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Impact of irradiated chitosan and biofertilizers on growth and yield of *kharif* finger millet (*Eleusine coracana* L.) in Konkan region of Maharashtra

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Abstract
A field experiment was carried out during *Kharif* season of 2023 at Agronomy Farm, Dr. Balasaheb Sawant Konkan Krishi Vidyapeeth, College of Agriculture, Dapoli, Dist. Ratnagiri, Maharashtra, to study the Effect of irradiated chitosan and biofertilizers on growth and yield of *kharif* finger millet (*Eleusine coracana* L.*)* in Konkan region of Maharashtra. The experiment was laid out in Randomized Block Design with Nine treatment combinations replicated thrice. The treatments of the experiment were T_1: Control, T_2: Seed treatment with PSB + *Azospirillum*, T_3: Seed treatment with IR-CSN @ 50 ppm, T_4: Seed treatment with PSB + *Azospirillum* + IR-CSN @ 50 ppm, T_5: T_2 + *Acetobacter* spraying at one day before transplanting, 50, 75 DAT, T_6: T_3 + foliar spray of IR-CSN @ 50 ppm at one day before transplanting, 50, 75 DAT, T_7: T_3 + foliar spray of IR-CSN @ 100 ppm at one day before transplanting, 50, 75 DAT, T_8: T_4 + foliar spray *Acetobacter* + IR-CSN @ 50 ppm at one day before transplanting, 50, 75 DAT, T_9: T_4 + foliar spray *Acetobacter* + IR-CSN @ 100 ppm at one day before transplanting, 50, 75 DAT. 20x15 cm was the spacing used for sowing the finger millet cultivar, Dapoli 2. Result found that growth parameters like plant height (cm), number of functional leaves hill^{-1}, number of tillers hill^{-1}, dry matter accumulation (g) hill^{-1}. and yield parameters like grain yield (q ha^{-1}), straw yield (q ha^{-1}), biological yield (q ha^{-1}), harvest index (%) were recorded significantly maximum values in treatment T_9 (T_4 + foliar spray *Acetobacter* + IR-CSN @ 100 ppm at one day before transplanting, 50, 75 DAT) over control.

Keywords: Chitosan, bio-fertilizers, finger millet, growth, yield

Introduction
Finger millet is an important millet grown extensively in various regions of India and Africa. The popular name "Finger millet" is derived from the finger-like branching of the panicle on the plant *Eleusine coracana* (L.), commonly known as African millet or Ragi. It is a member of the Gramineae family. It is the third most significant millet in India, behind sorghum and pearl millet. It is a resilient crop that may be produced in a variety of climates, from virtually at sea level in south India to high lands in the Himalayas (altitudes of 1850 to 2300 meters), and from poor soils on hill slopes to rich soils in the Indo-Gangetic plains region. It is frequently referred to as the "poor man's crop". In many regions of India, finger millet serves as a staple food for a sizable portion of the agriculture dependent and economically marginalized communities. In comparison to other important grains like wheat, rice, and sorghum, it has significant levels of protein and minerals Gupta *et al.* 2017 [10]; Sharma *et al.* 2017 [19]. The whole seeds of finger millet contain about 0.34% calcium (Ca), which is significantly higher than the other cereal crops. In addition to being gluten-free, the seeds are a rich source of dietary fiber, iron, and the important amino acids isoleucine, leucine, methionine, phenylalanine, and phytates Chandra *et al.* 2016 [6]; Sood *et al.* 2016 [22].

Several cultivars have been recognized. In Africa and India, two groups are familiar Afro-Asiatic forms with full-grown grains visible outside the florets, and African highland types with grains enclosed inside the florets. Finger millet is native to the Ethiopian highlands and commonly cultivated in more than 25 countries Uganda, Nepal, India, Sri Lanka, Bangladesh, East China, Tanzania and Kenya etc. It is understood that Uganda or nearby areas are the primary Centre of foundation of *E. coracana*, and it was brought into India probably over 3,000 years before. Karnataka leads the market of finger millet production in India accounting 58% global sharing, but only limited sections of population are aware about its nutritional and health importance Chandra *et al.* 2016[6]. While concerning the production area in India, finger millet secures sixth rank after wheat, maize, sorghum, rice and bajra. It is world's fourth important millets after pearl millet, sorghum and foxtail millet Devi *et al.* 2014 [8].

It is mainly cultivated in Thane, Raigad, Ratnagiri, Sindhudurg, Dhule, Jalgaon, Nashik, Ahmednagar, Pune, Satara and Kolhapur districts. It is a sustainable crop that can thrive at high elevations, on marginal terrain, and with ease in saline and drought environments. Compared to other crops, it requires substantially less irrigation and other inputs. In India, finger millet is cultivated on an area of 1.26 million hectares with a production of 1.79 million tonnes. Anonymous, 2017-18 [3]. In Maharashtra, Finger millet occupies an area of about 80,130 hectares with a production of 84,850 tonnes. The 30,200 hectares area is found in the Konkan region of Maharashtra comprising Raigad, Thane, Palghar, Sindhudurg and Ratnagiri districts with a production of 33,200 tones with a productivity of 1100 kg ha^{-1} Anonymous, 2018-19 [4].

Natural biopolymers like chitosan are made from chitin, which is the primary structural element of squid pens, some fungus cell walls, and prawn and crab shells. In nature, chitosan and chitin are Copolymers that coexist. Their intrinsic qualities of being easily degradable and environmentally benign are what make them such. Thailand is one of the top exporters of frozen prawns worldwide. Consequently, there are plenty of raw ingredients available to produce chitosan. There are several uses for chitosan. It does not affect humans or livestock due to its high affinity and lack of toxicity. Plant immune systems are regulated by chitosan, which also causes resistant enzymes to be excreted. A few researches were carried on the effects of chitosan on plant growth and development and its productivity Patil *et al*. 2024a [16], Patil *et al*. 2024b [17]. Recently, chitosan enhanced plant growth and development have been reported Chibu *et al.* 2002 [7], Mondal *et al.* 2012 [14].

Beneficial microorganisms in the form of biofertilizers, which boost agricultural output by providing more nutrients. Plants can utilize the unavailable phosphorus pool when it is mobilized by phosphorus biofertilizers. These biofertilizers don't pollute the environment and are affordable and easy to use. In light of this, wise application of both chemical and biofertilizers will support soil health and productivity in addition to fulfilling some of the fertilizer needs of various crops. Therefore, it is crucial to design a practical and compatible nutrient management strategy using biofertilizers along with the suggested dosage of chemical fertilizers, taking into account local conditions, economic viability, and scientific data.

Material and methodology

The experiment was carried out in the *kharif* season of 2023. From a geographical standpoint, the experimental plot of the Agronomy farm of the Department of Agronomy, College of Agriculture, Dapoli, is located in the subtropical zone at 17°45'57" N and 73°10'29" E. Slightly above mean sea level, at an elevation of 157.8 meters. General view of the experimental plot showed in plate no. 1.

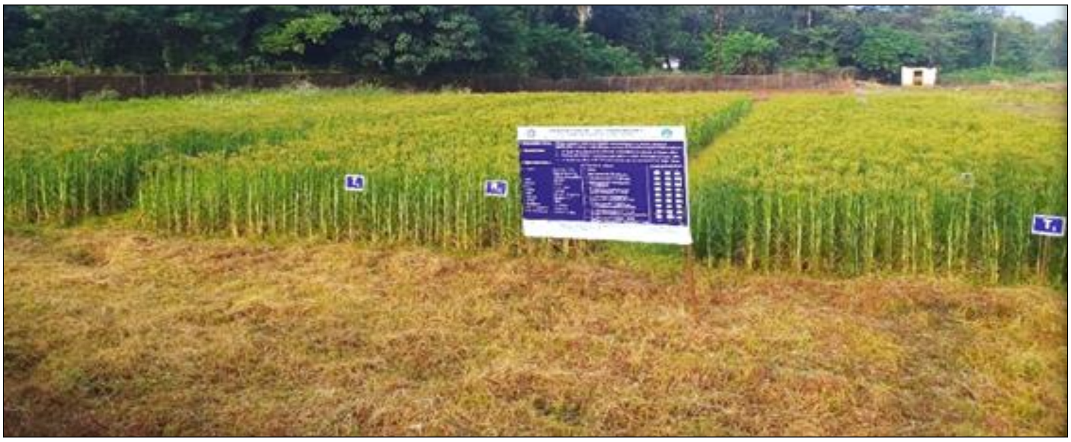

Plate 1: General view of the experimental plot

Table 1: Treatment details along with the symbols used

Symbols	Treatment Details
T_1	Control
T_2	Seed treatment with PSB + *Azospirillum*
T_3	Seed treatment with IR-CSN @ 50 ppm
T_4	Seed treatment with PSB + *Azospirillum* + IR-CSN @ 50 ppm
T_5	T_2 + *Acetobacter* spraying at one day before transplanting, 50, 75 DAT
T_6	T_3 + foliar spray of IR-CSN @ 50 ppm at one day before transplanting, 50, 75 DAT
T_7	T_3 + foliar spray of IR-CSN @ 100 ppm at one day before transplanting, 50, 75 DAT
T_8	T_4 + foliar spray *Acetobacter* + IR-CSN @ 50 ppm at one day before transplanting, 50, 75 DAT
T_9	T_4 + foliar spray *Acetobacter* + IR-CSN @ 100 ppm at one day before transplanting, 50, 75 DAT

The experiment was conducted using a Randomized Block design. There were three replications and Nine treatment combinations in total. The size of the experimental plot was 2.40 m x 5.10 m (Gross plot) and 2.00 m x 4.80 m (Net plot). The finger millet seedlings were transplanted at spacing of 20 cm x 15 cm. The treatment details along with their symbols which are frequently used in this experiment are mentioned in Table 1.

Urea and single super phosphate (SSP) fertilizers were used to apply the nutrients N and P_2O_5, respectively. The recommended dose of conventional fertilizers applied was 80:40:00 NPK kg ha^{-1}. During the transplanting process, the entire dose of SSP as well as half of the basal dose of urea was applied. The experimental plot's soil was found to have a sandy clay loam texture, a high level of organic carbon (11.30 g kg^{-1}), and a slightly acidic reaction (pH 5.50). The available phosphorus content was medium at 12.2 kg ha^{-1}, the available potassium content was low at 220.2 kg ha^{-1}, and the available nitrogen content was low at 230.3 kg ha^{-1}.

Results and Discussions

Effect on growth parameters

Characteristics of finger millet growth can be identified by recording and analyzing the data.

Plant height

As per the data presented in the Table 2 and showed in fig. 1 among the different treatments highest plant height was recorded (103.20 cm) was observed under treatment T_9 at harvest and which was found at par with treatment T_8 and treatment T_7. However, significantly lowest plant height (80.70 cm) was recorded in treatment T_1. The plant height increasing with different application of treatments in finger millet crop. Chitosan has been shown to increase plant growth, in plant these finding was corroborated with the results of Patil *et al.* 2024a [16], Mondal *et al.* 2013 [15] similarly reported that foliar application of chitosan improved plant height, in crop. The free-living N_2-fixing rhizobacteria of the genus *Azospirillum* live in close association with plants, and may promote plant growth under appropriate conditions Burdman *et al.* 1997 [5]. In pearl millet crop inoculation of nitrogen fixing and phosphate solubilizing microorganisms alone or in combination increased plant height showed by Jaga *et al.* 2015 [12].

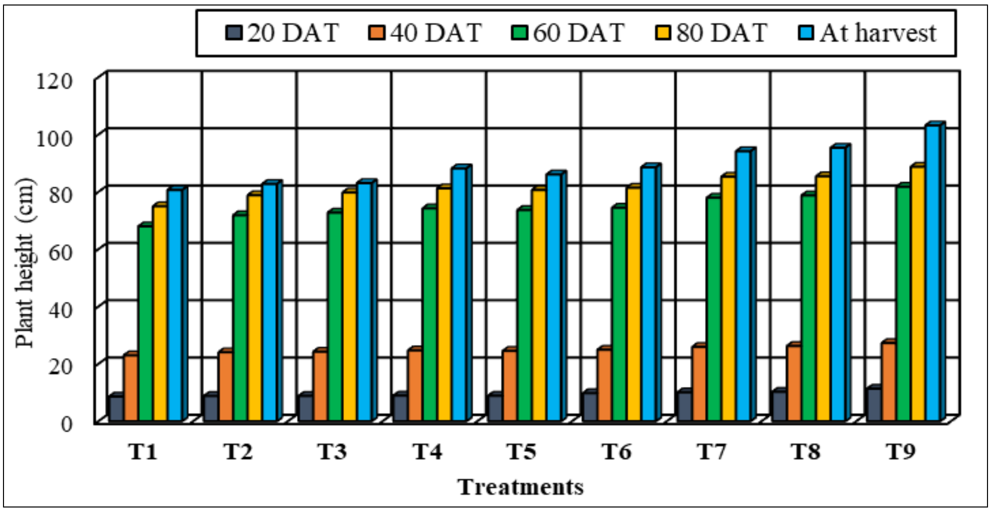

Fig 1: Plant height (cm) of finger millet as influenced periodically by different treatments

Number of functional leaves hill^{-1}

The data presented in the Table 2 and depicted in fig. 2 on number of functional leaves $plant^{-1}$ was recorded at 20, 40, 60, 80 DAT and at harvest stage of crop. It was observed that at 20, 40, 60, 80 DAT and at harvest, number of functional leaves $hill^{-1}$ was recorded significantly maximum in treatment T_9 i.e., (9.37, 18.80, 37.73, 25.63 and 15.20) which was found at par with treatment T_8 and T_7. However, treatment T_1 (Control: No foliar spray) showed the lowest number of functional leaves $hill^{-1}$. The role of chitosan in increasing ionic content may be due to its effects on stabilizing cellular membranes through increasing antioxidants substances, saving cell membranes from oxidative stress and hence improving plant cell permeability. This observation is supported by the results obtained by Guan *et al.* 2009 [9]. *Azospirillum* can produce *in vitro* the phytohormones IAA, gibberellins, cytokinin Jabbar *et al.* 2014 [11] and ethylene Singh *et al.* 2016 [20]. Auxin, gibberellins, or cytokinin, among other hormones that promote growth produced by Phosphate solubilizing microorganisms, encourage division of cell, and shoot growth, and xylem distinction, these results are in conformity with Jaga *et al.* 2015 [12].

Table 2: Plant height (cm) and Number of functional leaves $hill^{-1}$ of finger millet as influenced periodically by different treatments

Treatments	Plant height (cm)					Number of Functional Leaves hill^{-1}				
	20 DAT	40 DAT	60 DAT	80 DAT	At harvest	20 DAT	40 DAT	60 DAT	80 DAT	At harvest
T_1	8.63	23.00	68.00	75.00	80.70	6.20	13.60	31.30	21.73	11.73
T_2	8.83	24.07	71.87	78.87	82.80	7.13	14.33	32.27	22.17	12.07
T_3	8.85	24.27	72.80	79.80	83.10	7.20	15.27	33.23	22.33	12.33
T_4	8.97	24.73	74.27	81.27	88.20	7.80	16.17	34.10	23.60	13.00
T_5	8.90	24.53	73.70	80.70	86.10	7.77	15.73	33.93	22.93	12.83
T_6	9.80	24.95	74.50	81.50	88.59	7.83	16.23	34.40	23.40	13.20
T_7	10.13	25.93	77.97	85.30	94.20	8.53	17.87	36.50	24.30	14.10
T_8	10.30	26.27	78.80	85.47	95.40	8.80	18.63	36.83	24.90	14.73
T_9	11.37	27.30	81.80	88.80	103.20	9.37	18.80	37.73	25.63	15.20
S.Em. (±)	0.43	0.73	2.38	2.42	4.30	0.34	0.70	1.02	0.73	0.48
C.D. at 5%	1.29	2.19	7.12	7.24	12.88	1.02	2.11	3.06	2.19	1.44

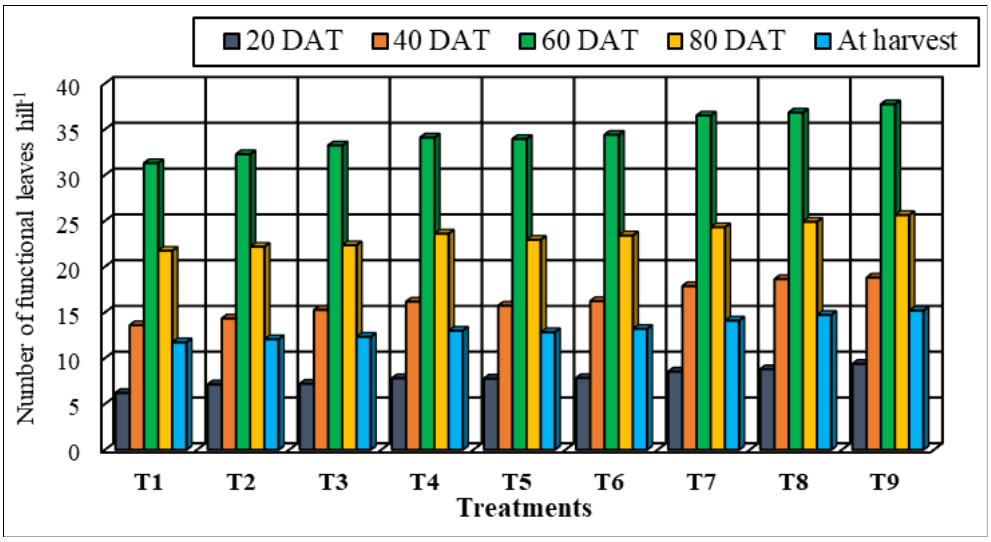

Fig 2: Number of functional leaves hill^{-1} of finger millet as influenced periodically by different treatments

Number of tillers hill^{-1}

The data presented in the Table 3 and depicted in fig. 3 that, the number of tillers hill^{-1} was recorded at 20, 40, 60, 80 DAT and at harvest stage of crop. It was observed that at 20, 40, 60, 80 DAT and at harvest, number of tillers hill^{-1} was recorded significantly maximum in treatment T_9 i.e., (1.70, 1.77, 2.50, 2.60, and 2.60) which was found at par with treatment T_8 and T_7. However, treatment T_1 (Control: No foliar spray) showed the lowest number of tillers hill^{-1}. Seed treatments and foliar application of biofertilizers and chitosan play important role during the growth stages of finger millet crop which the result revealed that Chitosan treated plants produced the higher number of tillers compare to control Ahmad *et al.* 2017 [1]. Tillering enhanced significantly due to application of bio-fertilizer these results also corroborated with the findings of Singh and Prasad 2011 [21].

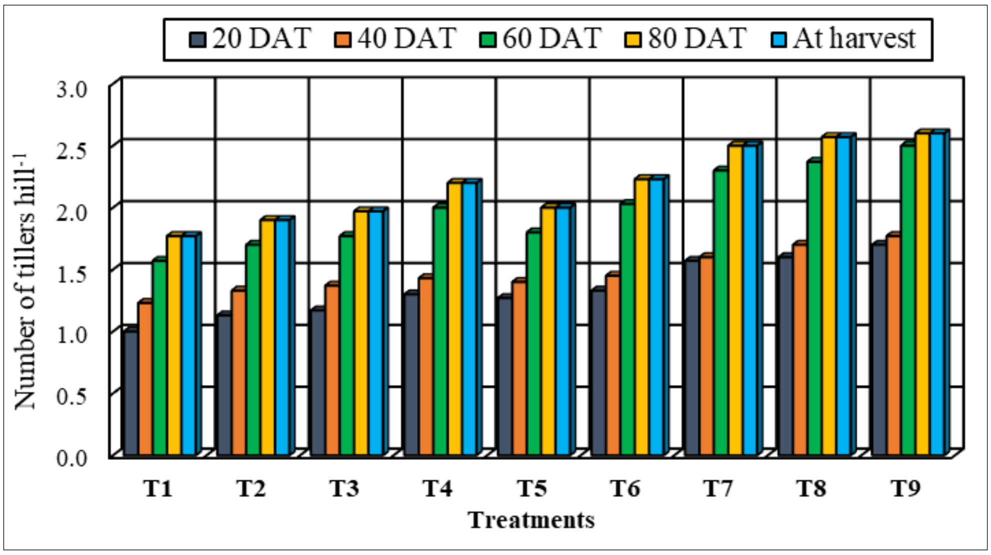

Fig 3: Number of tillers hill^{-1} of finger millet as influenced periodically by different treatments

Dry matter accumulation (g) hill^{-1}

The data presented in the Table 3 and depicted in fig. 4 shows that, the dry matter accumulation (g) hill^{-1} was recorded at 20, 40, 60, 80 DAT and at harvest stage of crop. It was observed that at 20, 40, 60, 80 DAT and at harvest, dry matter accumulation (g) hill^{-1} was recorded significantly maximum in treatment T_9 i.e., (1.93, 5.51, 20.24, 30.34, and 34.99) which was found at par with treatment T_8 and T_7. However, treatment T_1 (Control: No foliar spray) showed the lowest dry matter accumulation (g) hill^{-1}. chitosan increasing dry weights and shoot plants The present results are in consonance with those of by Mondal *et al.* 2012 [14], Patil *et al.* 2024a [16]. PSBs release auxin in response to interactions between plants and ethylene precursor, producing solubilizing microorganism that causes biological changes in plants like increased biomass growth Meena *et al.* 2014 [13] *Azospirillum* produced significantly higher dry matter yields than those from inoculation Selvakumar *et al.* 2009 [18].

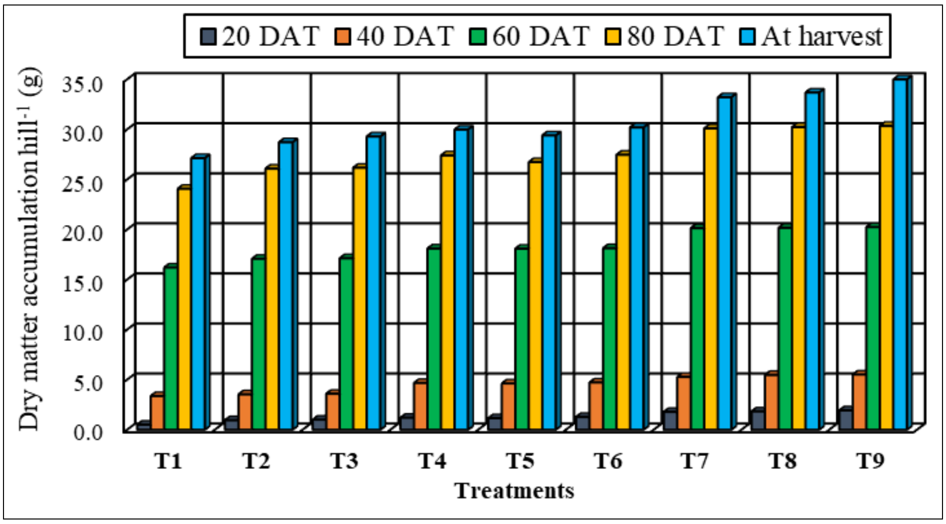

Fig 4: Dry matter accumulation hill-1 (g) of finger millet as influenced periodically by different treatments

Table 3: Number of tillers hill-1 and Dry matter accumulation hill-1 (g) of finger millet as influenced periodically by different treatments

Treatments	Number of Tiller hill-1					Dry matter accumulation hill-1 (g)				
	20 DAT	40 DAT	60 DAT	80 DAT	At harvest	20 DAT	40 DAT	60 DAT	80 DAT	At harvest
T_1	1.00	1.23	1.57	1.77	1.77	0.50	3.36	16.20	24.07	27.13
T_2	1.13	1.33	1.70	1.90	1.90	0.95	3.53	17.07	26.08	28.72
T_3	1.17	1.37	1.77	1.97	1.97	1.00	3.59	17.13	26.17	29.29
T_4	1.30	1.43	2.00	2.20	2.20	1.20	4.67	18.10	27.40	29.98
T_5	1.27	1.40	1.80	2.00	2.00	1.15	4.62	18.08	26.73	29.40
T_6	1.33	1.45	2.03	2.23	2.23	1.27	4.72	18.13	27.47	30.20
T_7	1.57	1.60	2.30	2.50	2.50	1.78	5.27	20.13	30.10	33.21
T_8	1.60	1.70	2.37	2.57	2.57	1.83	5.47	20.17	30.23	33.68
T_9	1.70	1.77	2.50	2.60	2.60	1.93	5.51	20.24	30.34	34.99
S.Em. (±)	0.06	0.07	0.12	0.10	0.10	0.06	0.25	0.70	0.94	0.83
C.D. at 5%	0.19	0.21	0.35	0.31	0.31	0.18	0.75	2.10	2.82	2.49

Effect on yield attributes and yield

The yield result showed in Table 4 and in fig. 5 significantly higher grain yield (23.55 q ha-1), straw yield (56.35 q ha-1), biological yield (79.90 q ha-1), harvest index (29.47%) was recorded with treatment T_4 + foliar spray *Acetobacter* + IR-CSN @ 100 ppm at one day before transplanting, 50, 75 DAT (T_9). However, treatment T_4 + foliar spray *Acetobacter* + IR-CSN @ 50 ppm at one day before transplanting, 50, 75 DAT (T_8) and treatment T_3 + foliar spray of IR-CSN @ 100 ppm at one day before transplanting, 50, 75 DAT (T_7) were statistically at par to the treatment T_9. Increased yield by the PSB could be due to the greater availability of nutrients in the soil and better nodulation under the influence of inoculation resulting in better growth and development which might be attributed to better mobilization of phosphorus and increased allocation parts and also hormonal balance on the plant system. The findings corroborate with the findings of Alam *et al.* 2008 [2], Singh *et al.* 2016 [20]. Chitosan a new plant growth promoter like GA_3 that may have many uses to modify the yield to the plant Patil *et al*. 2024a [16]; Patil *et al*. 2024b [17].

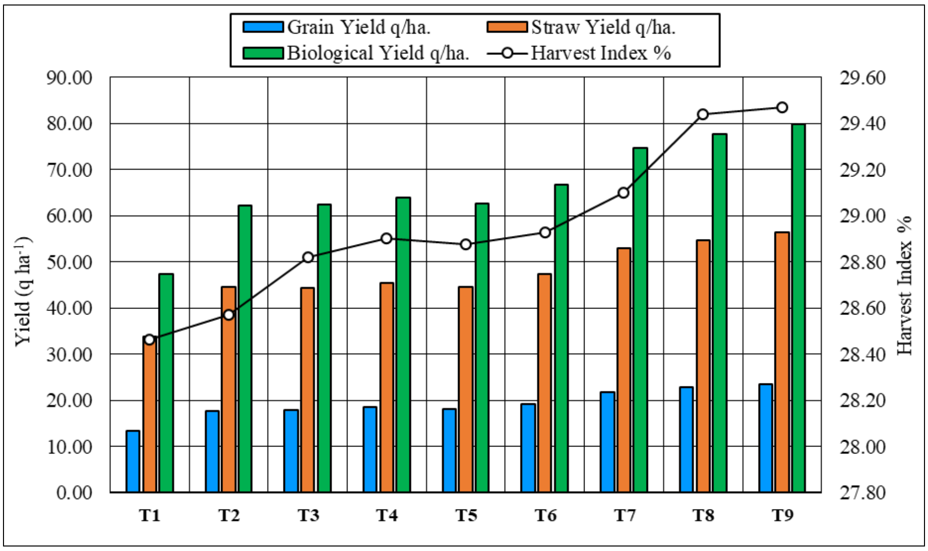

Fig 5: Grain yield, straw yield, biological yield (q ha-1) and harvest index (%) of finger millet as influenced by different treatments

Table 4: Yield of finger millet as influenced by different treatments

Treatments	Yield (q ha^{-1})			Harvest index (%)
	Grain	Straw	Biological	
T_1	13.50	33.93	47.43	28.46
T_2	17.79	44.48	62.28	28.57
T_3	17.96	44.35	62.31	28.82
T_4	18.49	45.45	63.95	28.90
T_5	18.10	44.52	62.62	28.88
T_6	19.28	47.36	66.64	28.93
T_7	21.75	52.93	74.68	29.10
T_8	22.84	54.74	77.59	29.44
T_9	23.55	56.35	79.90	29.47
S.Em. (±)	1.11	2.56	3.67	-
C.D. at 5%	3.33	7.66	10.99	-

Conclusion

It could be concluded that, the higher growth parameters such as plant height (cm), number of functional leaves hill^{-1}, number of tillers hill^{-1}, dry matter accumulation (g) hill^{-1} and yield parameters such as grain, straw and biological yields (q ha^{-1}), harvest index (%) from *kharif* finger millet could be obtained by application of treatment T_9 (T_4 + foliar spray *Acetobacter* + IR-CSN @ 100 ppm at one day before transplanting, 50, 75 DAT). In addition, it also improves nutritional composition of grain and straw.

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