. The full dose of phosphorus as per treatment was applied as basal in all treatments. The ryegrass variety used in the trial was Makkhan grass. The sowings was done on November 10, 2016; in rows at 30 cm apart using the seed rate of 15 kg ha^{-1}. Total four cuts were taken in all the treatments. First cut was taken 50 days after sowing and rest of the cuts were taken at 25-30 days interval of the previous cut. The harvested green fodder from each plot was weighed in situ and then converted into q ha^{-1}. A random sample of 500 g was taken from each plot at the time of green fodder at harvest, chopped well and put into paper bag. These bags were aerated by making small holes all over. The samples were first dried in the sun for 15 days and then transferred in an electric hot air oven for drying at a temperature of 60±5°C till constant weight was achieved. On the basis of dry weight of these samples, the green fodder yield was converted into dry matter yield (q ha^{-1}). Crude protein content and in-vitro dry matter digestibility (IVDMD) were estimated in dried and grinded samples (2 mm sieve size), collected at first cut. The crude protein content was calculated by multiplying the nitrogen percentage with 5.83 estimated by conventional micro-Kjeldhal method (AOAC, 1995). IVDMD was determined by method of Barnes *et al*. (1971). Crude protein yield and digestible dry matter yield were calculated by the multiplication of crude protein content (%) and in vitro dry matter digestibility (%) with dry matter yield (q ha^{-1}), respectively. The experimental data were analyzed by using OPSTAT software available on CCS Haryana Agricultural University home page (Sheoran *et al*., 1998).

Results and Discussion

Nitrogen levels : Among different nitrogen levels, highest number of tillers mrl^{-1} and plant height (278.10, 54.89 cm, respectively) were recorded with 220 kg N ha^{-1} which were significantly superior over the other two lower levels of nitrogen. Similar trend was observed for green fodder yield and dry matter yield (401.85 and 57.59 q ha^{-1}, respectively) being significantly highest with 220 kg N ha^{-1}. The total green fodder and dry matter yield recorded with 220 kg N ha^{-1} were 28.10, 10.40 and 35.51, 8.80 per cent higher over 120 and 170 kg N ha^{-1} respectively. The results are in conformity with Sarma *et al*., (2020). Sidhu *et al*., (2020) also reported improvement in fodder yield and quality of ryegrass with increasing levels of nitrogen up to 160 kg N ha^{-1}. The cut-wise green fodder and dry matter yield as influenced by different nitrogen levels is shown in Fig. 2 and Fig. 3, respectively. Highest crude protein content (10.15%) was estimated with 220 kg N ha^{-1} which was on a par with 170 kg

Table 2. Quality of annual ryegrass as influenced by different N and P levels

Treatments	Crude protein content (%)	IVDMD (%)	Crude protein yield (q ha^{-1})	Digestible dry matter yield (q ha^{-1})
N level (kg N ha^{-1})				
N_1 - 120	9.14	59.05	3.88	25.05
N_2 - 170	10.04	62.28	5.32	33.03
N_3 - 220	10.15	62.34	5.85	35.91
SEm±	0.08	0.71	0.12	0.86
C.D. (P=0.05)	0.23	2.10	0.36	2.60
P Levels (kg P_2O_5 ha^{-1})				
P_1 - 30	9.69	60.65	4.09	25.5
P_2 - 40	9.77	61.91	5.33	33.6
P_3 - 50	9.86	61.12	5.63	34.9
SEm+	0.08	0.71	0.12	0.86
C.D. (P=0.05)	NS	NS	0.36	2.60
N x P				
SEm±	0.14	1.24	0.21	1.49
C.D. (P=0.05)	NS	NS	NS	NS

Table 3. Nutrient content and uptake of annual ryegrass as influenced by different N and P levels

Treatments	N content (%)	P content (%)	N uptake (kg ha^{-1})	P uptake (kg ha^{-1})
N level (kg N ha^{-1})				
N_1 - 120	1.57	0.44	66.85	18.96
N_2 - 170	1.72	0.45	93.26	24.08
N_3 - 220	1.74	0.47	102.63	26.93
SEm±	0.02	0.004	2.38	0.57
C.D. (P=0.05)	0.06	0.01	7.19	1.73
P Levels (kg P_2O_5 ha^{-1})				
P_1 - 30	1.66	0.42	70.69	17.70
P_2 - 40	1.68	0.46	94.46	25.01
P_3 - 50	1.69	0.48	97.60	27.26
SEm±	0.02	0.004	2.38	0.57
C.D. (P=0.05)	NS	0.01	7.19	1.73
N x P				
SEm±	0.03	0.01	4.12	0.99
C.D. (P=0.05)	NS	NS	NS	NS

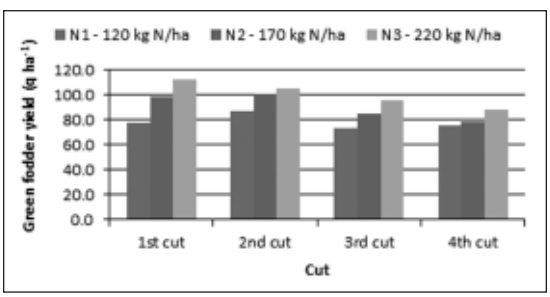

Fig. 2. Cut wise green fodder yield of ryegrass at different nitrogen levels

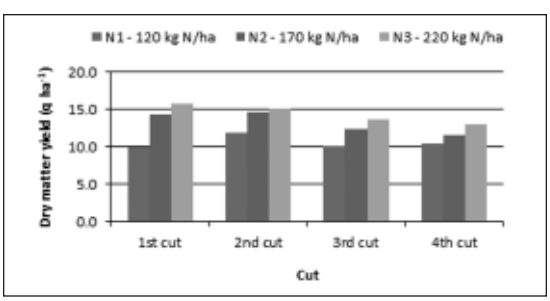

Fig. 3. Cut wise dry matter yield of ryegrass at different nitrogen levels

N ha^{-1}. Crude protein content is the function of per cent nitrogen content. There was better assimilation of N in the presence of higher nitrogen levels resulting on increased protein synthesis (Bora *et al.*, 2020). However, maximum crude protein yield (5.85 q ha^{-1}) was estimated with 220 kg N ha^{-1} which was significantly higher over the lower nitrogen levels. Crude protein yield depends on crude protein content and dry matter yield and further the higher dry matter at 220 kg N ha^{-1} increased the crude protein yield significantly. Among different nitrogen levels, highest IVDMD content (62.34%) was estimated with 220 kg N ha^{-1} which was on a par with 170 kg N ha^{-1}. However, maximum digestible dry matter yield (35.91 q ha^{-1}) was estimated with 220 kg N ha^{-1} which was significantly higher over the lower nitrogen levels. Maximum N and P content (1.74 and 0.47%) was estimated with 220 kg N ha^{-1} which was significantly higher over the lower N levels for N content but for P content on a par with 170 kg N ha^{-1}. Highest N and P uptake (102.63 and 26.93 kg ha^{-1}, respectively) was also estimated with 220 kg N ha^{-1} which was significantly higher over the lower N levels for N and P uptake.

Phosphorus levels : Among different phosphorus levels, highest number of tillers/mrl (266.58) and plant height (53.6 cm) were recorded with 50 kg P_2O_5 ha^{-1} which were on a par with 40 kg P_2O_5 ha^{-1} but significantly superior over 30 kg P_2O_5 ha^{-1}. Similar trend was observed for green fodder yield and dry matter yield (388.61 and 56.82 q ha^{-1}, respectively) being significantly highest with 50 kg P_2O_5 ha^{-1} and being on a par with 40 kg P_2O_5 ha^{-1}. The green fodder and dry matter yield recorded with 50 kg P_2O_5 ha^{-1} were 3.78, 22.79 and 4.72, 35.51 per cent higher over 40 and 30 kg P_2O_5 ha^{-1} respectively. The cut wise green fodder and dry matter yield as influenced by different phosphorus levels is shown in Fig. 4 and Fig. 5, respectively. Crude protein content

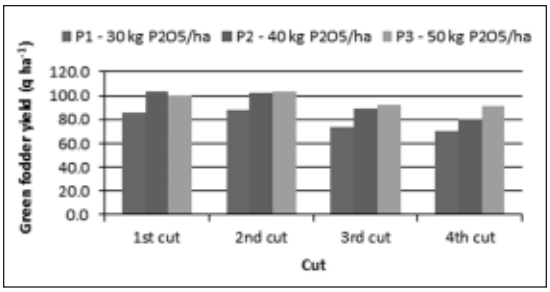

Fig. 4. Cut wise green fodder yield of ryegrass at different phosphorus levels

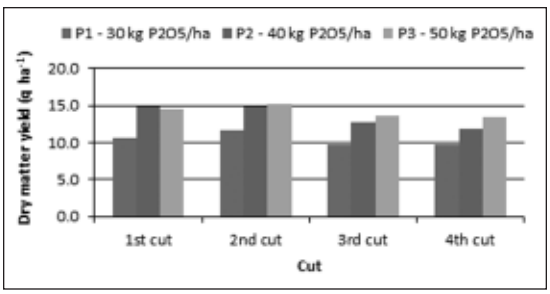

Fig. 5. Cut wise dry matter yield of ryegrass at different phosphorus levels

and IVDMD content were not affected significantly. However, maximum crude protein yield (5.63 q ha^{-1}) digestible dry matter yield (34.90 q ha^{-1}) were estimated with 50 kg P_2O_5 ha^{-1} which were on a par with 40 kg P_2O_5 ha^{-1}. The crude protein and digestible dry matter yields recorded with 50 kg P_2O_5 ha^{-1} were 5.63 & 37.65 and 3.87 and 36.86 per cent higher over 40 and 30 kg P_2O_5 ha^{-1}, respectively. CPY and DDMY are influenced by the dry matter yield directly. The estimated N content at different P levels was not affected significantly. However, maximum P content (0.48%) was estimated with 50 kg P_2O_5 ha^{-1} which was significantly higher over the lower P levels. Highest N and P uptake (97.60 and 27.26 kg ha^{-1}, respectively) was also estimated with 50 kg P_2O_5 ha^{-1} which was significantly higher over the lower N levels for N and P uptake.

Conclusion

Based on the results, it can be concluded that the soils of semi-arid ecosystem (low in available nitrogen and medium in available phosphorus) responded well to the applied nitrogen and phosphorus in annual ryegrass crop. The application of the 80 kg Nitrogen+40 kg P_2O_5 as basal dose followed by 20 kg N ha^{-1} as topdressing at three Weeks after sowing and 40 kg N ha^{-1} just after each cut per hectare may be recommended to realize higher fodder yield of ryegrass.

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Effect of Foliar Application of Water Soluble Fertilizers on Growth and Yield of Hybrid Tomato cv. Phule Raja

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Abstract

The investigation was conducted on hybrid tomato cv. Phule Raja at Tomato Improvement Scheme, MPKV., Rahuri during *rabi* season of 2017-18, 2018-19 and 2019-20. Foliar application of three water soluble fertilizers NPK 19:19:19, 00:52:34 and 13:00:45 at different crop growth stages and in different concentrations was experimented along with soil application of gross recommended fertilizer dose for hybrid tomato. The experiments were laid out in a randomized block design with eleven treatments and three replications. The results of the experiments revealed that The maximum plant height(177.79 cm), fruit Weight (87.98 g), pericarp thickness (6.65 mm), equatorial diameter (5.09 cm) and Yield (2.07 kg plant^{-1}, 73.03 kg plot^{-1} and 61.41 t ha^{-1}) recorded in treatment T5 i.e. combination of 87.5% GRDF i.e. 262.5:131.25:131.25 kg NPK ha^{-1} with foliar application of WSF 19:19:19 (1.5%) at 15, 30 and 45 DAT, 00:52:34 (1.5%) at 60, 75 and 90 DAT and 13:00:45(1.5%) at 105 and 120 DAT.

Key words :

Tomato (*Lycopersicon esculentum* L.), is a member of Solanaceae family originated from Andean region. It is mostly used as a fresh vegetable, salad and also as processed products like paste, juice, sauce and powder or as a whole. Tomato is important source of minerals, vitamins, and antioxidants (Grierson and Kader, 1986). It is grown all over the world in India it occupying an area of about 0.81 M ha with production about 20.51 m MT and having productivity 16.1 MT ha^{-1} Production share of India to different countries are 11.2% (NHB 2018-2019). Success of tomato cultivation depends on careful application of fertilizers. The efficiency of fertilizers applied to soil is generally low due to various losses like fixation. Foliar application, of liquid fertilizers found beneficial to improve yield and quality of different vegetable crops. Water soluble fertilizers are used as foliar spray. Water soluble fertilizers are generally considered 100% soluble in water having low salt index to reduce the potential for burning of plant tissue and suitable for foliar application or fertigation. The NPK combination are starter grades (19:19:19) for growth in middle stage and mono-potassium phosphate (0:52:34); potassium nitrate (13:0:45) for sugar conversion and disease resistance. (Malhotra, S. K. 2016). Use of liquid or water soluble fertilizers in India is meagre in comparison to

developed countries. (Patel 2011). The present study was undertaken in hybrid tomato cv. Phule Raja to study the effect of foliar spray fertilizers, in combination with GRDF on growth and yield attributes of tomato.

Material and Methods

The investigation was carried out at Tomato Improvement Scheme, Department of Horticulture, MPKV., Rahuri during the *rabi* season of 2017-18, 2018-19 and 2019-20, to study the effect of water soluble fertilizers on growth and yield in hybrid tomato. Hybrid tomato cv. Phule Raja was selected for the study. The experimental field is irrigated and soil type is medium black. The experimental plots were of size 3.6m x 3.3 m. The seedlings were transplanted at the spacing of 90 x 30 cm. Three water soluble fertilizers NPK 19:19:19, 00:52:34 and 13:00:45 were selected for the study along with Gross Recommended Fertilizer Dose of hybrid tomato. GRDF of hybrid tomato is 300:150:150 kg NPK ha^{-1}. Foliar application of WSF NPK 19:19:19 was carried out on 15, 30 and 45 DAT. NPK 00:52:34 applied on 60, 75 and 90 DAT and NPK 13:00:45 applied on 105 and 120 DAT. Observations regarding plant height, fruit weight, polar and equatorial diameter of fruit, pericarp thickness, yield per plant and yield pot^{-1} were recorded. The experiment was laid out in RBD with eleven treatments and three replications. Treatment details are given in Table 1.

Result and Discussion

The pooled data recorded in Table 2 shows that the plant height significantly varied with the foliar application of water soluble fertilizers. The treatment T5 consist of 87.5% GRDF i.e. 262.5:131.25:131.25 kg NPK ha^{-1} with foliar application of 1.5% of water soluble fertilizers NPK 19:19:19, 00:52:34 and 13:00:45 recorded maximum (177.79 cm) plant height. Lowest plant height (150.01cm) observed in Control (T1). The increase in plant height might be due to more availability of macro and micro nutrients by soil and foliar application (Patil *et al*., 2008).

The maximum fruit Weight (87.98 g), pericarp thickness (6.65 mm) were recorded in treatment T5. The better supply of K with its split application and supplementation of secondary and micro nutrients might have enhanced the fruit size, fruit weight and pericarp thickness. (Batra et al., 2002). Treatment T5 recorded highest equatorial diameter (5.09 cm) and lowest polar diameter (3.33 cm). Fruit diameter might be increased due to uptake of nutrients and better utilization of photosynthesis resulting in food accumulation in edible parts (Guievence and Badem, 2000).

Table 2 pooled data of treatments indicates that treatment T5 recorded maximum Yield (2.07 kg $plant^{-1}$, 73.03 kg $plot^{-1}$ and 61.41 t ha^{-1}). The optimum supply of N and phosphorus causes better synthesis of cytokine which results in more number of fruits (Premsekhar and Rajashree, 2009). There are also reports on higher fruit setting by soil or foliar supplementation of secondary and micro

Table 1. Treatment details

Treatment	GRDF (300:150:150 kg NPK $ha)^{-1}$ (%)	WSF dose (%)		
		19:19:19	00:52:34	13:00:45
T_1 (Control)	100	-	-	-
T_2	100	0.5	0.5	0.5
T_3	100	1	1	1
T_4	87.5	1	1	1
T_5	87.5	1.5	1.5	1.5
T_6	75	1.5	1.5	1.5
T_7	75	2	2	2
T_8	62.5	2	2	2
T_9	62.5	2.5	2.5	2.5
T_{10}	50	2.5	2.5	2.5
T_{11}	50	3	3	3

Table 2. Effect of foliar application of water soluble fertilizers on growth and yield of hybrid tomato cv. Phule Raja (Pooled mean of three years)

Treatments	Plant height (cm)	Fruit weight (g)	Diameter (cm)		Pericarp thickness cm)	Yield plant-1 (kg)	Yield plot-1 (kg)	Yield (t ha-1)
			Polar	Equatorial				
T_1	150.01	75.58	5.40	4.50	6.40	1.53	58.00	46.92
T_2	153.87	78.07	5.23	4.72	6.16	1.77	64.80	54.78
T_3	157.42	80.34	5.22	4.81	6.49	1.90	68.11	57.53
T_4	169.80	82.24	5.08	4.91	6.43	1.86	67.28	56.77
T_5	177.79	87.98	3.33	5.09	6.65	2.07	73.03	61.41
T_6	171.21	79.71	5.45	5.02	6.23	1.83	66.74	55.89
T_7	168.98	83.67	5.18	4.94	6.62	1.98	70.46	59.17
T_8	169.69	79.66	5.20	4.85	6.34	1.71	61.78	51.38
T_9	155.59	82.83	5.25	5.04	6.19	1.69	63.92	53.79
T_{10}	155.96	80.02	5.19	4.98	5.98	1.69	62.58	52.42
T_{11}	162.49	79.66	5.18	4.87	6.33	1.71	60.05	51.21
S.E. ±	6.34	1.15	0.33	0.17	0.16	0.05	1.14	1.22
C.D. at 5%	18.71	3.41	0.98	0.50	0.49	0.14	3.37	3.62

nutrients which may be attributed to supply of nutrients at critical stage i.e. at flowering and fruit set (Naik *et al.*, 2002).

Conclusion

From the study it can be concluded that, the T5 treatment i.e. combination of 87.5% GRDF i.e. 262.5:131.25:131.25 kg NPK/ha with foliar application of WSF 19:19:19 (1.5%) at 15, 30 and 45 DAT, 00:52:34 (1.5%) at 60, 75 and 90 DAT and 13:00:45(1.5%) at 105 and 120 DAT found to be highly beneficial for maximizing the yield of hybrid tomato cv. Phule Raja in *rabi* season.

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Estimation of Crop Coefficients Based on Normalize Difference Vegetation Index

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Abstract

Crop coefficient is one of the most important parameters used for the estimation of crop evapotranspiration (ETc). Crop coefficient (Kc)-based estimation of crop evapotranspiration is most commonly used methods for irrigation water management. However, crop coefficient approach used for estimation ETc using the generalized crop coefficients mentioned in Irrigation and Drainage Paper No. 56 of the Food and Agricultural Organization of the United Nations can contribute to crop evapotranspiration estimates that are substantially different from actual crop evapotranspiration. The colinear relationship between the crop coefficient curve and a satellite-derived Normalized Difference Vegetation Index (NDVI) showed potential for modeling a crop coefficient as a function of the NDVI, which is also one among the methods used for estimation of ETc in irrigation water management. The present study was conducted with objectives to present the techniques and procedures to develop and estimates Kc based on vegetation index (NDVI) extracted from satellite data. The relationships between and NDVI and crop coefficients (Kc) of wheat and chickpea for corresponding months were developed. The regression models developed are: $(Kc)_{NDVI}$ = 6.3268*NDVI-1.4207 for wheat and $(Kc)_{NDVI}$ = 5.7866 * NDVI-1.6699 for chickpea. The models showed strong relationships with R^2= 0.86 and R^2=0.84 for wheat and chickpea, respectively. The model and techniques to develop and estimate crop coefficients can be used in other regions in the global, and hence estimate crop evapotranspiration. The crop coefficients (Kc) estimated based on NDVI are useful for irrigation scheduling, evaluating irrigation performance, irrigation water management, and estimation of water use efficiency.

Key words : NDVI, Crop coefficient, Sentinel, Remote sensing and GIS, Sina command area, India.

Crop coefficient is a ratio between the actual crop evapotranspiration (ETc) under the standard condition and the reference crop evapotranspiration (ETo). The Kc values integrate crop characteristics, which are, crop type, climate, and growing stages and integrated or averaged effects of evaporation from the soil surface (Allen *et al*. 1998). Crop coefficient (Kc) can be estimated by applying different methods, but mainly, conventional and remote sensing. The conventional method uses two approaches, the first is single Kc approach, this method integrates the relationship between ETc and ETo into a time-averaged Kc curve that does not separate evaporation and transpiration. The second, is the dual Kc approach, this approach separates Kc into the algebraic sum of a basal crop coefficient (Kcb) and a wet soil evaporation coefficient (Ke) and it account separately evaporation and transpiration (Allen *et al*, 1998). Basal crop coefficient (Kcb) is the ration between crop evapotranspiration (ETc) to the reference evapotranspiration (ETo) at a dry soil surface and with a little soil evaporation and at a potential rate of transpiration (Wright 1982; Allen *et al*., 1998, Allen; 2000; Singh and Irmak, 2015). The basal crop coefficient represents crop transpiration and their Kc values have to be adjusted for surface soil moisture condition. Between the two, a dual approach is preferred mostly for better estimation of Kc values, particularly for daily basis irrigation

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scheduling. It is very difficult to accurately estimate the crop coefficient by dual due to the dynamic of soil water content in space and time, which also be challenging tasks in the computation of crop evapotranspiration (ETc) especially in regional scale.

Single Kc approach has mainly used conventional methods by the researchers, but this method has some errors in estimating crop evapotranspiration ETc due to the empirical nature, especially when used with different climatic conditions away from where it or they were developed. For these reasons, Kc values have to be calibrated to overcome these errors.

Remote sensing is a powerful and effective technology that overcome all issues of conventional single crop coefficient method and the potential exists for estimating locally calibrated Kc curves. The Kc values derived from remotely sensed data provides information about the level of crop stand in the field (Bausch and Neale 1987; Singh and Irmak, 2015), crop development stage (Neale *et al*. 1989; Singh and Irmak, 2015), crop conditions (Bausch 1993; Singh and Irmak, 2015), water stress conditions (Bausch 1993; Singh and Irmak, 2015), and some of the management practices (Bausch and Neale 1987; Singh and Irmak, 2015).

Researchers have been using vegetation indices derived from multispectral remote sensed data or images to estimate crop coefficient (Kc) values at the field scale of corn (Bausch and Neale 1987; Bausch and Neale 1989; Bausch, 1995 and Singh and Irmak, 2015), wheat (Hunsaker *et al*. 2005 and Singh and Irmak, 2015), cotton (Hunsaker *et al*. 2003), and beans (Jayanthi *et al*. 2001 and Singh and Irmak, 2015). Singh and Irmak (2009) developed a regression model of type "Kcr = a NDVI + b" to establish the relationship between the NDVI and the ETo-based crop coefficients (Kc) for corn, soybeans, sorghum, and alfalfa. The results showed that, the coefficient of variation for NDVI and that of Kc of crops were lower during the midseason as compared to the early and late growing seasons. High values of coefficient of variation (CV) during early growing seasons can be attributed to differences in planting dates between the fields, whereas high CV during rate season can be attributed to differences in maturity dates of the crops, variety, and management practices. All crops showed a good relationship between Kc and NDVI except alfalfa. This approach is can be a useful tool for a large scale estimation of crop evapotran-spiration using the crop coefficient and reference evapotranspiration approach. Jorge *et al*. (2010) developed the linear relationship between NDVI and Kc considering maximum and minimum NDVI and corresponding maximum and minimum Kc values to determine the reflectance-based crop coefficients for corn. The relationship is Kcb-NDVI =1.37(NDVI)-0.017 with R^2=0.99. They converted this into grass-based Kcb using Kcb =1.36*(NDVI) - 0.031 relationship. The developed relationship facilitates computations of transpiration, considering only points over dry soil, but also without limiting transpiration. Water soil balance must be considered to get the important contribution of evaporation in crop coefficient from the soil to the crop coefficient during the days after irrigation or rainfall.

Kadam (2014a) developed linear, exponential, logarithmic, power, and second-order polynomial type of relationships between Kc, and NDVI by considering the growth and decline phases independently during the total crop growth period. The analysis showed that the best relationship of a second order polynomial with the maximum coefficient of determination (R^2) for sorghum being ($KcL=0.354(NDVIspg)^2 + 0.504(NDVIspg) + 0.329$, $R^2= 0.974$), chickpea being ($KcL=1.147*(NDVIspg)^2 - 0.747*(NDVIspg) + 0.977$, $R^2 = 0.993$) and wheat (KcL =

0.317*(NDVIspg)^2 + 0.562*(NDVIspg)+0.539, R2= 0.999). Pimpale *et al*. (2014a) estimated the spatial crop coefficient of chickpea using remote sensing and GIS. Using a standardized FAO56 Penman-Monteith approach for estimating ETc from reference evapotranspiration and tabulated generalized Kc. It was observed that, the pattern of vegetation index (VI) during the growing period is similar to the corresponding crop coefficient pattern. Also, a regression model was developed to establish the relationship between Normalized Difference Vegetation Index and the crop coefficients for chickpea crop, It was found that there exists a good linear relationship between Kc and NDVI (Kc_{PM} = 3.094 NDVI - 0.354) with the value of coefficient of determination (R^2) being 0.874 and a low root mean square difference. The results indicated that, the approach can be a very useful tool for estimation of spatial evapotranspiration of a large scale using the estimated crop coefficient. Kadam (2014 b) estimated Kcr, Kcrs, and Kca values for sorghum, chickpea, and wheat crops using "KcL-NDVIspg approach", "KcL-NDVIimg approach" and "Kc-analytical approach". The same 2 x 2 IRS LISS-III pixels selected for estimation of ETc were used to estimate Kc for these crops. The Kcr, Kcrs, and Kca values varied from 0.36 to 0.99, 0.35 to 0.96, and 0.76 to 1.0, respectively for sorghum. The Kcr, Kcrs, and Kca values varied from 0.17 to 1.20, 0.22 to 1.21, and 0.74 to 0.92, respectively for chickpea. The Kcr, Kcrs, and Kca values varied from 0.37 to 1.37, 0.29 to 1.38, and 0.33 to 1.01, respectively for wheat.

The main objective of the present study was to investigate the applicability of NDVI from Sentinel 2 satellite data to develop spatially representative of crop coefficients of wheat and chickpea grown in the Sina command area during *Rabi* season. Whereby the specific objectives were, to analyze the seasonal dynamics of crop coefficients (Kc) and the vegetation index (NDVI) and to develop a regression model to establish the relationship between the Kc values and vegetation index (NDVI) for wheat and chickpea crops.

Materials and Methods

Description of Study Area : The command area of the Sina Medium Irrigation Project is located between Ahmednagar and Beed districts, Maharashtra, India. The area lies between 74°57'0"E longitude and 18°49' 0"N latitude with 565m elevation. The study area is located in a scarcity area, having a mean daily maximum and minimum temperature of 39.4°C (May) to 12.6°C (December) respectively. The area has wind speed varying from 4.95 to 17.55 km h^{-1}, and is maximum during July month. The relative humidity (RH) varies from 20.5 to 81.5 percent and is maximum during August. The maximum, minimum, and average rainfall observed at Nimgaon Gangarda located within the command is 1258, 392, and 503mm, respectively. The study area has a total command area of 22468.35 ha. The soils in the command are classified as fine (clay, silt clay) and is distributed in about 42 percent area, moderately fine (clay loam) in 43 percent and medium (silt loam and loam) in 15 percent of the area. The command area comprises with gentle to moderate slope, very gentle to gently sloping pediment plains and inner terraces. The major crops grown in the Sina command area during *Rabi* season are wheat, chickpea, sorghum, onion, pigeon pea, sugarcane, cotton, and other mixed crops. The main source of water for irrigation is Sina Dam constructed in 1985 and it has a Gross capacity of 67.95 million cubic meters. The *Rabi* season in the study area starts from October and ending in April.

Data and resources used in this study

Remote sensing data : The Sentinel 2 satellite data were used as a primary input in this study. Sentinel 2 have a wide range of

applications related to Earth's land and coastal water. This satellite mission provides information concerning agricultural and forestry activities helping in managing food security. Sentinel satellite images can be used to determine various plant indices including, leaf area chlorophyll and water content indexes. It is particularly very important for effective yield prediction and applications related to Earth's vegetation, as well as monitoring of the plant growth (Source: https://en.wikipedia.org/wiki/Sentinel-2). Spatial, spectral, and temporal resolution of satellite images are very important for the studies dealing with crop water requirements. Many studies on irrigation water management have indicated that Sentinel-2 has a high resolution which is applicable for hydrological purposes. These sensors are suitable for agricultural areas with medium to big fields due to their high spatial resolution. Sentinel-2 covering the part of the study area have been used in the present work. Sentinel 2 satellite has the following features; Multi-spectral data with 13 bands in the visible, near-infrared and short wave infrared part of the spectrum, systematic global coverage of land surfaces from 56°S to 84°N, coastal waters, and all of the Mediterranean Sea, revisiting every 5 days under the same viewing angles. At high latitudes, Sentinel swath overlap and some regions will be observed twice or more every 5 days, but with different viewing angles, has also spatial resolution of 10 m, 20 m and 60, 290 km field of view and is free and open data policy

Sentinel-2 satellite image has been downloaded from the United States Geological Survey website: https://earthexpolorer.usgs.gov acquired during the *Rabi* season of 2016-17. The details of the band characteristics and date of acquisition are presented in Table 1.

The acquisition of the satellite data considered crop data which includes crop phenology and canopy characteristics such as development stages and height (FAO – 56), crop area, and irrigation practices of the crops. Since the vegetation index (NDVI) of the crops increases from the initial to the mid-stage and decrease from mid to late final stage. The initial (stage1) of wheat takes 10-15 days, whereby development stage (stage 2) is 25 days, mid-season on stage (stage 3) is 50 days, late-season stage (stage 4) is 30 days, and the total height of wheat crop is 90-100 cm. For chickpea the initial stage (stage 1) have 10 days, whereby development stage (stage 2) takes 30 days, mid-season on stage (stage 3) takes 50 days and late-season stage (stage 4) takes 10 days, the total height of the crop ranges from 20-50 cm.

Ground truth data : The ground truth data collected using Hand GPS during *Rabi* season of 2016-17 were used in the identification of crops and aiding in the selection of training sets for image classification.

Software used : ArcGIS software v10.2 and Erdas Imagine v15 were used in this study, whereby ArcGIS 10.2 software was used to generate the GIS database and generation of the different thematic maps, and Erdas Imagine in this was used for generation of NDVI of Sina command area.

Methodology : The procedures and the techniques followed to develop thematic and derived maps, and hence estimation of crop coefficients of wheat and chickpea crops are explained here below;

Creation of False Composite Color (FCC) : Sentinel 2 satellite images were

Table 1. Acquisition dates of Sentinel-2 images used for the study covering crop growth stages

Date of pass	Crop growth stages
22/10/2016	Stage 1
21/11/2016	Stage 2
21/12/2016	Stage 3
20/01/2017	Stage 3
09/02/2017	Stage 4

processed in ArcMap v10.2 software to create False Composite Maps for *Rabi* seasons of 2016/17 by combining bands 2, 3, 4, and 8. The main objective of creating FCC is to increase spectral separation and enhances the interpretation and classification of features in the images. The FCC map created from an image acquired in 21st December 2016 were used to generate land use land cover map of the study area.

Image classification and selection of training sets : Image classification is the process of extracting information which categorized into classes from a multiband raster image. The resulting raster image is used to create raster maps. The idea of image classification is that different features on the surface of the earth have a different properties of spectral reflectance and emittance, in which their recognition is done through the classification processes. In other words, image classification process involves categorizing all pixels in an image or raw remotely sensed satellite data to obtain a given set of labels or land cover themes (Lillesand and Keifer, 1994; Mansor and Shafri, 2013).

In this study, supervised classification techniques were applied by selecting maximum likelihood. Whereby sample pixels in an image were selected as a representative of other pixels in ArcMap v10.2 software by taking training sets with the help of ground truth data taken by hand GPS in October 2016 and also with the help of NDVI map. The training set selections were taken according to major crop production in the study area during the *Rabi* season. Major crops like cotton, sorghum, sugarcane, chickpea, maize, onion, wheat, mixed crops, and other features such as water bodies, built-up land, fallow land, etc. in the study area were taken into considerations. Finally the crop types were identified under supervised classification and the cropping pattern map was successfully created. Later crop-wise distribution maps were created through reclassification of cropping pattern map and conversion of a raster image to a polygon. The areas under wheat and chickpea (polygons or distribution maps) were extracted to be used in creating crop-wise NDVI maps.

Estimation of NDVI from satellite data: NDVI stands for Normalized Difference Vegetation Index, which normally gives vegetative proportions in an area. NDVI is also a widely used graphical indicator of photosynthetically healthy green vegetation and used to estimate biophysical parameters of vegetation cover. Normalize Difference Vegetation Index (NDVI) quantifies vegetation by measuring the difference between near-infrared and red light. The NDVI ranges from -1 to +1, whereby negative value indicates the presence of water in the area and positive value close to +1 indicates the presence of dense green and healthy vegetation. And NDVI value close to zero, indicates an urbanized area, fallow, and or wasteland.

The False Composite Color (FCC) maps were processed in Erdas Imagine v15 software to extract vegetation information. Band 8 which is near-infrared and band 4 red light of sentinel 2 were used in the estimation of NDVI. The NDVI was calculated from the following formula;

$$NDVI = \frac{NIR - RED}{NIR + RED} \quad (1)$$

where, NIR = near-infrared band 0.842 µm and R = red band 0.665µm

The distribution maps (polygons) of wheat and chickpea were then used to get crop-wise NDVI maps through masking. The crop-wise NDVI values for the entire growth of the wheat and chickpea crops were created.

Development of Kc and NDVI relationships: The crop coefficient equations for wheat and

chickpea crops developed as per the growth stages recommended by FAO and Mahatma Phule Krishi Vidyapeeth (MPKV), Rahuri, and which is denoted by Kct, were used to compute daily crop coefficients for wheat and chickpea. The calculated Kc values were used to develop the relationship with the crop-wise NDVI values of each crop. The empirical equations of wheat and chickpea are presented here below;

Wheat: $Kct=10.092(t/T)^5 - 20.039 (t/T)^4 + 12.871 (t/T)^3 - 7.0936 (t/T)^2 + 3.7412(t/T) + 0.5942$ 2)

Chickpea: $Kct=2.3266(t/T)^5 + 8.5503(t/T)^4 - 24.573 (t/T)^3 + 14.708 (t/T)^2 -1.8175(t/T) + 0.8965$ (3)

where; Kct = Crop Coefficient on t^{th} day, t = Day after sowing (DAS) and T = Total crop growth period (days)

The relationship between the estimated crop-wise NDVI and daily Kct values for wheat and chickpea crops was developed and the resulting equation is denoted as Kc_NDVI. The NDVI values used to develop a relationship with Kc can describe the canopy biophysical parameters. The linear, logarithmic, exponential, power, and second-order polynomial type of relationships were developed between Kc values estimated from equations 2 and 3 above and NDVI values estimated from satellite data. The relationships were developed by considering a single growth phase for crops during the growth period. The best relation was selected based on the maximum value of the coefficient of determination (R^2).

Results and Discussion

Estimation of crop-wise NDVI : The crop-wise NDVI values for wheat and chickpea crops derived from Sentinel-2 satellite data during the growth period are presented in Table 2, for the respective date of the satellite overpass.

The output from the ArcGIS software shows that, the NDVI values under wheat in October varied 0.24-0.76 with an average of 0.40, November ranged from 0.24-0.79 with an average of 0.41, in December the NDVI values ranged from 0.29-0.79 with the average of 0.41 and in January the NDVI values varied from 0.24-0.69 with the average of 0.32, similarly the NDVI values for chickpea in November ranged from 0.30-0.77 with the average of 0.46, December values ranged from 0.30-0.76 with the average of 0.56, January NDVI values ranged 0.29-0.70 with an average of 0.40 and February ranged 0.31-0.67 with the average of 0.32. The average values of NDVI were used in the development of a relationship with Kct.

The spatial distribution of NDVI values for the wheat and chickpea are shown in Fig. 1 and Fig. 2, respectively.

Development of Kc-NDVI relationships: The relationships between Kc and NDVI for different crops were developed using the values presented in Table 3. The analysis between Kc and NDVI was carried out over the entire growth period of the crops. The best fit linear relationships were developed for both wheat and chickpea. The Kc-NDVI model relationships developed are presented below;

For wheat: $Kc_{NDVI} = 6.3268*NDVI - 1.4207$ (4)

For chickpea: $Kc_{NDVI} = 5.7866*NDVI - 1.6699$ (5)

Table 2. NDVI values for wheat and chickpea crops during growth period - *Rabi* season 2016-17

Crop	DAS	NDVI
Wheat	39	0.40
	68	0.41
	98	0.41
	118	0.32
Chickpea	29	0.46
	59	0.56
	89	0.40
	109	0.32

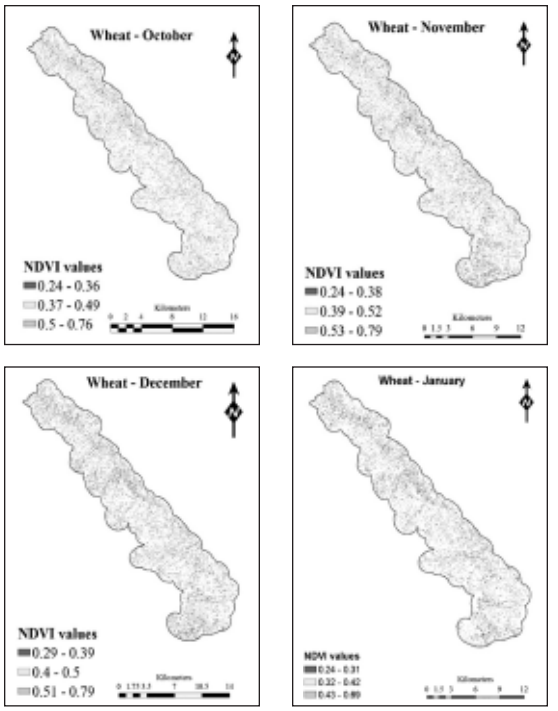

Fig. 1. Spatially distributed NDVI of wheat

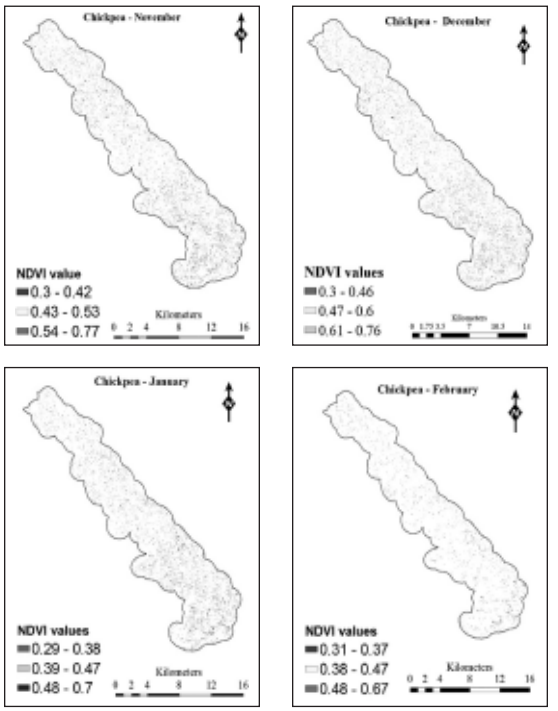

Fig. 2. Spatially distributed NDVI of chickpea

Table 3. NDVI, Kc_t values for wheat and chickpea crops

	NDVI	Kc_t
Wheat	0.40	0.84
	0.41	1.32
	0.41	1.29
	0.32	0.65
Chickpea	0.46	0.97
	0.50	1.20
	0.39	0.65
	0.32	0.15

There is a good relationship between Kct and NDVI as the coefficient of determination for wheat (R^2 = 0.7026) and that of chickpea (R^2 = 0.9832), meaning that the model developed can be used to determine the Kc values for wheat and chickpea, respectively. The models were used to estimate the spatially distributed Kc values for wheat and chickpea for the *Rabi* season of 2016-17.

After the development of Kc and NDVI relationships, crop coefficients Kc based on NDVI of different dates were generated using the Raster calculator available in ArcGIS software. The output from the software showed that, the estimated Kc values increased as the crops grow up and decrease as crop became matured and dried. The coefficient of determination between the spatially estimated Kc and that of the conventional method was 0.84 and 0.89 for wheat and chickpea crops, respectively, for the data obtained during *Rabi* season 2016-17.

Conclusion

The present study developed the linear regression models for wheat (Kc_{NDVI} = 6.3268*NDVI - 1.4207) and chickpea (Kc_{NDVI} = 5.7866*NDVI - 1.6699) to establish the general relationship between the vegetation index (NDVI) from Sentinel 2 satellite data and the crop coefficients (Kc). Also, NDVI is specific

to crop at each pixel and Kc represents the actual crop growth conditions in the field. Sentinel 2 satellite images were used to estimate crop coefficients of wheat and chickpea, spatially and temporally during the *Rabi* season 2016-17. Coefficients of determination R^2 for all crops explains the strength of the model developed, in which all models developed were very strong.

NDVI is an indication for the presence of health and density vegetation cover and the plant vigor, and it also measures the surface reflectance and gives a quantitative estimation of vegetation growth and biomass (Wu, Li, Wang, and Yan, 2016), meaning that it captures most of the variation observed in crop coefficients, under no water stress condition. The coefficient of determination of the models developed are 0.70 and 0.98 for wheat and chickpea. Whereby when tested with the satellite images of *Rabi* season 2016-17, the coefficient of determination between values obtained through conventional equations and those of satellite were 0.84 and 0.89 for wheat and chickpea, respectively.

The techniques and procedures used to develop these models and quantifying crop coefficients from NDVI which are presented in this study can be useful in other regions in the global, for managing irrigation water. It is concluded that, the crop coefficients (Kc) estimated based on NDVI are useful for irrigation scheduling, evaluating irrigation performance, irrigation water management, and estimation of water use efficiency.

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