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Research Article

Enhancing growth and yield of the wheat-chickpea intercropping system through a combination of different row ratios and biostimulants

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Abstract
Intercropping of wheat (*Triticum aestivum*) and chickpea (*Cicer arietinum*) invigorates a sustainable agricultural system with a desirable effect on crop productivity. This study investigates the potential of seaweed extracts, humic and fulvic acids and amino acids as biostimulants for certifying wheat and chickpea intercropping enhancements. Field experiments were conducted during the *Rabi* season of 2022–2023. A split plot design was employed, with main plot treatments of varying row ratios (M_1: sole wheat, M_2: sole chickpea, M_3: wheat : chickpea ratio 2:1 and M_4: wheat : chickpea ratio 4:1) and sub plot treatments with different biostimulants (S_0: no biostimulant, S_1: seaweed extract, S_2: humic acid + fulvic acid and S_3: amino acid). Results revealed significance of row ratios and biostimulants on growth and yield attributes. Notably, the 2:1 row ratio treatment (M_3) magnified plant height with a maximum of 101.45 cm for wheat crop and 58.44 cm for chickpea at 120 DAS. The seaweed extract application treatment (S_1) demonstrated maximum plant height of 104.18 cm and 61.00 cm for wheat and chickpea crops, respectively, at 120 DAS. The grain yield of wheat was established to be higher in the sole cropping system (M_1: 7.59 kgha^{-1}) with an accumulated harvest index of 41.23%. Seed yield of chickpea was also higher in the sole crop (M_2: 2.09 kgha^{-1}) with a harvest index of 49.00%. This research delves into the application of biostimulants to maximize the benefits of wheat and chickpea intercropping, potentially advancing sustainability for future food security.

Keywords: Biostimulants, Sustainability, Productivity, Seaweed extract, Intercropping

INTRODUCTION

Intercropping is a sustainable farming approach involving two or more crops being concurrently grown on a single plot of land. The increasing human population and decreasing cultivable land resources necessitate intensifying agricultural production (Maitra *et al*. 2021). Intercropping practices have been associated with certain ecosystem services and benefits such as optimizing resource utilization, soil moisture and nutrient conservation, minimizing the risk of crop failure due to climatic anomalies, and aiding the farmers with additional revenue (Meena *et al*. 2024). When cultivated together, wheat (cereal crop) and chickpea (pulse crop) have different root structures and physiological traits that might enhance soil health, control of pests and diseases, and overall agronomic performance (Hauggaard-Nielsen *et al*. 2001). Cereal crops like wheat usually possess strong competitive qualities for light and nutrients, while legumes like chickpea can fix atmospheric nitrogen to improve soil fertility and benefit neighbouring crops (Księżak *et al*. 2023). Biostimulants are compounds that can generate an overall improvement in the plant and soil microbiome, and they further enhance nutrient uptake and stress tolerance. Intercropping practices coupled with biostimulant application could boost crop productivity while envisaging a sustainable environment (Kumar *et al*. 2023). Biostimulants demonstrate a critical role in improving the efficiency of an intercropping system through enhanced root development, assimilation of nutrients, and reducing abiotic stresses (Rakkammal *et al*. 2023).

In addition, the relationship between biostimulants and crop species in intercropping systems is dynamic and complicated, impacted by many variables such as crop genotype, environmental circumstances, and management techniques (Naseri *et al*. 2020). It is imperative to comprehend these interactions to optimize the use of biostimulants in intercropping systems and realize their full potential for improving crop resilience and productivity. Plant physiology, metabolism, and stress tolerance are all impacted in different ways by biostimulants, which are made up of a wide range of materials such as humic acids, seaweed extracts, and advantageous microbes (Rouphael and Colla, 2020). The present study aimed to explore how biostimulants can be used to increase the growth and yield of chickpea and wheat in an intercropping system, which can lead to improved ecological sustainability and agricultural output.

MATERIALS AND METHODS

The field study was carried out at Lovely Professional University's research farm in Phagwara during the *Rabi* season of 2022–2023. The study area (Fig. 1) lies at 31º14'39.10" N latitude and 75 º41'51.67" E longitude with an altitude of 254m above sea level. The climate of Phagwara is characterized by humid subtropical and semiarid conditions with extreme summer and winter temperatures. The southwest monsoon brings about torrential rainfall from June to September, with a yearly average of 500-700 mm. The texture of the soil was determined with a hydrometer using the method proposed by Bouyoucos (1962), and the soil had a sandy loam texture. pH of soil was measured in a soil water suspension ratio of 1:2.5 given by Jackson (2005) and the value was 7.62 (normal range). The macronutrients in soil were assigned as 150.4 kg/ha (low range) of available nitrogen (determined through Kjeldahl distillation) given by Goyal *et al*. (2022), available phosphorus (11.67kg/ha) (medium range) (determined using Bray's II method) given by Bray and Kurtz (1945) and available potassium (273.75kg/ha) (medium range) as determined with Sodium acetate extraction method by Wheeting (1930). Split plot design was incorporated for the experimental investigation, which included four row ratios, four biostimulants levels, and three replications. The main plots were divided into four row ratio (M_1: Sole wheat, M_2: Sole Chickpea, M_3: Wheat:chickpea 2:1 and M_4: wheat:chickpea 4:1 and four biostimulants levels (S_0: No biostimulant, S_1: Seaweed extract, S_2:

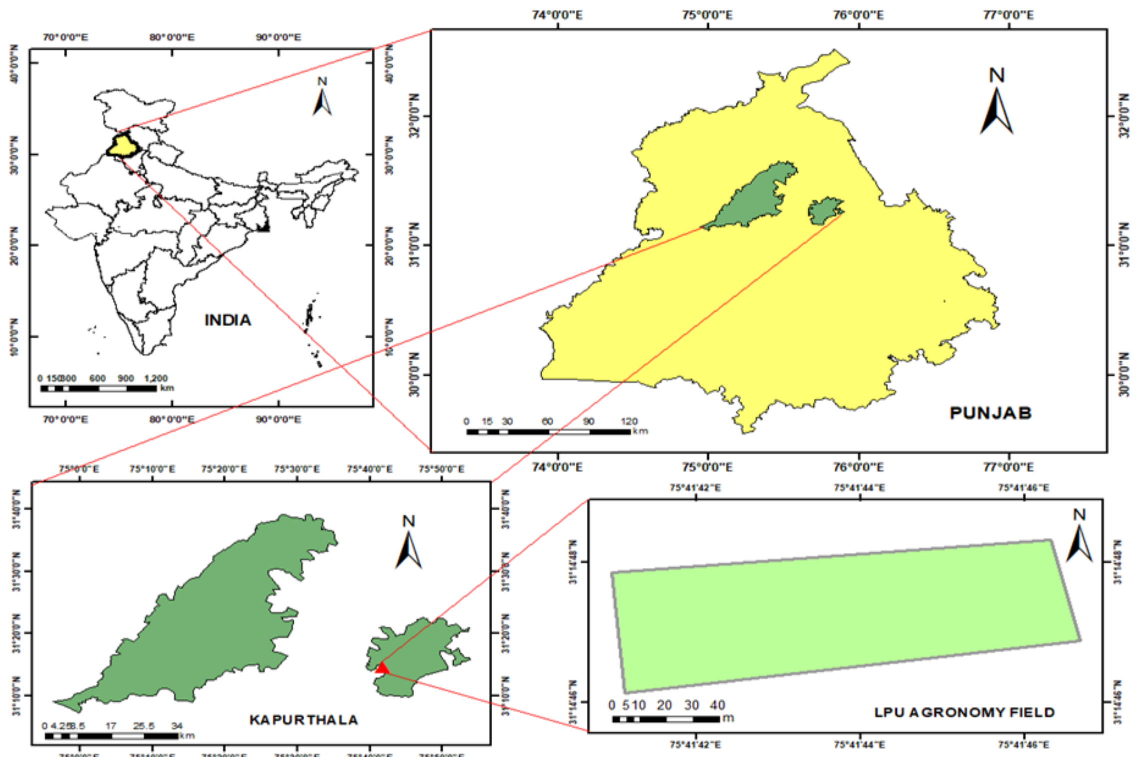

Fig. 1. *Study area: Research farm, Department of Agronomy, Lovely Professional University, Phagwara, Punjab*

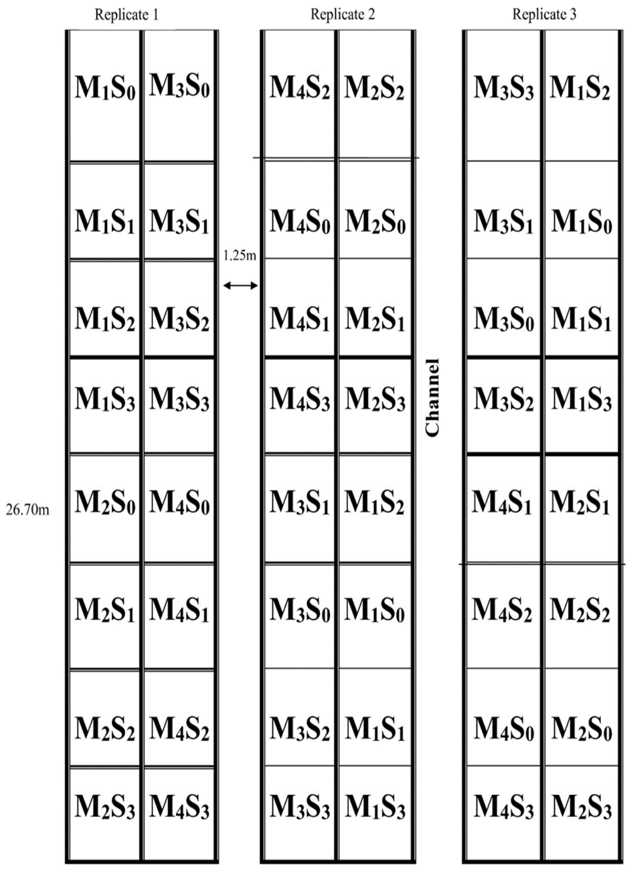

Fig. 2. *Experimental design (Split plot design) ; M_1: Sole Wheat, M_2: Sole chickpea, M_3: Wheat: chickpea at 2:1 ratio, M_4: wheat: chickpea at 4:1 ratio; S_0: No biostimulant, S_1: Seaweed extract as biostimulant, S_2: Humic acid + fulvic acid as biostimulant, S_3: Amino acid as biostimulant.*

Humic acid+ fulvic acid, S_3: Amino acid) within subplots (Fig. 2). Each plot measured 5 x 3 meters (15m^2). The seed varieties DBW-303 for wheat and GNG-469 for chickpea seeds were sown by drilling method at row spacing 20 cm (row to row) of wheat and spacing 30cm x 10cm of chickpea. Chickpea was sown on 16 November 2022 and wheat on 3 December 2022. The different biostimulants were applied through foliar application according to the treatments with recommended dose of NPK at sowing and second half dose after 45 days after sowing. Weeds were managed with hand weeding at 30, 60 and 90 days after sowing. Irrigation was provided to the crops at least three times. The harvesting of wheat was done manually on 140-145 days after sowing and chickpea on 130-35 days after sowing. Using a sickle, the crop was harvested. After the net plot harvesting for each plot, the crop was tied and left in the sun to lose moisture. Subsequently, the crop was threshed, and the seeds were cleaned and plotted using an electronic balance (Bhullar and Salaria, 2024). From each plot, five randomly chosen plants were measured for plant height. Each plot had three randomly chosen sites where the number of dry materials accumulated. The harvest index (HI), which is given as a percentage, was computed by dividing the entire biological yield (grain + straw) by the economic yield (grain) (Chen *et al*. 2021). A standard analysis of variance was used to assess the data, and mean comparisons based on the critical difference test, which was 0.05 %, were carried out.

The wheat equivalent yield (WEY) was examined with the formula given by Anjaneyulu *et al*. (1982):

$$WEY = Grain\ yield\ of\ Wheat + \frac{Seed\ yield\ of\ chickpea \times price\ of\ chickpea}{price\ of\ wheat} \quad \text{Eq. 1}$$

And the land equivalent ratio (LER) was calculated using the formula given by Willey (1985) which is provided below:

$$LER = \sum_{i=1}^{m} \left(\frac{Yij}{Yii}\right) \quad \text{Eq. 2}$$

Where Y_{ij} = yield of i^{th} component from a unit area of intercrop expressed as a fraction of yield

Y_{ii} = yield of i^{th} component grown as a sole crop over the same area.

RESULTS AND DISCUSSION

Growth attributes of wheat and chickpea

Plant height

The growth parameter (plant height) for both crops (wheat and chickpea) were recorded at 30 DAS, 60 DAS, 90 DAS and 120 DAS. In the case of wheat crop, there were significant variations in plant height among the treatments. At 30 DAS, the M_3 treatment (2:1) in the main plots indicated maximum plant height (17.07 cm) which was significantly at par M_4 (4:1) and M_1 (sole wheat) with values of 15.37 cm and 15.04 cm, respectively. The biostimulant application treatments in the subplots also developed significant variations. The application of seaweed extract (S_1) induced a significant effect on plant height (17.68 cm). It was closely followed by Humic acid + Fulvic acid treatment (S_2: 17.32 cm) and Amino acid treatment (S_4: 16.03 cm). The S_0 treatment with no biostimulant application had the least effect on the plant height (12.30 cm). Similarly, the plant height recorded at 60 DAS and 90 DAS were significantly higher at M_3 treatment (2:1). The sub plots also indicated that the seaweed extract treatment (S_1) was more effective than the other treatments. At 120 DAS, maximum recorded value of wheat plant height was (M_2: 101.45 cm) and minimum was (M_4: 99.80 cm) in the main plots. Upon observation in the subplots, seaweed extract treatment (S_1) maintained maximum plant height (104.18 cm) subsequently followed by S_2 (101.29 cm) and S_3 (100.00 cm). The lowest plant height was registered in no biostimulant treatment (S_0), with a recorded value of 95.19 cm (Table 1). The increase in plant height at M_3 (2:1) may be attributed to the proper distribution of the planting geometry, which

Table 1. Effect of row ratio and biostimulant on plant height of wheat and chickpea at 30, 60, 90 and 120 DAS intervals

Treatments	Wheat Plant Height (cm)				Chickpea Plant Height (cm)			
	30 DAS	60 DAS	90 DAS	120 DAS	30 DAS	60 DAS	90 DAS	120 DAS
Main plots								
M_1: Sole Wheat	15.04	54.85	93.38	99.26	-	-	-	-
M_2: Sole Chickpea	-	-	-	-	12.41	18.61	38.31	56.22
M_3: Wheat : Chickpea (2:1)	17.07	57.19	96.37	101.45	13.09	21.01	39.64	58.44
M_4: Wheat : Chickpea (4:1)	15.37	56.39	94.77	99.80	12.65	19.32	38.12	57.24
SEd(±)	0.19	0.41	0.54	0.49	0.11	0.22	0.24	0.53
C.D (P =0.05)	0.55	1.15	1.50	1.38	0.31	0.61	0.69	1.49
Sub-plots								
S_0: No biostimulant	12.29	53.33	91.44	95.19	12.16	17.27	36.72	52.22
S_1: Seaweed extract	17.68	59.21	98.17	104.18	13.48	21.77	41.85	61.00
S_2: Humic acid + Fulvic acid	17.32	56.86	95.28	101.29	12.72	20.62	38.28	59.10
S_3: Amino acid	16.02	55.17	94.46	100.00	12.52	18.91	37.91	56.88
SEd(±)	0.13	0.41	0.43	0.33	0.13	0.21	0.23	0.49
C.D (P =0.05)	0.28	0.87	0.90	0.70	0.28	0.43	0.50	1.03
Interaction M x S								
SEd(±)	0.23	0.72	0.74	0.58	0.23	0.37	0.41	0.85
C.D (P =0.05)	0.48	1.51	1.56	1.22	0.50	0.78	0.87	1.78

leads to better growth attributes. A 2:1 intercropping method involving wheat + lentil contributed to enhanced plant height followed by a synergistic effect with plant growth and seaweed extract biostimulant, leading to an increase in the plant growth attributes (Singh *et al*., 2019; Prajapati *et al*.,2024).

Chickpea recorded maximum plant height at 30 DAS (13.09 cm) in M_3 treatment which was statistically similar with M_4 (12.65 cm) and M_2 (12.41 cm). In the subplots, seaweed extract biostimulant application significantly enhanced the plant height (13.48 cm). It was closely associated with other biostimulant treatments with denoted readings in S_2 (Humic acid + Fulvic acid) and S_3 (Amino acid) treatments being 12.72 cm and 12.52 cm, respectively. The no biostimulant (S_0) managed the least growth attributes with recorded value of 12.16 cm. The plant height in the main plot and subplots at 60DAS and 90DAS retained similarities with 30 DAS, whereby maximum plant height was measured in M_3 and S_1, respectively. At 120 DAS, the observed values at main plots and sub-plots were: M_3 (58.44 cm) > M_4 (57.24 cm) > M_2 (56.22 cm) and S_1 (61.00 cm) > S_2 (59.10 cm) > S_3 (56.88 cm) > S_0 (52.22 cm) respectively (Table 1). This could be a clear suggestion that the biostimulants have a pronounced effect on the growth of plants. The increase of plant height in row ratio treatments might be due to the competition for light with the main crop (Luo *et al*. 2021). Singh *et al*. (2017) and Das *et al*. (2011) annotated an increase in plant height in intercropping of wheat and chickpea with an ameliorative effect on plant height of chickpea from the plant growth promoting enzymes in seaweed extracts (Beghdady *et al*. 2016; Kumari *et al*. 2022).

Dry matter accumulation (g plant^{-1}):

The dry matter accumulation also developed significant changes in both crops at the consecutive days after sowing. In wheat crop, the dry matter accumulation was maximum at M_3 (0.37) which was statistically at par with M_4 (0.34) and M_1 (0.28) at 30 DAS. In subplots, the highest accumulation was observed at S_1 (0.48), which was consequently followed by S_2 (0.35), S_3 (0.29), and S_0 (0.19). The maximum dry matter accumulation recorded at 60 DAS and 90 DAS were at M_3 (4.24), S_1 (5.35) and M_3 (17.40), S_1 (19.08) respectively. Minimum values ensued in M_1 (3.69), S_0 (2.24) at 30 DAS and M_3 (16.16), S_0 (14.84) at 60 DAS (Table 2). At 120 DAS, dry matter accumulation in the main plots were purportedly as follows: M_3 (22.10) > M_1 (20.39) > M_4 (20.09). The value of M_4 was at par with M_1. The sub plots recorded maximum value in S1 (23.69) and followed by S_2 (21.75), S_3 (20.31), S_0 (17.68). In this case, there is a suggestive notion that biostimulant application offers better dry matter accumulation. The higher dry matter accumulation of wheat in the row ratio might be associated with the higher plant population of the system (Kaushik *et al*. 2016; Amanullah *et al*. 2021).

Chickpea expressed sub optimal changes in the dry matter accumulation at 30 DAS. The assessed values in main plots and subplots were M_3 (0.48), M_4 (0.42), M_2 (0.39) and S_1 (0.55), S_2 (0.50), S_3 (0.44) and S_0 (0.23). However, the dry matter accumulation in the days after sowing was observed to be a spike in the sole cropping treatment (M_2). The recorded values at 60 DAS were M_2 (4.02) > M_3 (3.87) > M_4 (5.57) in the main plots and S_1 (4.94) > S_2 (4.39) > S_3 (3.66) > S_0 (2.31) in subplots (Table 2). The trend remained in the next 90 DAS and

Table 2. Effect of row ratio and biostimulant on dry matter accumulation of wheat and chickpea at 30, 60, 90 and 120 DAS intervals

Treatments	Dry matter accumulation of Wheat (g plant^{-1})				Dry matter accumulation of Chickpea (g plant^{-1})			
	30 DAS	60 DAS	90 DAS	120 DAS	30 DAS	60 DAS	90 DAS	120 DAS
Main plots								
M_1: Sole Wheat	0.28	3.69	17.13	20.39	-	-	-	-
M_2: Sole Chickpea	-	-	-	-	0.39	4.02	6.00	9.00
M_3: Wheat : Chickpea (2:1)	0.37	4.24	17.40	22.10	0.48	3.87	5.78	7.58
M_4: Wheat : Chickpea (4:1)	0.34	4.09	16.16	20.09	0.42	3.57	5.45	6.14
SEd(±)	0.02	0.08	0.06	0.09	0.01	0.02	0.03	0.08
C.D (P =0.05)	0.06	0.21	0.17	0.25	0.02	0.07	0.08	0.23
Sub-plots								
S_0: No biostimulant	0.19	2.24	14.84	17.68	0.23	2.31	4.28	4.81
S_1: Seaweed extract	0.48	5.35	19.08	23.69	0.55	4.94	6.76	9.58
S_2: Humic acid + Fulvic acid	0.35	4.39	17.82	21.75	0.50	4.39	6.34	8.94
S_3: Amino acid	0.29	4.05	15.85	20.31	0.44	3.66	5.59	6.97
SEd(±)	0.01	0.10	0.05	0.26	0.01	0.03	0.03	0.10
C.D (P =0.05)	0.02	0.22	0.11	0.55	0.02	0.06	0.06	0.22
Interaction								
M x S								
SEd(±)	0.01	0.18	0.09	0.45	0.01	0.05	0.05	0.18
C.D (P =0.05)	0.03	0.39	0.19	0.95	0.03	0.11	0.11	0.38

120 DAS, which intimated readings of M_2 (6.00) > M_3 (5.78) > M_4 (5.45); S_1 (6.76) > S_2 (6.34) > S_3 (5.59) > S_0 (4.28) and M_2 (9.00) > M_3 (7.58) > M_4 (6.14); S_1 (9.58) > S_2 (8.94) > S_3 (6.97) > S_0 (4.81). This could result from chickpeas benefitting little from intercropped wheat when used in conjunction with seaweed extract as a biostimulant and occupying the largest area when grown as a sole crop. Chickpea and wheat may have also faced competition for moisture and nutrients (Ullah, 2007; Yang *et al*. 2021). Consequently, the row ratio has comparatively less space under chickpea (Singh and Aulakh, 2017). This could induce lower dry matter accumulation of chickpea in the intercropping system as there were more rows of wheat.

Yield attributes of wheat:

The associated yield parameters showed significant changes due to the implementation of row-ratio and biostimulant application in the treatments. The number of effective tillers was maximum in M_3 (25.08) and after that followed by M_4 (23.09) and M_1 (22.05). The biostimulant-treated subplots indicated maximum reading in S_1 (27.32) > S_2 (24.91) > S_3 (23.14) > S_0 (18.27). The number of spikelets per spike surmised maximum value in M_3 (22.30). The 4:1 ratio treatment (M_4) obtained a reading of 20.61 which was statistically at par with the sole wheat cropping treatment M_1 (20.04). The subplots indicated highest number in S_1 (22.46) which was at par with S_2 (22.15). It was consequently followed by S_3 (20.54) and S_0 (18.77) (Table 3). The number of grains per spike indicated maximum estimate of 53.02 in M_3. M_1 (50.35) was relatively at par with M_4 (50.07) in the main plots. Seaweed extract application (S_1) showed reasonably higher no. of grains per spike (56.35) in the subplots, which were followed by S_2 (55.54), S_4 (53.77) and S_0 (38.93). Sarita *et al*. (2021) and Pramanick *et al*. (2014) suggested that applying seaweed extract biostimulant could induce a positive relationship with the number of grains per spike in wheat and rice crops, respectively. The 1000-grain weight was 41.17 g in M_3 treatment. M_4 (39.74 g) was reportedly at par with M_1 (39.55 g). The subplots evaluated the S_1 (41.11 g) as the maximum closely followed by S_2 (40.88 g), S_3 (39.61 g) was at par with S_0 (39.01 g) (Table 3). There was no significant interaction between the main plots and subplots for this yield parameter. Bold grains may have developed since there was lesser competition for moisture and nutrients in intercropping systems than in sole wheat, which increased the amount of photosynthates transferred to the grains (Singh *et al*. 2019).

The straw yield was relatively higher in the sole wheat treatment (M_1: 5.46 tha^{-1}) and M_4 (4.51 tha^{-1}) was at par with M_3 (4.49 tha^{-1}). The subplots denoted less variation in the straw yield except for S_0. The seaweed extract application treatment (S_1)computed the highest of 7.58 tha^{-1} which was statistically at par with S_2: 7.52 tha^{-1}, 7.48 tha^{-1} in S_3 and 5.26 tha^{-1} in S_0. Grain yield is a vital parameter for estimating the crop's productivity and economic viability (Garbelini *et al*. 2022). The analysis for variations in grain yield obtained from the treatments were compiled. The sole wheat (M_1) reportedly observed maximum grain yield (5.46 tha^{-1}). This was followed by the 4:1 row ratio treatment (M_4: 4.51 tha^{-1}) and 2:1 row ratio treatment (M_3: 4.49 tha^{-1}). In the sub-

Table 3. Effect of row ratio and biostimulants on yield components of wheat

Treatments	Yield parameters for Wheat							
	No. of effective tiller per running meter	**No. of spike-lets per spike**	**No. of grains per spike**	**1000-grain weight (g)**	**Straw yield (t/ha)**	**Grain yield(t/ha)**	**Biological yield (t/ha)**	**Harvest Index (%)**
Main plots								
M_1: Sole Wheat	22.05	20.04	50.35	39.55	7.59	5.46	13.05	41.23
M_2: Sole Chickpea	-	-	-	-	-	-	-	-
M_3: Wheat : Chick-pea (2:1)	25.08	22.30	53.02	41.17	6.39	4.49	10.88	41.41
M_4: Wheat : Chick-pea (4:1)	23.09	20.61	50.07	39.73	6.91	4.51	11.42	39.16
SEd(±)	0.31	0.32	0.19	0.24	0.02	0.02	0.04	0.13
C.D (P =0.05)	0.86	0.91	0.54	0.68	0.07	0.07	0.12	0.36
Sub-plots								
S_0: No biostimulant	18.27	18.77	38.93	39.01	5.26	3.16	8.43	37.96
S_1: Seaweed extract	27.32	22.46	56.35	41.11	7.58	5.95	13.53	43.97
S_2: Humic acid + Fulvic acid	24.91	22.15	55.54	40.88	7.52	5.29	12.82	41.05
S_3: Amino acid	23.14	20.54	53.77	39.61	7.48	4.88	12.37	39.41
SEd(±)	0.48	0.57	0.26	0.47	0.06	0.02	0.05	0.34
C.D (P =0.05)	1.02	1.21	0.55	0.98	0.13	0.05	0.11	0.72
Interaction								
M x S								
SEd(±)	0.84	0.99	0.45	0.81	0.10	0.04	0.09	0.59
C.D (P =0.05)	1.77	2.09	0.96	NS	0.22	0.09	0.19	1.25

plots, the seaweed extract treatment (S_1) and Humic acid + fulvic acid treatment (S_2) highly interacted with the productivity factor. It indicated 5.95 tha^{-1} and 5.29 tha^{-1} values in S_1 and S_2, respectively. This was followed by S_3 (4.88 tha^{-1}) and S_0 (3.16 tha^{-1}). The interaction effect in Table 5 clearly shows the combined ability between the main plots and subplots. The combination of sole crop (M_1) and seaweed extract treatment (S_1) or M_1S_1 developed higher efficiency with the productivity factor with an acknowledged yield of 6.55 tha^{-1}, much higher than the other interactions. The highest biological yield in the main plot was observed in M_1 (13.05 tha^{-1}) and subsequently M_3 (11.41 tha^{-1}) and M_2 (10.88 tha^{-1}). The subplots measured biological yield were in the following order: S_1 (13.53 tha^{-1}) > S_2 (12.82 tha^{-1}) > S_3 (12.37 tha^{-1}) > S_0 (8.43 tha^{-1}). The harvest index (HI) of M_3 (41.41%) was relatively at par with M_1 (41.23 %) and the HI of M_4 was 39.16 %. The HI in the subplots were recorded in the order: S_1 (43.97 %) > S_2 (41.05 %) > S_3 (39.41 %) > S_0 (37.96 %) (Table 3). The results indicated that sole wheat had potent effect on yield parameters. Similar results are supported by the outcomes of Kaushik *et al*. 2016 and Rebouh *et al*. (2023) in a wheat cropping system; whereupon the application of seaweed extract biostimulant increases photosynthetic rate and postponed leaf senescence, which has been shown to improve yield parameters in rice, wheat and snap beans (Singh *et al*. 2015; Ramzan and Younis 2022; El Sheikha *et al*. 2022).

Yield attributes of chickpea

The number of pods per plant were higher in the main plot with sole chickpea cropping (M_2: 64.15). The other row ratio treatments obtained (M_3: 62.61) and (M_4: 56.82) in the cropping system. In subplots, seaweed extract treatment (S_1) indicated significant results (66.92) followed by Humic acid + Fulvic acid (S_2: 63.43) and Amino acid treatments (S_3: 60.97); the lowest was noted in no biostimulant treatment (S_0: 53.44). In the yield parameter of the chickpea, the number of seeds per pod was highest in the main plot of sole chickpea (M_2: 2.16). The remaining row ratio treatments M_3 and M_4 obtained 2.10 and 1.91, respectively. In the case of subplots, seaweed extract application (S_1) denoted 2.70 seeds per pod which was significantly higher as compared to Humic acid +Fulvic acid treatment (S_2) (2.35) and Amino acid treatment (S_3) (2.18). A significant decrease in the number of pods $plant^{-1}$ and seeds pod^{-1} was observed in chickpea intercropping with maize (Shivakumar *et al*. 2021). Pod $plant^{-1}$ count in beans is reduced as a result of flower and pod dropping brought on by shadowing by the taller component (Das *et al*. 2011). The 100-grain weight was 29.01 g in M_2 treatment. M_3 (27.01 g) was reportedly at par with M_4 (26.50 g). The subplots evaluated S_1 (29.40 g) as the maximum, closely followed by S_2 (28.60 g), S_3 (28.34 g)

Table 4. Effect of row ratio and biostimulants on yield components of chickpea

Treatments	Yield parameters of chickpea					
	No. of pods per plant	**No. of seeds per pod**	**100- grain weight(g)**	**Seed yield (t/ha)**	**Biological yield (t/ha)**	**Harvest Index (%)**
Main plots						
M_1: Sole Wheat	-	-	-	-	-	-
M_2: Sole Chickpea	64.15	2.16	29.01	2.09	4.13	49.00
M_3: Wheat : Chickpea (2:1)	62.61	2.10	27.01	1.67	3.52	44.86
M_4: Wheat : Chickpea (4:1)	56.82	1.91	26.50	1.37	2.88	43.21
SEd(±)	0.57	0.06	0.30	0.01	0.08	1.12
C.D (P =0.05)	1.58	0.18	0.84	0.02	0.24	3.11
Sub-plot						
S_0: No biostimulant	53.44	1.00	23.69	0.59	1.99	29.50
S_1: Seaweed extract	66.92	2.70	29.40	2.35	4.51	51.99
S_2: Humic acid + Fulvic acid	63.43	2.35	28.60	2.05	4.02	50.76
S_3: Amino acid	60.97	2.18	28.34	1.78	3.52	50.50
SEd(±)	0.78	0.09	0.40	0.02	0.07	1.10
C.D (P =0.05)	1.64	0.19	0.83	0.04	0.16	2.32
Interaction						
M x S						
SEd(±)	1.35	0.16	0.69	0.03	0.13	1.91
C.D (P =0.05)	2.85	0.34	1.45	0.07	0.28	4.02

Table 5. Interaction table between different components for wheat grain yield and chickpea seed yield

Sub plot / Main plot	Grain yield (t/ha)					Seed yield (t/ha)				
	S_0	S_1	S_2	S_3	Mean	S_0	S_1	S_2	S_3	Mean
M_1	3.23	6.55	6.45	5.62	5.46	-	-	-	-	-
M_2	-	-	-	-	-	0.93	2.73	2.55	2.15	2.09
M_3	3.14	5.54	4.74	4.54	4.49	0.54	2.55	1.92	1.66	1.67
M_4	3.14	5.76	4.68	4.50	4.52	0.32	1.78	1.67	1.54	1.33
Mean	3.17	5.95	5.29	4.89		0.60	2.35	2.05	1.79	
M at the same level of S			SEd(±)	CD (P =0.05)				SEd(±)	CD (P =0.05)	
			0.04	0.09				0.03	0.07	
S at the same or different levels of M			0.04	0.10				0.03	0.07	

was at par with S_0 (23.69 g) (Table 4).

Variations in seed yield from the treatments were compiled in Table 4. The sole cropping of chickpea (M_2) obtained the highest seed yield (2.09 tha^{-1}). The 4:1 row ratio treatment (M_4: 1.37 tha^{-1}) and 2:1 row ratio treatment (M_3: 1.67 tha^{-1}) were ensued thereafter. In the subplots, the seaweed extract treatment (S_1) and the fulvic acid + humic acid treatment (S_2) strongly interacted with the productivity component. S_1 and S_2 denoted associated valuations of 2.35 tha^{-1} and 2.05 tha^{-1} respectively. The remaining treatments produced S_0 (0.59 tha^{-1}) and S_3 (1.78 tha^{-1}) readings. The interaction between the main plots and subplots in Table 5 investigated a better interaction between the sole crop (M_2) and the foliar seaweed extract application treatment (S_2) or M_2S_2. This interaction substantially increased seed yield with a value of 2.73 tha^{-1}, which was higher than the other interactions. The biological yield was significantly higher at the main plot sole crop (M_2: 4.13 tha^{-1}), were as followed by M_3 (3.52 tha^{-1}) and M_4 (2.88 tha^{-1}). In sub plot the Seaweed extract (S_1) recorded 4.51 $tha^{-1,}$ which was higher than the humic acid+ fulvic acid ($S_{2:}$ 4.02 tha^{-1}) and amino acid (S_3: 3.52 tha^{-1}) treatments. The harvest index (HI) of chickpea was significantly higher in the sole crop (M_2: 49.00 %) than the other row ratio treatments M_3: 22.86 % and M_4: 43.21 %. Subsequently, in sub plot, the seaweed extract (S_1) determined a 51.99 % HI followed by Humic acid +Fulvic acid (S_2: 50.76 %) and Amino acid (S_3: 50.50 %) (Table 4). The sole chickpea plants encounter less competition from wheat and a comparatively larger area allocated to chickpea cultivation, which may be the reason for their highest seed output (Muruiki *et al*. 2021). Since there was comparatively less space under chickpea in the row ratio, the wheat + chickpea (4:1) pairing may have the lowest seed output (Singh and

Table 6. Effect of row ratio and biostimulants on wheat equivalent yield (WEY) and land equivalent ratio (LER)

Treatments	Yield parameter of wheat	
	Wheat equivalent yield (t/ha)	Land equivalent ratio
Main plots		
M_1: Sole Wheat	5.46	1.00
M_2: Sole Chickpea	4.20	1.00
M_3: Wheat : Chickpea (2:1)	7.73	1.60
M_4: Wheat : Chickpea (4:1)	7.20	1.46
SEd(±)	0.08	0.00
C.D (P =0.05)	0.19	0.01
Sub-plots		
S_0: No biostimulant	3.44	1.22
S_1: Seaweed extract	7.96	1.33
S_2: Humic acid + Fulvic acid	6.86	1.24
S_3: Amino acid	6.33	1.27
SEd(±)	0.10	0.01
C.D (P =0.05)	0.20	0.03
Interaction M x S		
SEd(±)	0.17	0.02
C.D (P =0.05)	0.35	0.04

Aulakh, 2017). El Sheikha *et al*. 2022 also discussed increase in the yield components of snap beans; while the increase in yield through seaweed extract application in chickpea crop was also purportedly given by Beghdady *et al*. 2016, Kurakula and Rai, 2021.

Wheat equivalent yield (WEY)

The wheat equivalent yield (WEY) was statistically highest in the main plot M_3 (7.73 tha^{-1}) consequently followed by M_4 (7.20 tha^{-1}), M_1 (5.46 tha^{-1}) and M_2 (4.20 tha^{-1}) respectively. The seaweed extract biostimulant application (S_1) in the sub plot recorded a WEY of 7.96 tha^{-1} which was significantly higher than the humic acid +Fulvic acid (S_2: 6.86 tha^{-1}) and amino acid (S_3: 6.33 tha^{-1}) treatments (Table 6). Due to their improved compatibility for the consumption of resources, a relationship with increased yields of both component crops and relevant increase in WEY in row ratios was observed under wheat-chickpea intercropping systems (Kaushik *et al*. 2016; Singh *et al*. 2019).

Land equivalent ratio (LER)

LER in sole cropping M_1 and M_2 were at par with each other. However, it increased in row ratio treatment M_3 (1.60) and M_4 recorded value of 1.46. In sub plots, significantly higher LER were observed under seaweed extract treated plot (S_1: 1.33). S_3 (1.27) remained at par with S_2 (1.24) (Table 6). Das *et al*. 2011, Kaushik *et al*. (2016) and Singh *et al*. (2019) also reported an increase of land equivalent ratio in the row ratio treatments under wheat-legumes and wheat-chickpea intercropping system. When LER > 1, the intercropping system utilises the land more efficiently. It results from either higher plant density or more resource-efficient intercropping. LER demonstrated that intercropping wheat and chickpea have advantages (Raza *et al*. 2023). When compared to sole crop, intercropping treatments have greater values of LER, which could be attributed to improved use of water, light, nutrients, and land. When planted alongside other plants, legumes can fix nitrogen in the soil for the benefit of the other plants, increasing agricultural yield (Jena *et al*., 2022).

Correlation analysis:

The analysis signifying the correlation between growth and yield parameters of wheat and chickpea has been plotted with the help of r-plot technique (Fig. 3 and Fig. 4). The r-plot relies on colour plotting with a more pronounced blue and red colour indicating a strong positive and negative correlation respectively. Wheat grain yield draws a significant positive correlation with the plant height (r = +0.76) and the no. of grains per spike (+0.76). Also, it was highly correlated with the effective tillers (r = +0.72), dry matter accumulation (r = +0.69), harvest index (r = +0.73) and straw yield (r = +0.87). Similarly, the straw yield of wheat was strongly correlated with plant height (r = +0.60), no. of grain per spike (r= +0.81) and effective tillers (r = +0.58). The seed yield of chickpea also exhibited significant positive correlation with the plant height (r = +0.75), no. of seeds per pod (r = +0.89), no. of pods/plant (r= +0.92), test weight (r = +0.96), harvest index (r = +0.63) and dry matter accumulation (r = +0.93).

Conclusion

The present findings highlight the significant potential of biostimulants in enhancing the productivity and sustainability of wheat and chickpea intercropping systems. Through the field experiments conducted over the *Rabi*

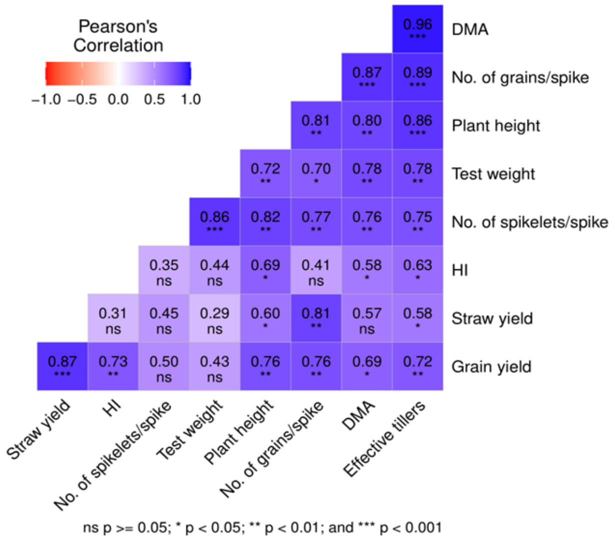

Fig. 3. *Correlation of parameters in wheat*

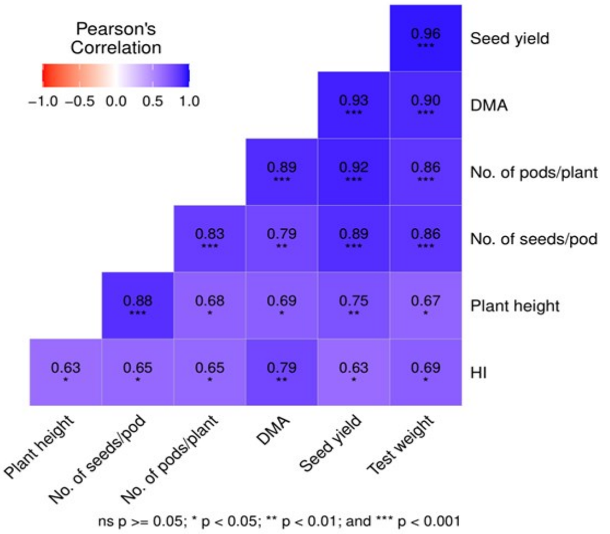

Fig. 4. *Correlation of parameters in chickpea*

season (2022–2023), notable effects of biostimulants application remained paramount on certain crop growth and yield parameters. Seaweed extract emerged as a particularly effective biostimulant, consistently improving plant height, dry matter accumulation, and yield attributes in wheat and chickpea. The study exhibited valuable insights into optimizing agricultural practices for sustainable food production. By harnessing the potential of biostimulants in intercropping systems, farmers could derive resource efficiency and ecological sustainability. However, further research is warranted to explore additional biostimulants, crop combinations, and management strategies to maximize the benefits of intercropping for future food security. In conclusion,the present findings underscore the importance of integrating biostimulants into agricultural practices, paving the way for more sustainable food production systems in the face of evolving environmental challenges.

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Conflict of interest

The authors declare that they have no conflict of interest.

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