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Assessment of the Potential of Antitranspirants in Yield Enhancement of *Brassica napus* L. under Water Stress Conditions

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

Background: This experiment uses various antitranspirants to increase leaf resistance to water vapor transfer. Irrigation scheduling is based on soil field capacity, which means irrigation was provided at 100%, 75%, and 50% field capacity. Research aims to conserve soil water and maintain water balance in plants by reducing transpiration. As water scarcity increases, assessing the anti-transpirant's effectiveness could help develop better-rainfed farming crop technology.

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Methods: In this experiment 5 sub-plot treatments (antitranspirants) and 3 main plot treatments (different irrigation levels) were there. The antitranspirants are applied by foliar spray and the interval of spraying of antitranspirants was 30 days. The first spray was done at 21 days after sowing. The growth and yield parameters were taken manually and analyzed using STATISTIX-10 and OPSTAT.

Results: Moisture aids plant growth and development, but high moisture causes more vegetative growth and less economic yield. Based on the analysis of the data it was observed that a moderate level of irrigation that is irrigation at 75% FC, produced the highest yield. Antitranspirants like Kaolin 6% showed improved physiology and WUE, highest production, crop growth, and development. Kaolin 6% was observed to be reducing proline content which indicates stress level, as a result increasing chlorophyll content, reducing stomatal densities, and improving nutrient uptake. Thus Kaolin 6% with irrigation at 75% FC was the most effective for yield, development and stress resistance. Cycocel 1000ppm being a growth retardant showed potential in yield increase and stress tolerance.

Keywords: Antitranspirants; water stress; irrigation; water conservation; field capacity.

ABBREVIATIONS

CD: Critical Difference; cm: Centimetre; °C: Degree Celsius; DAS: Days after sowing; et al, et alia (meaning "and others"); FC: Field Capacity; Fig: Figure; g: gram; K: Potassium; kg: Kilogram; kg ha^{-1} or kg/ha: Kilogram per hectare; M: Molarity; mg: Milligram; mg g^{-1} or mg/g: Milligram per gram; ml: Millilitre; mm: Millimetre; Mt: Metric-ton; N: Nitrogen; P: Phosphorus; ppm: Parts per million; Sem: Standard error mean; WUE; Water Use Efficiency; µg: Microgram; µg g^{-1} or µg/g: Microgram per gram; %, Percentage.

1. INTRODUCTION

Rapeseed mustard, a common oil crop in Punjab, yielded an average of 15.24 quintals per hectare in 2018-19. Gobhi Sarson, a type of mustard-rapeseed agriculture in India, accounts for 75% of the total area under this system. This uses rainfed conditions to convert natural resources into biological energy. Agricultural irrigation aims to produce more with less water, maximize per capita income, and improve efficiency. However, water imbalances can hinder plant growth and yield. To address this, antitranspirants like Kaolin, Acetylsalicylic acid, Cycocel, and Hexadecanol were applied to improve leaf resistance to water vapor transfer and reflect radiation. The growth retardant type anti-transpirant reduces shoot growth and increases root growth, thus resisting scarcity of water. During reproductive growth water scarcity reduces the economic yield by declining the amount of siliqua per plant (Ghobadi. *et al.* 2006). Reduction of oil concentration occurs when the plant is at the site of anthesis and a water crisis arises. (Merrien and Champolivier, 1996). Different research is being carried out by researchers to cope with the water deficit condition for increasing productivity by decreasing the transpiration loss so that maximum efficiency of water use can be achieved under minimum water availability. Under water-scarcity conditions, antitranspirants like pusa hydrogel and chitosan combined with 60% irrigation were observed to be most efficient in boosting the growth and yield attributing characteristics as well as reproductive parts because pusa hydrogel can conserve a larger quantity of water, and chitosan helps to reduce the transpirational rate (Burondkar *et al.,* 2018). This research aimed to conserve soil water and maintain plant water balance by controlling or suppressing transpiration. The study aimed to investigate the effectiveness of antitranspirants in improving crop physiology and yield under various irrigation levels and their underlying mechanisms. Checking transpiration rates can improve crop technology for rainfed farming, reducing temporary dry conditions and increasing water balance, potentially saving farmers from potential yield loss.

2. MATERIALS AND METHODS

2.1 Experimental Sight

The experiment was conducted in the agriculture field of Lovely Professional University. The area was in the central plane region. Sub-tropical monsoons occur in this area. The zone comes under the semi-arid zone.

2.2 Season and Climatic Condition

The research was carried out in the winter season in October when the average temperature lies between 10-15°C. The winter in Punjab starts approximately from October and it last till the end of March. The temperature goes down severely during December – January. During this period of winter season, very little rainfall occurs in the Punjab region.

2.3 Cropping Material

The variety GSC-07 was chosen for the experiment. This variety takes 150-160 days to mature. The sowing time for this variety is October. It is resistant to Alternaria blight and white rust and yields 9-10 quintals per acre with nearly 36-40% oil content.

2.4 Treatments and Experimental Design

The study investigates the effectiveness of various antitranspirants on rapeseed variety GSC-07 under three irrigation levels: irrigation at 100%, 75%, and 50% FC. The process of scheduling irrigation is described in Appendix-III. The antitranspirants used were reflectant type (Kaolin 6%), stomatal closing type (Acetylsalicylic acid 10^{-3}M), growth retardant type (Cycocel 1000ppm), and film forming type (Hexadecanol 5%). The field plot design was split-plot, and statistical analysis was performed using STATISTIX-10 and OPSTAT. Data were collected at 40, 80, and 120 days after sowing for growth parameters and harvest data or yield data on 160th days after sowing. The treatment combinations are as follows: I_1S_0 (Irrigation at 100% FC + Control (No Antitranspirants)), I_1S_1 (Irrigation at 100% FC + Kaolin 6%), I_1S_2 (Irrigation at 100% FC + Acetylsalicylic acid 10^{-3} M), I_1S_3 (Irrigation at 100% FC + Cycocel 1000 ppm), I_1S_4 (Irrigation at 100% FC + Hexadecanol 5%), I_2S_0 (Irrigation at 75% FC + Control (No Antitranspirants)), I_2S_1 (Irrigation at 75% FC + Kaolin 6%), I_2S_2 (Irrigation at 75% FC + Acetylsalicylic acid 10^{-3} M), I_2S_3 (Irrigation at 75% FC + Cycocel 1000 ppm), I_2S_4 (Irrigation at 75% FC + Hexadecanol 5%), I_3S_0 (Irrigation at 50% FC + Control (No Antitranspirants)), I_3S_1 (Irrigation at 50% FC + Kaolin 6%), I_3S_2 (Irrigation at 50% FC + Acetylsalicylic acid 10^{-3} M), I_3S_3 (Irrigation at 50% FC + Cycocel 1000 ppm), I_3S_4 (Irrigation at 50% FC + Hexadecanol 5%).

2.5 Crop Growth Parameters

Data were taken at an interval of 40, 80 and 120 DAS. The plant height, number of branches and leaves, and dry matter weight were taken by choosing randomly three plants from each plot. The average value of the observations obtained from three plants was taken for analysis. The leaf area index was measured by taking the area of fresh leaves from each treatment by using a leaf area meter. It was calculated by using the formula;

$$(\,No.of\ leaf \text{ x } Area\ of\ the\ leaf) \div spacing$$

2.6 Crop Yield Parameters

The yield parameters such as seed yield, biological yield, number of seeds per siliqua, number of siliquae per plant and 1000 seed weights were calculated manually after collecting all the plants from $1m^2$ area from each plot. The harvesting index was calculated by dividing the grain yield by total dry matter and multiplied by 100. Harvest index (%) = Economic yield/ Biological yield x100. The oil percentage was calculated by using the Soxhlet method and the formula used for estimating the oil percentage was (W2 – W1) x 100/S [W2= weight of extracted oil and flask, W1= Weight of empty flask, S= weight of the sample].

2.7 Crop Water Use Efficiency (CWE)

It is the ratio of crop yield (y) to the amount of water depleted by the crop in the process of evapotranspiration. It can be calculated as;

$$\text{CWE}= \frac{\text{Yield (Y)}}{Crop\ \text{Evapotranspiration } (\text{ET}_c)}$$

ET_c= ET_0 x K_c where ET_c= Crop evapotranspiration, ET_0= Evapotranspiration and K_c Crop coefficient
ET_0= E_p x K_p where ET_0= Evapotranspiration, Ep= Pan evaporation and Kp= Pan coefficient.
(Detail calculation given in Appendix I and II)

2.8 Consumptive Use

Consumptive use of water is the depth of water consumed by the plant in the process of interception, transpiration, and evaporation during crop growth.

$$\frac{(\text{FC} - \text{PWP})\text{ BD x Effective root zone depth}}{100} \text{ x } No.of\ irrigation\ applied$$

where

FC= Field capacity,
PWP= Permanent wilting point,

BD= Bulk density. Multiply it with the number of irrigation provided.

Proline estimation: Bates method (Bates *et al.* 1973).

Chlorophyll estimation: Hiscox method (Hilcox and Israelstam, 1979).

Stomata count: Using a stereo microscope.

N, P, K uptake: N, P, and K content in grain and stover, both multiplied with their respective yields and then added.

3. RESULTS

3.1 Crop Growth Parameters

3.1.1 Plant height

In 40, 80, and 120 DAS, it was observed that the significantly highest plant height was obtained from I_1 (Irrigation at 100% FC) followed by I_2 (Irrigation at 75% FC), and the significantly lowest plant height was obtained from I_3 (Irrigation at 50% FC). Among the antitranspirants, the significantly highest plant height was obtained in Kaolin 6% (S_1) and the significantly lowest plant height was obtained from Cycocel 1000ppm (S_3). However, The study found that at 40 DAS, S_1 (Kaolin 6%) followed by S_4 (Hexadecanol 5%), S_2 (Acetylsalicylic acid 10^{-3}M), S_0 (Control), and S_3 (Cycocel 1000 ppm). Similarly, the observations taken at 80 and 120 DAS follow the same trend. The observations are presented in Table 1.

The plant height recorded during all the observations at 40, 80, and 120 DAS was found to be significant between irrigation and antitranspirant treatment interaction effects. In main-plots treatment it has been observed that with decreasing water availability, the plant height seems to be decreasing while in sub-plots treatment, the highest plant height observed in Kaolin 6% and lowest plant height was observed in Cycocel 1000ppm as it was a growth retardant which was close to plant heigh in Control plots with no antitranspirants. But when irrigation and antitranspirants were combined and applied in the field, the treatment Kaolin 6% with irrigation at 100% FC (I_1S_1) was observed to be producing significantly higher plant height where as the significantly lowest plant height was obtained from the treatment Cycocel 1000ppm with irrigation at 50% FC (I_3S_3) which means Cycocel in one hand suppressing the growth and the limited water availability suppressing the growth to a greater extent. Though Kaolin is not a growth promoter but from this experiment it has been observed that it helps to create a favourable condition for the growth of plants. Similar observations obtained from the plant height reading taken at 40, 80, and 120 DAS. The observations are presented in Table 2 and in the Fig. 1.

3.1.2 Number of branches per plants

In 40, 80, and 120 DAS, it was observed that the significantly highest number of branches per plant was obtained from I_1 (Irrigation at 100% FC) followed by I_2 (Irrigation at 75% FC), and the significantly lowest number of branches was obtained from I_3 (Irrigation at 50% FC). Among the antitranspirants, a significantly higher number of branches was obtained in Cycocel 1000ppm (S_3) and the significantly lowest number of branches was obtained from controlled plots. However, at 40 DAS, the study found that S_4 (Hexadecanol 5%) had a higher number of branches per plant compared to S_2 (Acetylsalicylic acid 10^{-3}M) which was at par with S_0 but S_4 (Hexadecanol 5%) was significantly higher than S_0 (Control)). Both antitranspirants produced significantly fewer branches compared to S_1 (Kaolin 6%) and S_3 (Cycocel 1000ppm). Similarly in the observation taken at 80 and 120 DAS, similar trend was observed. The observations are recorded in Table 3.

The number of branches per plant recorded significant differences between the interaction effects of irrigation levels and antitranspirants at 40 DAS. In main-plots treatment it has been observed that with decreasing water availability, the number of branches per plant seems to be decreasing while in sub-plots treatment, the highest number of branches per plant observed in Cycocel 1000ppm as it was a growth retardant which reduces growth and increases branching and helps root elongation and lowest number of branches per plant was observed in Control plots with no antitranspirants. But when the irrigation and antitranspirants were combined to applied in the field it was observed that significantly highest number of branches per plant was obtained in the plots treated with Cycocel 1000ppm with irrigation at 100% FC (I_1S_3). Similarly the significantly lowest number of branches per plant was observed at the plots treated with irrigation at 50% FC with no antitranspirants (I_3S_0). The observations showed that antitranspirants and irrigation levels both influences formation of branches when compared to the controlled plots are recorded in the Table 4.

3.1.3 Number of leaves per plant

In the observations taken at 40, 80 and 120 DAS, it was observed that the significantly highest number of leaves per plant was obtained from I_1 (Irrigation at 100% FC) followed by I_2 (Irrigation at 75% FC), and the significantly lowest number of leaves was obtained from I_3 (Irrigation at 50% FC). Among the antitranspirants, a significantly higher number of leaves was obtained in Cycocel 1000ppm (S_3) and the significantly lowest number of leaves was obtained from controlled plots (S_0). However, in the observations taken at 40 DAS, it has been observed that, S_3 (Cycocel 1000ppm) which produced highest number of leaves was followed by S_1 (Kaolin 6%). Similarly in the observations taken at 80 and 120 DAS, the same trend was observed as of the observations taken at 80 DAS. The observations are recorded in Table 5.

Table 1. Influence of different irrigation levels and antitranspirants on the plant height (cm)

Tr. No	Treatments	40 DAS	80 DAS	120 DAS
	A. IRRIGATION			
I_1	At 100% FC	40.924±0.87	152.257±0.75	206.559±0.49
I_2	At 75% FC	33.134±1.03	140.533±0.60	189.295±0.68
I_3	At 50% FC	26.205±0.74	120.749±0.59	159.666±1.30
	SEm (±)	1.051	1.24	1.723
	CD(P=0.05)	4.237	4.997	6.946
	B. ANTITRANSPIRANTS			
S_0	Control (No antitranspirants)	30.543±0.92	132.666±0.73	177.057±0.47
S_1	Kaolin 6%	40.932±0.80	145.86±0.17	201.303±1.02
S_2	Acetylsalicylic Acid 10^{-3}M	32.054±1.26	137.489±0.33	185.95±0.63
S_3	Cycocel 1000 ppm	27.688±0.15	131.937±0.26	171.486±0.73
S_4	Hexadecanol 5%	35.887±0.51	141.282±0.76	190.071±0.22
	SEm(±)	0.469	0.738	1.384
	CD(P=0.05)	1.378	2.166	4.064
	INTERACTION(AxB)			
	SEm(±)	2.350	2.772	3.852
	CD(P=0.05)	2.99	4.507	8.069

Table 2. Effects of interaction between irrigation levels and antitranspirants on plant height (cm)

Treatment interaction	40 DAS	80 DAS	120 DAS
I_1S_0	37.203±0.64	145.933±1.29	200.167±2.12
I_1S_1	48.307±0.70	162.757±0.48	220.827±1.52
I_1S_2	38.267±1.29	152.753±0.87	204.603±1.34
I_1S_3	34.423±1.03	144.203±0.64	195.387±1.54
I_1S_4	46.420±0.87	155.64±0.88	211.813±0.80
I_2S_0	28.947±2.59	135.917±1.12	175.52±1.80
I_2S_1	46.723±1.62	148.057±1.07	212.737±0.81
I_2S_2	30.95±2.36	137.767±0.96	192.547±0.71
I_2S_3	26.100±0.99	135.647±0.57	167.703±0.86
I_2S_4	32.947±1.45	145.28±0.99	197.967±1.75
I_3S_0	25.48±0.83	116.147±0.72	155.483±1.04
I_3S_1	27.767±0.78	126.767±1.05	170.347±1.24
I_3S_2	26.947±0.49	121.947±1.44	160.7±1.28
I_3S_3	22.54±1.00	115.96±0.64	151.367±0.61
I_3S_4	28.293±0.80	122.927±0.53	160.433±1.67
SEm(±)	2.350	2.772	3.852
CD(P=0.05)	2.99	4.507	8.069

Table 3. Influence of different irrigation levels and antitranspirants on the number of branches per plant

Tr. No	Treatments	40 DAS	80 DAS	120 DAS
	A. IRRIGATION			
I_1	At 100% FC	6.392±0.10	18.811±0.05	26.340±0.11
I_2	At 75% FC	5.457±0.03	17.703±0.06	23.533±0.37
I_3	At 50% FC	3.326±0.10	12.637±0.09	20.810±0.24
	SEm (±)	0.141	0.109	0.250
	CD(P=0.05)	0.568	0.437	1.006
	B. ANTITRANSPIRANTS			
S_0	Control (No antitranspirants)	3.889±0.03	15.214±0.09	21.659±0.44
S_1	Kaolin 6%	5.618±0.08	16.900±0.10	24.251±0.13
S_2	Acetylsalicylic Acid 10^{-3}M	4.059±0.16	15.739±0.09	23.029±0.41
S_3	Cycocel 1000 ppm	6.789±0.06	17.440±0.14	25.597±0.15
S_4	Hexadecanol 5%	4.939±0.12	16.624±0.14	23.268±0.34
	SEm(±)	0.169	0.17	0.441
	CD(P=0.05)	0.497	0.5	1.294
	INTERACTION(AxB)			
	SEm±	0.315	0.243	0.558
	CD(P=0.05)	0.932	NS	NS

Table 4. Effects of interaction between different irrigation levels and antitranspirants on the number of branches per plant

Treatment interaction	40 DAS	80 DAS	120 DAS
I_1S_0	4.581±0.10	17.840±0.17	23.588±0.91
I_1S_1	6.909±0.24	18.9±0.25	27.984±0.57
I_1S_2	4.84±0.19	18.38±0.07	24.972±0.51
I_1S_3	9.77±0.11	20.047±0.21	29.899±0.67
I_1S_4	5.863±0.13	18.89±0.28	25.254±0.44
I_2S_0	4.147±0.19	16.837±0.11	21.849±0.23
I_2S_1	6.296±0.13	18.19±0.02	23.665±0.65
I_2S_2	4.388±0.17	17.147±0.02	23.207±0.52
I_2S_3	6.864±0.26	18.503±0.11	25.457±0.35
I_2S_4	5.592±0.22	17.837±0.11	23.487±0.32
I_3S_0	2.938±0.07	10.967±0.29	19.539±0.21
I_3S_1	3.649±0.24	13.61±0.05	21.102±0.29
I_3S_2	2.948±0.15	11.69±0.23	20.909±0.20
I_3S_3	3.732±0.12	13.77±0.11	21.437±0.22
I_3S_4	3.363±0.12	13.147±0.06	21.063±0.34±
SEm(±)	0.315	0.243	0.558
CD(P=0.05)	0.932	NS	NS

The number of leaves per plants recorded significant differences between the interaction effects of the levels of irrigation and antitranspirants at 40 DAS. In main-plots treatment it has been observed that with decreasing water availability, the number of leaves per plant seems to be decreasing while in sub-plots treatment, the highest number of leaves per plant observed in Cycocel 1000ppm as it was a growth retardant and increases branching thus increases the leaf count per plant and lowest number of leaves per plant was observed in Control plots with no antitranspirants. But when the irrigation and antitranspirants were applied together, the significantly highest number of leaves per plant was observed in the treatment combination Cycocel 1000ppm with irrigation at 100% FC (I_1S_3) and the significantly lowest number of leaves per plant was observed in the treatment combination irrigation at 50% FC with no antitranspirants (I_3S_0). This shows that though, irrigation levels influences the leaf formation but the antitranspirants helps to mitigate the adverse effect that may arises due to reduction of water availability which can be observed by comparing all the treatment combinations at different levels of irrigation with the control plots under different levels of irrigations as shown in the Table 6.

3.1.4 Leaf area index

In the observation taken at 40, 80, and 120 DAS, it has been observed that the significantly highest LAI was observed in the I_1 (Irrigation at 100% FC) level of irrigation followed by I_2 (Irrigation at 75% FC), and significantly lowest LAI was observed in the I_3 (Irrigation at 50% FC) level of irrigation. However, in the observation taken at 40 DAS, I_1 and I_2 were statistically at par. In the observations taken at all the periodic intervals, among the antitranspirants, the significantly highest LAI was obtained in S_1 (Kaolin 6%) and the significantly lowest LAI was observed in S_0

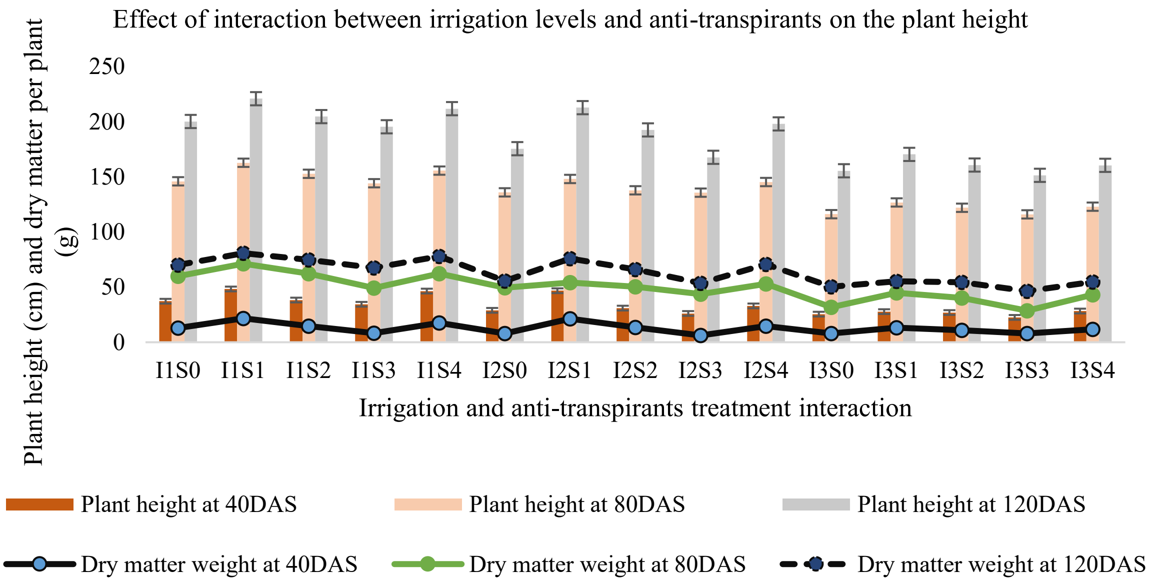

Fig. 1. Graph representing the effect of interaction between different irrigation levels and antitranspirants on the plant height (cm) and dry matter weight per plant (g)

Table 5. Influence of different irrigation levels and antitranspirants on the number of leaves per plant

Tr. No	Treatments	40 DAS	80 DAS	120 DAS
	A. IRRIGATION			
I_1	At 100% FC	7.119±0.11	24.615±0.13	30.841±0.13
I_2	At 75% FC	6.633±0.02	22.424±0.15	27.984±0.09
I_3	At 50% FC	4.806±0.02	19.870±0.10	22.140±0.11
	SEm (±)	0.107	0.215	0.189
	CD(P=0.05)	0.433	0.866	0.763
	B. ANTITRANSPIRANTS			
S_0	Control (No antitranspirants)	4.898±0.11	21.243±0.25	25.349±0.25
S_1	Kaolin 6%	6.942±0.02	22.348±0.14	27.553±0.05
S_2	Acetylsalicylic Acid 10^{-3}M	5.186±0.08	21.447±0.06	25.833±0.10
S_3	Cycocel 1000 ppm	8.053±0.08	23.648±0.14	28.754±0.13
S_4	Hexadecanol 5%	5.850±0.05	22.728±0.11	27.454±0.14
	SEm(±)	0.155	0.316	0.316
	CD(P=0.05)	0.456	0.927	0.926
	INTERACTION(AxB)			
	SEm±	0.240	0.480	0.423
	CD(P=0.05)	0.838	NS	NS

Table 6. Effects of interaction between irrigation levels and antitranspirants on the number of leaves per plant

Treatment interaction	40 DAS	80 DAS	120 DAS
I_1S_0	5.313±0.30	23.143±0.36	28.790±0.37
I_1S_1	8.433±0.05	24.778±0.30	31.311±0.39
I_1S_2	5.453±0.16	23.664±0.39	29.697±0.27
I_1S_3	10.447±0.10	26.438±0.35	32.985±0.33
I_1S_4	5.947±0.16	25.050±0.28	31.425±0.30
I_2S_0	5.28±0.09	22.120±0.46	27.1±0.42
I_2S_1	7.347±0.08	22.340±0.22	28.913±0.40
I_2S_2	5.457±0.10	21.933±0.38	26.493±0.40
I_2S_3	8.447±0.17	23.213±0.07	29.093±0.12
I_2S_4	6.633±0.14	22.513±0.45	28.320±0.20
I_3S_0	4.1±0.06	18.467±0.19	20.157±0.18
I_3S_1	5.047±0.09	19.926±0.40	22.434±0.09
I_3S_2	4.647±0.22	18.744±0.10	21.310±0.08
I_3S_3	5.267±0.10	21.593±0.20	24.183±0.21
I_3S_4	4.97±0.22	20.620±0.06	22.616±0.42
SEm(±)	0.240	0.480	0.423
CD(P=0.05)	0.838	NS	NS

(Control). In 40 DAS, it was observed that S_1 (Kaolin 6%) followed by S_3 (Cycocel 1000ppm) and S_0 (Control) was statistically at par with S_2 (Acetylsalicylic acid 10^{-3}M) but significantly less than S_4 (Hexadecanol 5%). the effect of S_4 (Hexadecanol 5%) was statistically at par with S_2 (Acetylsalicylic acid 10^{-3}M). Similar results were obtained in the observations taken at 80 and 120 DAS. The observations are recorded in Table 7.

The LAI recorded significant differences between the interaction effects of the levels of irrigation and antitranspirants in all the intervals of 40, 80, and 120 DAS. In main-plots treatment, it has been observed that with decreasing water availability, the LAI seems to be decreasing while in sub-plots treatment, the highest LAI was observed in Kaolin 6% and the lowest LAI was observed in Control plots with no antitranspirants. But when irrigation and antitranspirants were applied together, the application of Kaolin 6% with irrigation at 100% FC led to significantly higher LAI and the significantly lowest number of LAI was observed due to the treatment of irrigation at 50% FC without antitranspirants (I_3S_0). It was observed that treatment with antitranspirants at different levels of irrigation caused a positive effect on the crops compared to the control where no antitranspirants were applied. The observations are presented in Table 8 and Fig. 2.

3.1.5 Dry matter per plant

In the observation taken at 40 DAS, significantly higher dry matter was obtained in the I_1 (Irrigation at 100% FC) level of irrigation compared to the I_3 (Irrigation at 50% FC) level of irrigation which produced significantly lowest dry matter and both are at par with the I_2 (Irrigation at 75% FC) level of irrigation. However, in the observations taken at 80 and 120 DAS, it was observed that significantly higher dry matter was obtained from the I_1 (Irrigation at 100% FC) level of irrigation followed by the I_2 (Irrigation at 75% FC) level of irrigation and significantly lowest dry matter was obtained from the I_3 (Irrigation at 50% FC) level of irrigation. At 40 DAS, S_1 (Kaolin 6%) was followed by S_4 (Hexadecanol 5%) which was at par with S_2 (Acetylsalicylic acid 10^{-3}M). S_3 (Cycocel 1000ppm) was statistically at par with the control (S_0) which produced significantly lowest dry matter per plant. Similar trend was observed in the observations taken at 80 and 120 DAS. The observations are recorded in Table 9.

The dry matter per plant recorded significant differences between the interaction effects of the levels of irrigation and antitranspirants at 120 DAS. In main-plots treatment, it has been observed that with decreasing water availability, the dry matter weight per plant seems to be decreasing while in sub-plots treatment, the highest dry matter per plant observed in Keolin 6%, and the lowest dry matter per plant was observed in Control plots with no antitranspirants. When the antitranspirants were combined with irrigation the significantly higher dry matter was obtained from the plots with Kaolin 6% with irrigation at 100% FC (I_1S_1) which was at par with I_1S_2 and I_1S_4. Irrigation at 50% FC with no antitranspirants (I_3S_0) produced significantly the lowest dry matter per plant as of Table 10 and Fig 1. From this, it was observed that reducing irrigation adversely influences crop growth and dry matter production but antitranspirants at any level of irrigation enhance the same.

3.2 Yield Parameters

As per the observations recorded in Table 1_1 and 1_2, in terms of different irrigation levels, the significantly highest number of siliqua per plant, seeds per siliqua, 1000 seed weight, seed yield, and harvest index were obtained from I_2 (Irrigation at 75% FC) level of irrigation. In contrast, the significantly highest biological yield was obtained from I_1 (Irrigation at 100% FC) level of irrigation. Similarly, significantly lowest siliqua per plant, seeds per siliqua, 1000 seed weight, seed yield, harvest index, and biological yield were obtained from I_3 (Irrigation at 50% FC) level of irrigation. In terms of sub-plots treatment antitranspirants, the significantly highest number of siliqua per plant, seeds per siliqua, 1000 seed weight, seed yield, harvest index, and biological yield was obtained from S_1 (Kaolin 6%), whereas the significantly lowest of which was obtained from S_0 (Control) that is plots with no antitranspirants treatment. The effect of Kaolin 6% was followed by Cycocel 1000ppm.

Table 7. Influence of different irrigation levels and antitranspirants on the leaf area index (LAI)

Tr. No	Treatments	40 DAS	80 DAS	120 DAS
	A. IRRIGATION			
I_1	At 100% FC	0.833±0.01	4.929±0.03	3.548±0.02
I_2	At 75% FC	0.813±0.02	3.679±0.05	2.671±0.01
I_3	At 50% FC	0.442±0.01	2.343±0.03	1.448±0.04
	SEm (±)	0.024	0.061	0.037
	CD(P=0.05)	0.097	0.245	0.148
	B. ANTITRANSPIRANTS			
S_0	Control (No antitranspirants)	0.506±0.01	3.083±0.07	2.094±0.03
S_1	Kaolin 6%	1.062±0.02	4.326±0.06	3.110±0.06
S_2	Acetylsalicylic Acid 10^{-3}M	0.544±0.02	3.358±0.02	2.451±0.02
S_3	Cycocel 1000 ppm	0.746±0.01	3.767±0.04	2.623±0.01
S_4	Hexadecanol 5%	0.622±0.02	3.719±0.03	2.499±0.02
	SEm(±)	0.031	0.096	0.062
	CD(P=0.05)	0.092	0.283	0.181
	INTERACTION(AxB)			
	SEm(±)	0.054	0.136	0.082
	CD(P=0.05)	0.171	0.516	0.328

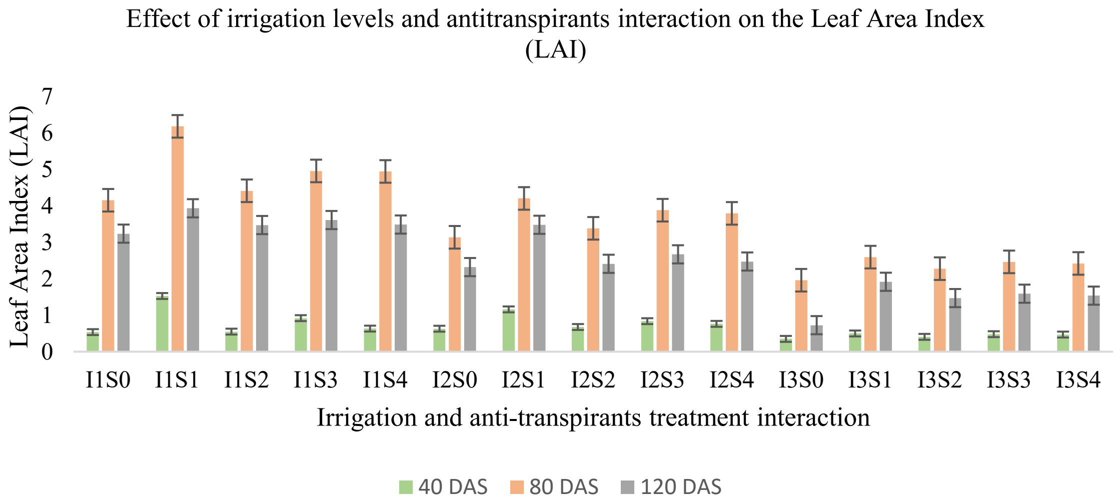

Fig. 2. Graph representing the effect of interaction between different irrigation levels and antitranspirants on the Leaf area index (LAI)

Table 8. Effects of interaction between different irrigation levels and antitranspirants on the leaf area index (LAI)

Treatment interaction	40 DAS	80 DAS	120 DAS
I_1S_0	0.537±0.23	4.153±0.11	3.237±0.02
I_1S_1	1.527±0.63	6.18±0.12	3.933±0.11
I_1S_2	0.55±0.18	4.413±0.10	3.473±0.09
I_1S_3	0.92±0.32	4.957±0.09	3.61±0.04
I_1S_4	0.633±0.23	4.943±0.10	3.487±0.06
I_2S_0	0.63±0.25	3.137±0.10	2.32±0.04
I_2S_1	1.16±0.44	4.203±0.16	3.48±0.07
I_2S_2	0.677±0.26	3.383±0.12	2.41±0.03
I_2S_3	0.837±0.29	3.88±0.08	2.67±0.09
I_2S_4	0.763±0.27	3.793±0.01	2.473±0.06
I_3S_0	0.351±0.14	1.96±0.03	0.727±0.02
I_3S_1	0.5±0.18	2.593±0.05	1.917±0.05
I_3S_2	0.407±0.14	2.277±0.01	1.47±0.03
I_3S_3	0.48±0.19	2.463±0.12	1.59±0.04
I_3S_4	0.47±0.20	2.42±0.03	1.537±0.06
SEm(±)	0.054	0.136	0.082
CD(P=0.05)	0.171	0.516	0.328

Table 9. Influence of different irrigation levels and antitranspirants on the dry matter weight per plant (g)

Tr. No	Treatments	40 DAS	80 DAS	120 DAS
	A. IRRIGATION			
I_1	At 100% FC	15.063±0.68	60.983±0.72	74.141±0.79
I_2	At 75% FC	12.728±0.37	50.133±0.54	64.313±1.08
I_3	At 50% FC	10.306±0.58	37.718±0.59	52.266±1.30
	SEm (±)	0.712	0.372	2.152
	CD(P=0.05)	2.872	1.499	8.677
	B. ANTITRANSPIRANTS			
S_0	Control (No antitranspirants)	9.622±1.18	47.093±0.76	58.784±0.75
S_1	Kaolin 6%	18.787±0.63	56.766±0.89	70.637±1.02
S_2	Acetylsalicylic Acid 10^{-3}M	12.980±0.90	50.926±0.43	65.001±0.50
S_3	Cycocel 1000 ppm	7.458±0.26	40.517±1.05	55.758±0.84
S_4	Hexadecanol 5%	14.648±1.05	52.756±1.08	67.687±0.72
	SEm(±)	1.13	1.420	1.206
	CD(P=0.05)	3.318	4.170	3.541
	INTERACTION(AxB)			
	SEm(±)	1.593	0.831	2.850
	CD(P=0.05)	NS	NS	7.438

A reducing trend of yield attributes was obtained with the reduction of water availability in main plots. However, with the application of antitranspirants in sub-plots, enhancement of yield attributes was obtained in all irrigation levels as compared to control plots where no antitranspirants were applied. But when antitranspirants were combined with irrigation levels, their interaction effect was observed, we found that the highest number of siliqua per plant was obtained when Kaolin 6% was applied with irrigation at 75% FC (I_2S_1) whereas when no antitranspirants were applied under irrigation at 50% FC (I_3S_0) the lowest number of siliqua per plant was observed. This shows that even when irrigation is limited, the antitranspirants have the potential to increase the yield. Reducing irrigation adversely effect the crop yield but this adverse effect can be reduced and yield can be increase with the help of antitranspirants. The interaction effect between different irrigation levels and antitranspirants showed non-significant result in case of number of seeds per siliqua and 1000 seed weight.

Table 10. Effects of interaction between different irrigation levels and antitranspirants on the dry matter weight per plant (g)

Treatment interaction	40 DAS	80 DAS	120 DAS
I_1S_0	12.947±1.45	59.943±1.03	70.167±2.12
I_1S_1	21.723±1.62	71.260±1.19	80.737±0.81
I_1S_2	14.753±0.87	62.193±1.99	74.603±1.34
I_1S_3	8.250±1.03	49.217±1.36	67.387±1.54
I_1S_4	17.640±0.88	62.3±1.19	77.813±0.80
I_2S_0	7.933±1.29	49.577±1.05	55.703±0.86
I_2S_1	21.423±1.71	54.063±0.23	75.827±1.52
I_2S_2	13.433±1.28	50.323±1.65	65.967±1.75
I_2S_3	6.203±0.64	43.707±1.03	53.52±1.80
I_2S_4	14.647±1.44	52.997±1.21	70.574±0.71
I_3S_0	7.987±1.01	31.760±1.36	50.483±1.04
I_3S_1	13.213±0.81	44.973±1.70	55.347±3.04
I_3S_2	10.753±0.81	40.260±2.42	54.433±1.67
I_3S_3	7.920±0.45	28.627±1.31	46.367±0.61
I_3S_4	11.657±1.20	42.970±1.25	54.7±1.28
SEm(±)	1.593	0.831	2.850
CD(P=0.05)	NS	NS	7.438

Table 11. Influence of different irrigation levels and antitranspirants on the number of siliqua per plant, number of seeds per siliqua, and 1000 seeds weight (g)

Tr. No	Treatments	Number of siliqua per plants	Number of seeds per siliqua	1000 seeds weight (g)
	A. IRRIGATION			
I_1	At 100% FC	734.533±0.60	35.017±0.07	7.924±0.05
I_2	At 75% FC	803.724±0.91	37.864±0.08	8.100±0.04
I_3	At 50% FC	612.349±0.59	33.501±0.06	7.693±0.07
	SEm (±)	1.341	0.149	0.048
	CD(P=0.05)	5.405	0.600	0.193
	B. ANTITRANSPIRANTS			
S_0	Control (No antitranspirants)	693.291±0.45	34.397±0.17	7.451±0.08
S_1	Kaolin 6%	730.193±0.17	36.497±0.19	8.324±0.02
S_2	Acetylsalicylic Acid 10^{-3}M	715.422±0.51	34.876±0.17	7.636±0.08
S_3	Cycocel 1000 ppm	724.616±0.76	36.254±0.13	8.230±0.04
S_4	Hexadecanol 5%	720.822±0.33	35.280±0.20	7.888±0.04
	SEm(±)	0.826	0.247	0.099
	CD(P=0.05)	2.426	0.725	0.290
	INTERACTION(AxB)			
	SEm(±)	2.998	0.333	0.107
	CD(P=0.05)	5.022	NS	NS

Again from the observations recorded in Tables 13 and 15, the significantly highest seed yield, harvesting index, and oil content was obtained in the I_2 (Irrigation at 75% FC) level of irrigation and the significantly lowest of which was obtained from I_3 (Irrigation at 50% FC) level of irrigation, whereas in the case of biological yield, a significantly highest quantity was obtained from the I_1 (Irrigation at 100% FC) level of irrigation, and a significantly lowest biological yield was obtained from the I_3 (Irrigation at 50% FC) level of irrigation. Among the antitranspirants, it was observed that the highest seed yield, biological yield, harvesting index, and oil content was obtained from S_1 (Kaolin 6%) and the significantly lowest of which was obtained from S_0 (Control) but the significantly lowest biological yield was obtained from S_3 (Cycocel 1000ppm) as it is a growth retardant eventually led to less weight.

Table 12. Effect of interaction between different irrigation levels and antitranspirants on the siliqua per plant, number of seeds per siliqua, and 1000 seeds weight (g)

Treatment interaction	Number of siliqua per plants	Number of seeds per siliqua	1000 seed weight (g)
I_1S_0	705.647±0.57	33.853±0.36	7.503±0.09
I_1S_1	748.057±1.07	36.010±0.17	8.320±0.04
I_1S_2	735.917±1.12	34.617±0.09	7.547±0.14
I_1S_3	745.280±0.99	35.707±0.21	8.280±0.15
I_1S_4	737.767±0.96	34.897±0.20	7.970±0.02
I_2S_0	791.267±2.16	36.737±0.22	7.687±0.23
I_2S_1	815.757±0.48	39.303±0.26	8.560±0.02
I_2S_2	797.203±0.64	37.170±0.26	7.870±0.01
I_2S_3	808.640±0.88	38.897±0.38	8.457±0.01
I_2S_4	805.753±0.87	37.213±0.17	7.927±0.04
I_3S_0	582.960±0.64	32.600±0.06	7.163±0.04
I_3S_1	626.767±1.05	34.177±0.17	8.093±0.04
I_3S_2	613.147±0.72	32.840±0.23	7.490±0.11
I_3S_3	619.927±0.53	34.160±0.09	7.953±0.02
I_3S_4	618.947±1.44	33.730±0.33	7.767±0.19±
SEm(±)	2.998	0.333	0.107
CD(P=0.05)	5.022	NS	NS

Table 13. Influence of different irrigation levels and antitranspirants on the seed yield, biological yield, and harvest index

Tr. No	Treatments	Seed yield (q ha^{-1})	Biological yield (q ha^{-1})	Harvest index
	A. IRRIGATION			
I_1	At 100% FC	23.773±0.26	111.816±0.47	0.212±0.002
I_2	At 75% FC	30.019±0.29	106.898±0.55	0.281±0.002
I_3	At 50% FC	16.283±0.57	80.112±1.35	0.203±0.004
	SEm (±)	0.665	1.445	0.005
	CD(P=0.05)	2.681	5.824	0.021
	B. ANTITRANSPIRANTS			
S_0	Control(No antitranspirants)	17.593±0.50	96.990±0.38	0.179±0.005
S_1	Kaolin 6%	29.365±0.46	111.485±0.99	0.262±0.002
S_2	Acetylsalicylic Acid 10^{-3}M	22.005±0.55	99.438±0.19	0.219±0.005
S_3	Cycocel 1000 ppm	24.739±0.22	89.405±1.16	0.275±0.004
S_4	Hexadecanol 5%	23.091±0.05	100.724±0.64	0.227±0.001
	SEm(±)	0.563	0.849	0.005
	CD(P=0.05)	1.653	2.492	0.016
	INTERACTION (AxB)			
	SEm(±)	1.487	3.230	0.012
	CD(P=0.05)	3.255	5.197	NS

The highest seed yield, oil content, and harvest index were obtained from main-plot treatment irrigation at 75% FC which gradually reduced with a decrease in water availability under irrigation at 50% FC. It also showed that higher irrigation can contribute to yield reduction as observed in irrigation at 100% FC. Similarly, sub-plot treatment anti-transpirant Kaolin 6% led to a significantly higher overall yield. However, when antitranspirants were applied with different irrigation levels, their interaction effect (Tables 14 and 16) observed that the highest seed yield and oil content were obtained from the interaction of Kaolin 6% with irrigation at 75% FC (I_2S_1) and the lowest of which was obtained from the irrigation at 50% FC with no antitranspirants (I_3S_0). Comparing the interaction effects of antitranspirants and irrigation levels with control plots (plants treated with only irrigation levels with no antitranspirants) it was observed that, even when the plants face water scarcity, the antitranspirants help the plants tolerate or adapt to that situation to produce more yield. In the case of biological yield, we observed that the significantly highest biological yield was obtained from irrigation at 100% FC with Kaolin 6% (I_1S_1) whereas the significantly highest grain yield was obtained from irrigation at 75% FC with Kaolin 6% (I_2S_1) which describes that more irrigation may lead to greater plant growth that eventually leads to increasing total weight but individually grain yield will be less. The interaction effect of antitranspirants and irrigation levels shows a non-significant effect in the case of harvest index. The relation between economic yield (seed), biological yield, and oil content are represented in Fig. 3.

Table 14. Effects of interaction between different irrigation levels and antitranspirants on the seed yield, biological yield, and harvest index

Treatment interaction	Seed yield (q ha^{-1})	Biological yield (q ha^{-1})	Harvest index
I_1S_0	19.467±0.54	108.00±0.62	0.181±0.006
I_1S_1	30.873±0.71	131.849±1.55	0.234±0.003
I_1S_2	21.481±0.55	108.695±0.62	0.198±0.006
I_1S_3	24.003±0.60	100.501±1.32	0.239±0.006
I_1S_4	23.044±0.39	110.034±0.59	0.210±0.003
I_2S_0	21.882±0.66	102.885±0.48	0.213±0.006
I_2S_1	36.976±0.84	118.183±1.73	0.313±0.003
I_2S_2	29.034±0.78	108.02±0.14	0.269±0.007
I_2S_3	32.553±0.60	96.363±1.21	0.338±0.009
I_2S_4	29.651±0.87	109.037±1.03	0.272±0.010
I_3S_0	11.431±0.52	80.086±1.28	0.142±0.004
I_3S_1	20.246±0.75	84.423±1.67	0.239±0.004
I_3S_2	15.499±0.48	81.599±1.25	0.190±0.003
I_3S_3	17.66±0.61	71.351±1.34	0.247±0.004
I_3S_4	16.58±0.53	83.101±1.25	0.199±0.003
SEm(±)	1.487	3.230	0.012
CD(P=0.05)	3.255	5.197	NS

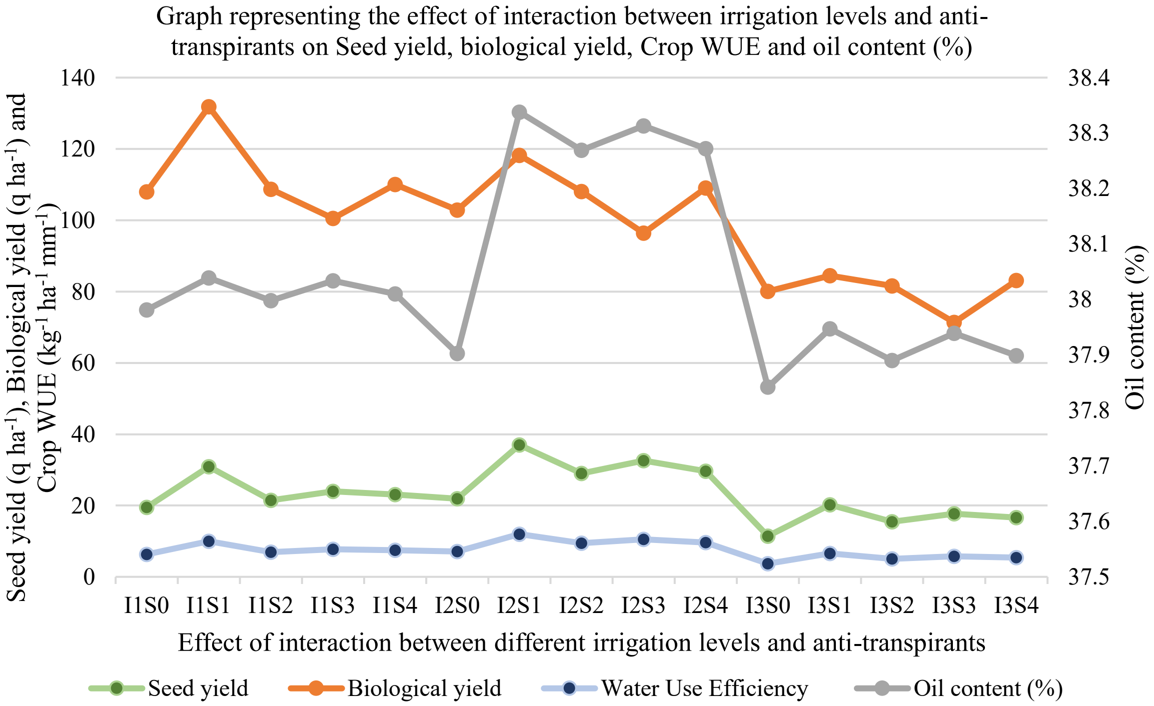

Fig. 3. Graph representing the effects of interaction between different irrigation levels and antitranspirants on the seed yield (q ha^{-1}), biological yield (q ha^{-1}), oil content (%) and Crop Water Use Efficiency (kg^{-1} ha^{-1} mm^{-1})

Table 15. Influence of different irrigation levels and antitranspirants on the Oil content (%)

Tr. No	Treatments	Oil content (%)
	A. IRRIGATION	
I_1	At 100% FC	38.012±0.002
I_2	At 75% FC	38.219±0.002
I_3	At 50% FC	37.903±0.004
	SEm (±)	0.010
	CD(P=0.05)	0.041
	B. ANTITRANSPIRANTS	
S_0	Control (No antitranspirants)	37.909±0.005
S_1	Kaolin 6%	38.108±0.004
S_2	Acetylsalicylic Acid 10^{-3}M	38.052±0.005
S_3	Cycocel 1000 ppm	38.095±0.002
S_4	Hexadecanol 5%	38.060±0.001
	SEm(±)	0.005
	CD(P=0.05)	0.014
	INTERACTION(AxB)	
	SEm(±)	0.023
	CD(P=0.05)	0.031

Table 16. Effects of interaction between different irrigation levels and antitranspirants on the Oil content (%)

Treatment interaction	Oil content (%)
I_1S_0	37.981±0.006
I_1S_1	38.039±0.006
I_1S_2	37.998±0.006
I_1S_3	38.034±0.003
I_1S_4	38.010±0.003
I_2S_0	37.903±0.006
I_2S_1	38.338±0.009
I_2S_2	38.269±0.007
I_2S_3	38.313±0.003
I_2S_4	38.272±0.010
I_3S_0	37.842±0.004
I_3S_1	37.947±0.004
I_3S_2	37.890±0.003
I_3S_3	37.939±0.004
I_3S_4	37.899±0.003
SEm(±)	0.023
CD(P=0.05)	0.031

3.3 Crop Water Use Efficiency

Estimating crop water usage efficiency is critical for increasing agricultural output, assuring sustainable water resource use, and improving farming systems' resilience and economic viability in the face of environmental problems. A significantly higher water use efficiency was observed in the I_2 (Irrigation at 75%FC) level of irrigation (9.731 kg^{-1} ha^{-1} mm^{-1}) followed by the I_1 (Irrigation at 100%FC) level of irrigation (7.707 kg^{-1} ha^{-1} mm^{-1}) and the lowest water use efficiency was observed in the I_3 (Irrigation at 50%FC) level of irrigation (5.278 kg^{-1} ha^{-1} mm^{-1}). Among the antitranspirants, the highest water use efficiency was observed in the plants treated with S_1 (Kaolin 6%) (9.520 kg^{-1} ha^{-1} mm^{-1}) followed by S_3 (Cycocel 1000ppm) (8.019 kg^{-1} ha^{-1} mm^{-1}) followed by S_2 (Acetylsalicylic acid 10^{-3}M) (7.133 kg^{-1} ha^{-1} mm^{-1}). The effect of anti-transpirant S_4 (Hexadecanol 5%) (7.487 kg^{-1} ha^{-1} mm^{-1}) was statistically at par with S_2 (Acetylsalicylic acid 10^{-3}M) (7.133 kg^{-1} ha^{-1} mm^{-1}) and S_3 (Cycocel 1000ppm) (8.019 kg^{-1} ha^{-1} mm^{-1}). The lowest water use efficiency was observed in the plants under control (5.702 kg^{-1} ha^{-1} mm^{-1}).

The water use efficiency by the crops recorded significant differences between the interaction effects of the levels of irrigation and antitranspirants. A significantly higher crop water use efficiency was observed in the treatment combination I_2S_1 (11.990 kg^{-1} ha^{-1} mm^{-1}) followed by I_2S_3 (10.553 kg^{-1} ha^{-1} mm^{-1}) which was statistically at par with I_1S_1 (10.007 kg^{-1} ha^{-1} mm^{-1}). The significantly lowest crop water use efficiency was observed in the treatment combination I_3S_0 (3.703 kg^{-1} ha^{-1} mm^{-1}). The data is represented in Table 17 and 18 and in Fig. 3.

Consumptive use: Consumptive use of water is the depth of water consumed by the plant in the process of interception, transpiration, and evaporation during crop growth. The water used by the crop and evaporated from surfaces also contributes to total consumptive usage. Basically it is the depth of water per unit area for a specific period of time. A significant portion of water is lost through evapotranspiration and evaporation, which are not recoverable for immediate reuse. Consumptive usage estimation is essential in agricultural experiments for water management, promote productive and sustainable farming methods, manage water-related expenses, and help in economic planning. The consumptive use chart is presented in Table 19.

3.4 An Overview of the Impact of Antitranspirants on Crop Physiology under Various Levels of Water Stress

The effect of antitranspirants at different irrigation levels as described in the Fig. 4, showed that there was a relation between all of them. With the gradual reduction of water availability from irrigation at 100% FC (I_1) to irrigation at 75% FC (I_2) followed by irrigation at 50% FC (I_3), the proline content was observed to be increasing however with the increase of proline content an indirect relationship observed with chlorophyll that means with increase of proline content, reduction of chlorophyll content was observed. Similarly, a direct relationship was observed between proline content and stomata density of fresh leaf. This means with the increase in proline content, an increasing trend of stomata density was observed. In short, proline denotes stress levels, thus with the increasing level of proline, a decreasing trend of chlorophyll content and increasing stomata density of fresh leaf was obtained. This stress effect was highly reduced by the antitranspirants at all irrigation levels which can be observed by comparing treatment interactions (I_nS_n) with the control (I_nS_0). Where I_nS_n represents interaction effects between irrigation levels and antitranspirants, (I_nS_0) represents interaction effects between irrigation levels with no antitranspirants.

Here the chlorophyll content increases with the growth and development of the crop but at the time of maturity or near maturity the chlorophyll starts to reduce even if the plants are not under stress. This is one of the physiological characteristics of the plants. Thus, we can see an increasing trend of chlorophyll content from the observations taken at 40 and 80 DAS but the chlorophyll content seems to be decreasing at the observations taken at 120 DAS. Irrigation increases water availability, which reduces stress signals and allows plants to concentrate on growth and development. It was observed that soil water content decreased, leading to increased stomatal production and density, but decreased stomatal size and aperture. This might be because, under increasing water stress, plants increase stomatal density as an adaptive response to balance CO_2 intake for photosynthesis and water conservation, assuring life and sustaining metabolic activities. Increased irrigation improved nutrient absorption, photosynthesis, growth conditions and cellular activity, all of which contribute to higher chlorophyll levels in plants. Water supply enables effective photosynthesis, allowing plants to spend more resources on making chlorophyll. The main reason behind the loss of chlorophyll with increasing water stress might be photo-oxidation which leads to oxidative damage. During performing experiment, it was observed that plants when exposed to sun radiation, kaolin increased the amount of photosynthetic pigments much more than the control. The highest increases in chlorophyll a and b and carotenoids were achieved with 6% kaolin. Kaolin creates a reflective coating on plant surfaces, limiting sunlight and heat absorption, lowering leaf temperature, and decreasing transpiration and water loss. This minimizes the demand for proline, an osmoprotectant and stress-related molecule, in less stressed plants.

While observing the trend of nutrient uptake as described in Fig. 5, it was observed that, with increasing irrigation levels, nutrient uptake increases. The plants treated with Kaolin 6% achieved the highest nutrient uptake and as a result produced the highest growth and yield attributes. When antitranspirants were applied with different irrigation levels, their interaction effect showed that the plants treated with irrigation at 100% FC with Kaolin 6% (I_1S_1) produced the highest crop growth as well as biological yield, and plants treated with irrigation at 75% FC with Kaolin 6% (I_2S_1) produced highest economic yield, both uptaken almost same amount of nutrients. This shows that even if plants uptake more nutrients it does not mean that the uptaken nutrients were totally used for economic yield. In high water availability regions (I_1), the plants utilized more nutrients in biomass production rather than grain yield whereas on the other hand, the plants treated with moderate levels of irrigation (I_2) utilized more amount of nutrients in grain production rather than biomass production.

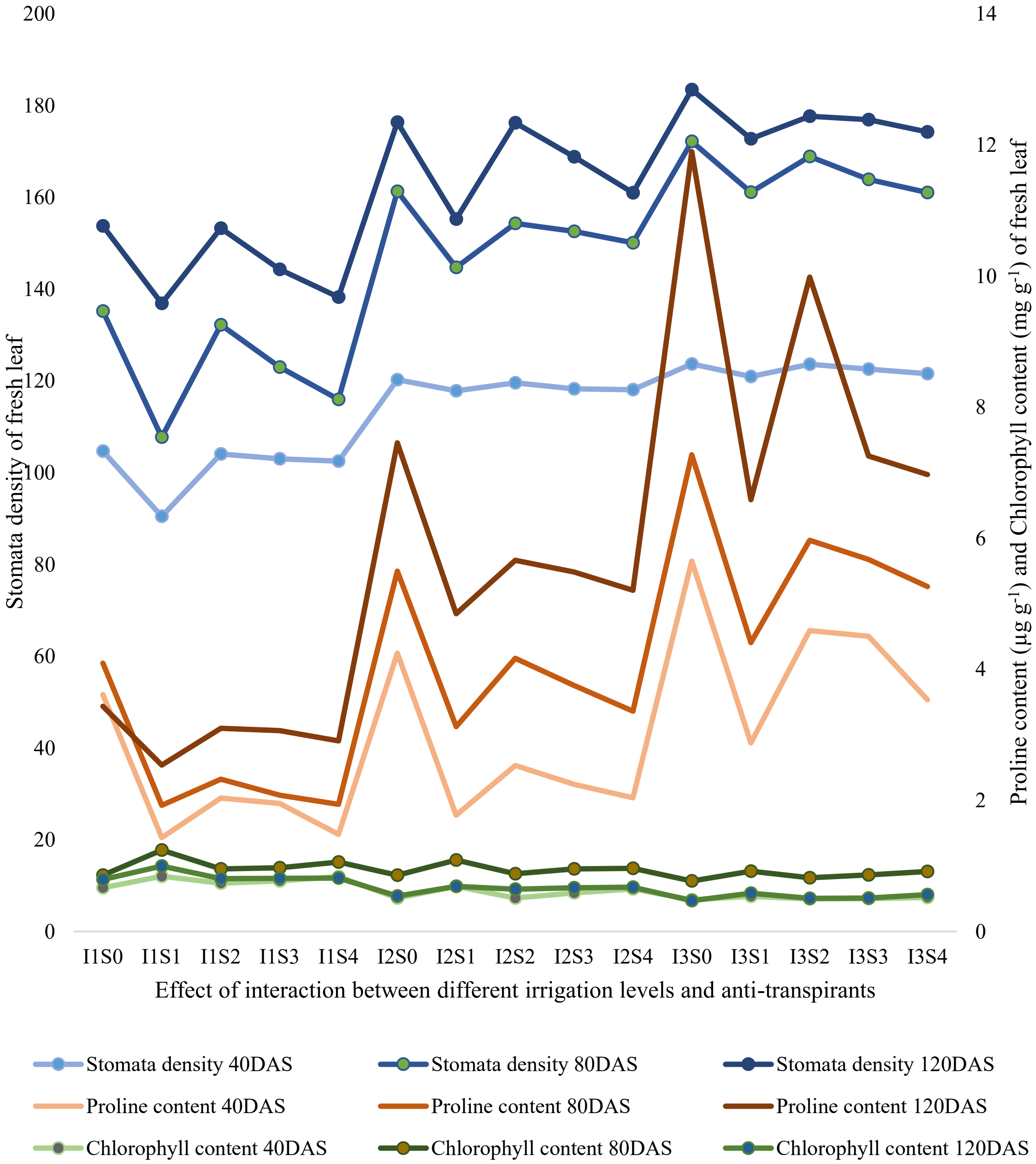

Fig. 4. Graph representing the effect of interaction between different irrigation levels and antitranspirants on the proline content (µg g^{-1}), Chlorophyll content (mg g^{-1}), and stomata density (number of stomata per mm^2) of fresh leaf

Table 17. Influence of different irrigation levels and antitranspirants on the Crop water use efficiency (kg^{-1} ha^{-1} mm^{-1})

Tr. No	Treatments	WUE (Water Use Efficiency) ($kg^{-1}ha^{-1}mm^{-1}$)
	A. IRRIGATION	
I_1	At 100% FC	7.707±0.08
I_2	At 75% FC	9.731±0.09
I_3	At 50% FC	5.278±0.19
	SEm (±)	0.216
	CD(P=0.05)	0.871
	B. ANTITRANSPIRANTS	
S_0	Control (No antitranspirants)	5.702±0.16
S_1	Kaolin 6%	9.520±0.15
S_2	Acetylsalicylic Acid 10^{-3}M	7.133±0.18
S_3	Cycocel 1000 ppm	8.019±0.07
S_4	Hexadecanol 5%	7.487±0.02
	SEm(±)	0.183
	CD(P=0.05)	0.536
	INTERACTION(AxB)	
	SEm(±)	0.483
	CD(P=0.05)	1.056

Table 18. Effects of interaction between different irrigation levels and antitranspirants on the crop water use efficiency (kg^{-1} ha^{-1} mm^{-1})

Treatment interaction	Water Use Efficiency (kg^{-1} ha^{-1} mm^{-1})
I_1S_0	6.310±0.17
I_1S_1	10.007±0.23
I_1S_2	6.967±0.18
I_1S_3	7.780±0.19
I_1S_4	7.473±0.13
I_2S_0	7.093±0.21
I_2S_1	11.990±0.27
I_2S_2	9.410±0.25
I_2S_3	10.553±0.19
I_2S_4	9.610±0.28
I_3S_0	3.703±0.17
I_3S_1	6.563±0.24
I_3S_2	5.023±0.16
I_3S_3	5.723±0.20
I_3S_4	5.377±0.17
SEm(±)	0.483
CD(P=0.05)	1.056

4. DISCUSSION

4.1 Crop Growth Parameter

Estimating crop growth parameters are crucial for resource optimization, yield prediction, breeding, disease control, climate adaptation, soil health management, economic planning, modeling, and policy formulation in agriculture, promoting food security, rural development, and environmental sustainability. The highest crop height and dry matter were obtained from the I_1 (Irrigation at 100%FC) level of irrigation during the observations taken at 40, 80, and 120 DAS. Kumar et. al., (2021), Saini et. al., (2023), and Noor et. al., (2018). This may be because increased irrigation boosts plant height by promoting cell expansion, nutrient uptake, photosynthesis, stomatal function, hormone activity, stress reduction, root development, and temperature control. Water enhances cell elongation, promotes nutrient absorption, supports healthy root systems, and regulates temperature, allowing plants to focus on growth. Similar findings have been obtained by Ismail, S.M. (2016), Akkamis, M., & Caliskan, S. (2023), Mazen, Khaled (2006), and Singh et. al., (2021). Similarly, number of branches per plant and the number of leaves per plant were also found to be highest in the I_1 level of irrigation, Saleh et. al., (2016). The highest leaf area index was observed in the I_1 level of irrigation. This might be because high irrigation reduces water stress, increasing photosynthesis, enabling nutrient absorption, controlling temperature, and promoting hormone production. It also encourages healthy leaf growth, the number of leaves, and the area on which LAI depends. Similar results were obtained by Heydari et. al., (2019).

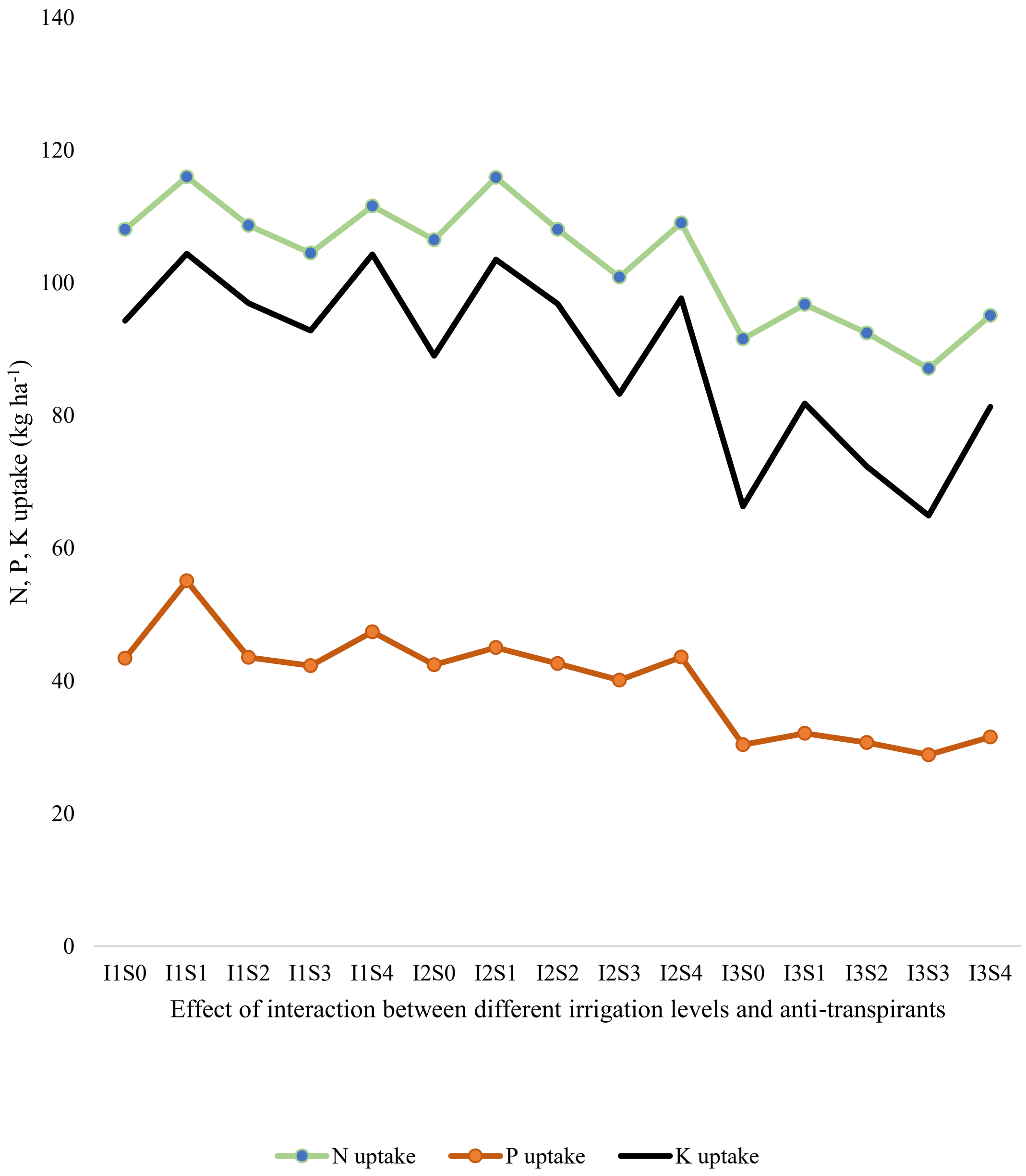

Fig. 5. Graph representing the effect of interaction between different irrigation levels and antitranspirants on the crop nutrient (N, P, and K) uptake in kg ha^{-1}

Table 19. Table representing the effects of different irrigation levels and antitranspirants on the consumptive use (cm)

Treatment interaction	Consumptive use throughout cropping period
I_1S_0	599.319
I_1S_1	599.319
I_1S_2	599.319
I_1S_3	599.319
I_1S_4	599.319
I_2S_0	119.864
I_2S_1	119.864
I_2S_2	119.864
I_2S_3	119.864
I_2S_4	119.864
I_3S_0	47.946
I_3S_1	47.946
I_3S_2	47.946
I_3S_3	47.946
I_3S_4	47.946

Among the antitranspirants, the highest crop height was obtained in S_1 (Kaolin 6%). This may be because of Kaolin spray improves crop height by reflecting sunlight, lowering water stress, increasing photosynthesis, and moderating environmental challenges, resulting in better plant development. Similar findings were obtained by Hamdy et. al. (2022). According to the observations, it was observed that the highest LAI was also obtained in anti-transpirant S_1 (Kaolin 6%). This may be because of the comparatively increased leaf area and the number of leaves. Madu et. al., (2023), Singh et. al., (2007). The number of branches and leaves was observed to be higher in the anti-transpirant treatment S_3 (Cycocel 1000ppm). This might be because chlormequat chloride regulates plant growth by inhibiting gibberellin synthesis, reducing stem length, promoting cytokinin activity, and improving photosynthesis. This leads to shorter, bush structure, increased cell division, and lateral buds.

4.2 Crop Yield Parameters

Yield attributes are essential to agricultural experiments, crop performance, and economic feasibility. They assess the impact of the environment, nutrition quality, resource efficiency, breeding, genetic improvement, risk management, and policy formulation. High yields lead to better economic results, sustainable practices, breeding, genetic improvement, and risk management. The harvest data were collected on the 160th day after planting and observed a significant increase in the yield of seed at the I_2 irrigation level and lower in I_3. In crop growth parameters, relatively better results were obtained at the irrigation level I_1. However, the yield obtained (seed yield, 1000 seed weight, number of siliqua per plant, seeds per siliqua and oil content) were better in the I_2 irrigation level, achieving a moderate irrigation rate. This might be because moderate irrigation supports the growth of plants by maintaining an appropriate soil moisture level, conserving water resources, preventing the loss of nutrients and diseases, improving the development of roots, maintaining the soil structure, and economically and environmentally sustainable. Together, these factors can improve the production of agricultural crops. Similar phenomena were observed by Lawal et. al., (2020), Bozkurt et. al., (2011), Franco et. al., (2022), and Abd El-Baset et. al., (2017). The same kind of observation was observed in the harvest index with higher values indicating towards I_2 level of irrigation and lowest in I_3 irrigation level. While collecting data of biological yield, it has been observed that I_1 yields more biological yield than I_2 but statistically, they were at par which means the difference is less. This might be because, in higher irrigation (I_1) the vegetative growth reaches a high range while the yield does not. Where as moderate level of irrigation (I_2) leads to comparatively less plant growth compared to I_1 but yields better. Together which makes the biological yield at par with each other among the I_1 and I_2 levels of irrigation treatment Singh et. al., (2018), Hossain et. al., (2015), Kumawat et. al., (2024), Ali et. al., (2023), Nautiyal et. al., (2020), and Rathore et. al., (2020).

Among antitranspirants, the highest number of siliqua per plant, seeds per siliqua, and 1000 seed weight were obtained due to the treatment of S_1 (Kaolin 6%) followed by S_3 (Cycocel 1000ppm). In some cases, they were statistically at par and sometimes they were significantly different but as per the observations, Kaolin performed the best among all anti-transpirant treatments. This is because Kaolin, a clay mineral, enhances crop yield by controlling pests, reducing heat stress, leaf reflectance, reducing water loss, improving photosynthesis, suppressing fungal diseases, and enhancing yield quality. It forms a protective barrier, reduces water loss, and promotes sustainable agriculture practices. Similarly, the highest seed yield, and biological yield were obtained because of the anti-transpirant treatment S_1 (Kaolin 6%). A similar result has been observed in Tetarwal et. al*.,* (2013), Tamboli et. al*.,* (2023), Madu et. al*.,* (2023), Patel et. al*.,* (2019), and Abdallah, A. (2019). The highest oil content was observed due to Kaolin 6%. Similar result was observed by Rajput, A. L. (2012), and Tetarwal et. al*.,* (2013). However, the lowest biological yield was obtained in S_3 (Cycocel 1000ppm) though as per yield it comes next to S_1 (Kaolin 6%) which produced the highest yield. This means though Cycocel reduces plant height and plant weight but increases yield significantly. A similar concept was obtained by Seyed Sharifi and Khalilzadeh (2018), Wijaya and Slameto (2017), Ghaffari et. al*.,* (2024), Damor et. al*.,* (2024), and Rani et. al*.,* (2020). Higher harvest index i.e. the ratio of economic yield to biological yield was also obtained in S3 (Cycocel 1000ppm) which was statistically at par with Kaolin. Yadav et. al*.,* (2017) observed that among different antitranspirants, comparatively higher harvesting index observed in the plants treated with Cycocel 1000ppm. Kumar et. al*.,* (2011), Ghaffari et. al*.,* (2024), and Gaikwad et. al*.,* (2022) observed that with the increasing concentration of cycocel the harvesting index tends to increase. This might be because cycocel reduces plant height, improves root and stem development, improves photosynthetic efficiency, allocates resources to reproductive growth, increases stress resistance, promotes uniformity and productive flowering, and affects biological yield. These combined effects promote healthier plants and potentially higher yields (Zhao et al. 2015).

4.3 Crop Water Use Efficiency

It is the ratio between crop yield and Evapotranspiration. "In simple terms, water use efficiency is the amount of crop yield produced per unit of water consumed by the plant. This is a very important topic in crop production."-Dejene Eticha, Senior Scientist, Yara Agronomic Research and Development. In this experiment, it was observed that the plants under the I_2 (Irrigation at 75%FC) level of irrigation produced more economic and biological yield compared to other levels of irrigation using the irrigated water most efficiently. In an experiment performed by El-Harty et. al*.,* (2023) under different irrigation levels based on field capacity and observed that moderate irrigation level leads to higher water use efficiency. It has been observed that high irrigation does not lead to high water use efficiency which means water losses increases with increasing irrigation water application. Similarly, on the other hand, very little irrigation availability also leads to a reduction of water use efficiency which means sufficient moisture is unavailable to the crops so the crops cannot able to utilize it. Among all the antitranspirants, the significantly higher crop water use efficiency was observed in the plants treated by S_1 (Kaolin 6%) followed by cycocel (S_3), and the lowest crop water use efficiency was observed in the plants in control (S_0) where no antitranspirants were used. Abdallah, A. (2019) observed a similar trend of increasing water use efficiency by the foliar application of Kaolin.

4.4 Effect of Antitranspirants on the Crop Physiology

Crop physiological observations are essential for agricultural experiments, assessing health and stress responses, predicting yield and quality, and assessing environmental impacts. The physiological observations of crops provide important data for the study and improvement of agricultural practices, improving crops' performance, sustainability, and resilience to various challenges. These observations bridge the gap between theoretical research and practical application in the field and ensure that agricultural practices are scientifically and effectively grounded. In the physiological observations, the observations of proline, chlorophyll, and stomata count were taken at an intervals of 40, 80, and 120 DAS. The proline content was observed to be higher at I_3 (Irrigation at 50%FC) level of irrigation and that gradually decreased with the increasing irrigation level. This shows that proline content at no stress I_1 (Irrigation at 100%FC) accumulated lesser proline compares to high stressed I_3 (Irrigation at 50%FC). This is because increased irrigation reduces proline levels in plants. Proline buildup is a physiological reaction to water stress. Proline is an osmoprotectant that accumulates in plant tissues during water stress to preserve cellular osmotic equilibrium. Irrigation increases water availability, which reduces stress signals and allows plants to concentrate on growth and development. Similar results were observed by Nazar et. al., (2015), Pospisilova et. al., (2011), and Sahoo et. al., (2019). Similarly, a higher stomata count per mm2 of the fresh leaf was observed in the I_3 (Irrigation at 50%FC) level of irrigation and it decreased with the increase in irrigation level, and lower stomata count per mm2 was obtained in I_1 (Irrigation at 100%FC). This may be because, under water stress, plants increase stomatal density as an adaptive response to balance CO_2 intake for photosynthesis and water conservation, assuring life and sustaining metabolic activities. This phenomenon of increasing stomatal density and decreasing stomatal length under water stress was also observed in the research performed by Driesen et. al., (2023), Xu et. al., (2008), Fraser et. al., (2009), Zhaw et. al., (2015), and Shekari et. al., (2016). Soil water content decreased, leading to increased stomatal production and density, but decreased stomatal size and aperture. Zhaw et. al., (2015). In the observation related to chlorophyll content, significantly higher chlorophyll content was observed in the I_1 level of irrigation and it has been observed that with increasing stress the chlorophyll content decreases. This is because Increased irrigation improves nutrient absorption, photosynthesis, growth conditions, and cellular activity, all of which contribute to higher chlorophyll levels in plants. Water supply enables effective photosynthesis, allowing plants to spend more resources on making chlorophyll. Similar observations were obtained from Khaleghi et. al., (2012), Yildirim et. al., (2023), Chavan & Bodake (2023), Mahmoudian et. al., (2021), and Xu et. al., (2020). The main reason behind the loss of chlorophyll with increasing water stress is photo-oxidation which leads to oxidative damage. (Karimi & Tavallali, 2017).

Among the antitranspirants, significantly lowest proline accumulation was observed in S_1 (Kaolin 6%) compared to the control. This is because of Kaolin treatment inhibits proline buildup in plants by reducing heat and water stress. It creates a reflective coating on plant surfaces, limiting sunlight and heat absorption, lowering leaf temperature, and decreasing transpiration and water loss. This minimizes the demand for proline, an osmoprotectant and stress-related molecule, in less stressed plants. Similar results were obtained by Mahmoudian et. al., (2021), Abdallah et. al., (2019), and Noor et. al., (2018). Similarly, the lowest stomata count per mm2 was obtained from anti-transpirant treatment S_1 (Kaolin 6%) in which the lowest proline accumulation was observed which means it is the treatment that showed the lowest water stress. Elmasrya and Abd El-Radyb (2024). The phenomenon of decreasing stomatal count per mm^2 under reducing water stress was also observed in the research performed by Driesen et. al., (2023), Xu et. al., (2008). This might be because, under increasing water stress, plants increase stomatal density as an adaptive response to balance CO_2 intake for photosynthesis and water conservation, assuring life and sustaining metabolic activities. Anti-transpirant S_1 (Kaolin 6%) showed significantly the highest chlorophyll content in fresh leaves. This might be because treatment S_1 showed lower proline accumulation which means lower water stress and reducing the water stress improves nutrient absorption, photosynthesis, growth conditions, and cellular activity, all of which contribute to higher chlorophyll levels in plants. Water supply enables effective photosynthesis, allowing plants to spend more resources on making chlorophyll. Similar observations were obtained from Mahmoudian et. al., (2021), Gharghani et. al., (2018), Dinis et. al., (2018), and Hamdy et. al., (2022) also observed that when exposed to sun radiation, kaolin increased the amount of photosynthetic pigments much more than the control. The highest increases in chlorophyll a and b and carotenoids were achieved with 6% kaolin.

Analyzing crops' nitrogen (N), phosphorus (P), and potassium (K) uptake is essential to managing nutrients, crop yield, environmental protection, economic advantages, crop physiology and genetics, adaptation to climate change, and scientific advances. It ensures the efficient use of fertilizers, maintains soil fertility, maximizes crop yields, reduces pollution, and supports the innovation of fertilizers and precision agricultural technologies. The plant analysis was carried out after the harvest was done. It has been observed that the crops of I_1 have uptaken higher N compared to other levels of irrigation. In an experiment performed by Wang and Li (2002) observed that with the increasing water stress the growth and nutrient uptake decreases. They also stated that supplemental irrigation does not mean crops will uptake nutrients proportionally. With the increasing irrigation level the nutrient uptake increases. Singh et. al., (2007). Similar result was reported by Verma et. al., (2023), Crop N uptake under I_1 and I_2 levels of irrigation was at par. It has been also observed that the crops with higher biological yield uptake higher N. A similar result was observed in the case of P and K uptake by crop.

In the case of antitranspirants, the plants under S_1 treatment uptakes higher N, P, and K. When compared with biological yield it was observed that higher biological yield obtained in crops treated with S_1 Kaolin anti-transpirant uptaken higher N, P, and K. By comparing all of these, it was observed that higher biological yield leads to higher nutrient uptake.

5. CONCLUSION

After conducting the experiment, it was observed that while high levels of irrigation can encourage plant development, they do not ensure increased yield. It is true that water helps plants growth and development through moisture and nutrient uptake, but there is a maximum and minimum limit beyond which it has a negative impact on plant growth and development. The highest plant height, branches and leaves per plant, LAI and dry matter weight was observed in the crops under I_1 (Irrigation at 100% FC) level of irrigation. Among the antitranspirants, S_1 (Kaolin 6%) performed better in terms of plant height, dry matter weight, and LAI. In terms of yield, the crops under I_2 (Irrigation at 75% FC) level of irrigation produced the best result compared to other levels of irrigation. Among the antitranspirants, S_1 (Kaolin 6%) performed better result producing the highest seed yield, biological yield, seeds per siliqua. In terms of physiological parameters, it has been observed that with decreasing irrigation levels, the proline content and stomata count per mm^2 increases and chlorophyll content decreases. Lowest proline content, stomata count per mm^2 and and highest chlorophyll content was observed under I_1 (Irrigation at 100% FC) level of irrigation. Which means, with increasing stress the proline content and stomata count per mm^2 was observed to be increasing and chlorophyll content observed to be decreasing. Among the antitranspirants, S_1 (Kaolin 6%) which is a reflectant type anti-transpirant performed better in the physiological aspects of the crop which means plants under S_1 (Kaolin 6%) faced minimum stress under different levels of irrigation.

DISCLAIMER

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CONSENT

All the contributing authors of this research paper have consented to publication in the International Journal of Plant & Soil Science declaring that no part of this paper has been submitted to any other journal or book chapter.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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APPENDIX- I. Daily evaporation data

	Evaporation		Evaporation		Evaporation		Evaporation		Evaporation		Evaporation
Day 1	4.4	Day 31	3.2	Day 61	0	Day 91	1.2	Day 121	2	Day 151	2.5
Day 2	4.5	Day 32	3.2	Day 62	0.1	Day 92	0.8	Day 122	4	Day 152	3
Day 3	4.6	Day 33	3.3	Day 63	0.1	Day 93	1	Day 123	3.6	Day 153	3.5
Day 4	4.7	Day 34	3.4	Day 64	0.2	Day 94	0.7	Day 124	3.8	Day 154	4
Day 5	5.2	Day 35	3	Day 65	0.1	Day 95	1	Day 125	3.2	Day 155	2
Day 6	4.5	Day 36	2	Day 66	0.2	Day 96	1.2	Day 126	3	Day 156	2.5
Day 7	4.4	Day 37	1.7	Day 67	0	Day 97	1	Day 127	2.8	Day 157	1.6
Day 8	4.5	Day 38	1.9	Day 68	0.5	Day 98	0.9	Day 128	2.9	Day 158	2
Day 9	4	Day 39	2	Day 69	0	Day 99	0.8	Day 129	1.5	Day 159	3.5
Day 10	4.2	Day 40	1.8	Day 70	0	Day 100	0.5	Day 130	3	Day 160	2.5
Day 11	3.5	Day 41	1.5	Day 71	0	Day 101	0.9	Day 131	2.5		
Day 12	3.4	Day 42	2	Day 72	0	Day 102	0.6	Day 132	1.5		
Day 13	3.4	Day 43	1.7	Day 73	0.5	Day 103	1	Day 133	1.8		
Day 14	3.3	Day 44	1.5	Day 74	0	Day 104	1.3	Day 134	1.9		
Day 15	3.4	Day 45	2	Day 75	1	Day 105	1.4	Day 135	2		
Day 16	3.5	Day 46	1.3	Day 76	0.4	Day 106	1.2	Day 136	1.6		
Day 17	3.4	Day 47	1.8	Day 77	0.6	Day 107	1	Day 137	2		
Day 18	3.5	Day 48	1.5	Day 78	0.6	Day 108	1.6	Day 138	1		
Day 19	3.4	Day 49	1.5	Day 79	0.5	Day 109	2.5	Day 139	0.5		
Day 20	3.4	Day 50	1.3	Day 80	0.5	Day 110	2	Day 140	1.6		
Day 21	3.5	Day 51	1.7	Day 81	0.3	Day 111	2.5	Day 141	1.2		
Day 22	3.6	Day 52	1.5	Day 82	1.2	Day 112	2	Day 142	2		
Day 23	3.2	Day 53	1.5	Day 83	0.7	Day 113	1.8	Day 143	2.5		
Day 24	3.3	Day 54	1.3	Day 84	0.6	Day 114	1.3	Day 144	4		
Day 25	3.5	Day 55	1.5	Day 85	0.7	Day 115	1.5	Day 145	3.5		
Day 26	3.4	Day 56	1.8	Day 86	0.6	Day 116	2	Day 146	2.5		
Day 27	3.3	Day 57	1.2	Day 87	0.4	Day 117	2	Day 147	2.8		
Day 28	3.2	Day 58	1	Day 88	0.5	Day 118	2.3	Day 148	2.6		
Day 29	3.1	Day 59	0.5	Day 89	0.6	Day 119	2.2	Day 149	2		
Day 30	3.3	Day 60	0.3	Day 90	1.2	Day 120	2.4	Day 150	3		

APPENDIX -II. Calculation of crop evapotranspiration

Experimental period	Evaporation	ET_0	Crop ET
Week 1	32.3	22.61	24.6449
Week 2	26.3	18.41	20.0669
Week 3	24.1	16.87	18.3883
Week 4	23.5	16.45	17.9305
Week 5	22.5	15.75	17.1675
Week 6	12.9	9.03	12.5622
Week 7	11.3	7.91	17.402
Week 8	10.6	7.42	16.324
Week 9	3.2	2.24	4.928
Week 10	1	0.7	1.54
Week 11	2.5	1.75	3.85
Week 12	4.4	3.08	5.4635
Week 13	5.2	3.64	5.278
Week 14	6.6	4.62	6.699
Week 15	6.5	4.55	6.5975
Week 16	12.8	8.96	12.992
Week 17	13.1	9.17	13.2965
Week 18	22	15.4	22.33
Week 19	16	11.2	16.24
Week 20	10.6	7.42	10.759
Week 21	18.5	12.95	18.7775
Week 22	20.6	14.42	20.909
Week 23	14.1	9.87	14.3115
Total	320.6		308.4578

APPENDIX -III. Irrigation scheduling

The three levels of irrigation were I_1 (Irrigation at 100%FC), I_2 (Irrigation at 75%FC), and I_3 (Irrigation at 50%FC). After saturating the soil, the soil samples were collected every 24hr and the moisture percentage was observed and was noted. On the 3rd and 4th day, the soil moisture percentage remains constant, this is regarded as 100% field capacity (FC).

The soil moisture percentage at 100% FC was 17.64%.
The soil moisture percentage at 75% FC was 13.23%
The soil moisture percentage at 50% FC was 8.82%

Now this was done under a closed environment where no evaporation losses were there but this experiment was performed in open soil. So, In the open soil, after almost saturating the open soil, irrigation was discontinued, as a result, the moisture percentage started to decline. when the soil moisture percentage of open soil was equal to the soil moisture percentage at any of the 100%, 75%, or 50%FC, irrigation was delivered to the respective main plots that were marked to receive irrigation at the respective FC (100%, 75%, or 50%).

when soil moisture percentage of open soil = soil moisture percentage at 100%FC (17.64%), Irrigation was provided to the main plots denoted to apply irrigation at 100%FC (identified as I_1). Typically, within 7 days, the soil moisture percentage approaches 100% FC. So irrigation scheduling was done at an interval of 6-7 days.

when soil moisture percentage of open soil = soil moisture percentage at 75%FC (13.23%), Irrigation was provided to the main plots denoted to apply irrigation at 75%FC (identified as I_2). Within 14-18 days, the soil moisture percentage reaches 75%FC. Thus the irrigation scheduling was done at an interval of 14-18 days.

when soil moisture percentage of open soil = soil moisture percentage at 50%FC (8.82%), Irrigation was provided to the main plots denoted to apply irrigation at 50%FC (identified as I_3). Usually, within 30-35 days, the soil moisture percentage reaches 50%FC. So the irrigation scheduling was done at an interval of 30-35 days.

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