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Growth, development and yield response of transplanted rice (*Oryza Sativa* L.) to foliar application of a seaweed-based biostimulant (Zymegold®) in the north-western Himalayas

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ABSTRACT

A field experiment was conducted during the kharif season of 2022 at the Experimental Farm of the Department of Agronomy, College of Agriculture, CSK Himachal Pradesh Krishi Vishwavidyalaya, Palampur, to evaluate the response of transplanted rice to foliar application of the seaweed-based biostimulant Zymegold®. Rice productivity in the mid-hill sub-humid zone of the north-western Himalayas remains well below the national average, and options that raise yield without increasing fertilizer inputs are needed. Eleven treatments comprising four doses applied once at tillering (500, 750, 1000 and 1250 ml ha⁻¹), six doses applied twice at the tillering and boot-leaf stages (500, 750, 1000, 1250, 1500 and 2000 ml ha⁻¹) and an unsprayed water-spray control were tested in a randomized block design with three replications in rice variety PAC 807+. Two applications of Zymegold each at 1250 ml ha⁻¹ recorded the tallest plants (104.9 cm), the highest tiller density (237.2 tillers m⁻² at sixty days after transplanting), the greatest dry matter accumulation (1098.9 g m⁻² at harvest), the highest crop growth rate between sixty and ninety days after transplanting (19.40 g m⁻² day⁻¹), and the maximum values of all yield attributes, culminating in a grain yield of 56.08 q ha⁻¹ and a straw yield of 57.22 q ha⁻¹. This represented an increase of 29.3 per cent in grain yield over the control (43.38 q ha⁻¹). Doses above 1250 ml ha⁻¹ applied twice gave no further advantage, indicating a saturating response, and the two-spray schedule was consistently superior to a single spray at the same dose. Days to fifty per cent flowering, days to physiological maturity and harvest index were not significantly influenced. No phytotoxic symptoms were observed at any dose, including 2000 ml ha⁻¹. Double foliar application of Zymegold at 1250 ml ha⁻¹ at the tillering and boot-leaf stages is therefore recommended for transplanted rice in this agro-ecological zone.

Keywords: Crop growth rate, Grain yield, Seaweed biostimulant, Transplanted rice, Yield attributes, Zymegold

Introduction

Rice (*Oryza sativa* L.) is the staple food of more than half of the world's population and supplies about 20 per cent of global dietary energy, against 19 per cent from wheat and 5 per cent from maize (Alexandratos *et al.*, 2012) [1]. It occupies about 163.09 million ha globally [2] with a production of 769.22 million tonnes and a mean productivity of 4717 kg ha⁻¹. (In India) [3], rice is grown on 45.77 million ha with a production of 124.37 million tonnes and a productivity of 2717 kg ha⁻¹. The country must produce an estimated 140 million tonnes of rice by 2025 to meet the demand of its growing population (Duttarganvi *et al.*, 2016) [4].

In Himachal Pradesh, rice is among the most important *kharif* crops and ranks third in acreage, covering 68.46 thousand ha with an annual production of 138.46 thousand tonnes. The state mean productivity of 2022 kg ha⁻¹ lies well below the national average (Government of Himachal Pradesh, 2022) [5]. Much of the historical gain in rice production has come from chemical fertilizers and fertilizer-responsive high-yielding varieties, an approach accompanied by soil and environmental degradation and by a slowing of productivity growth. Options that raise productivity without further burdening the resource base are therefore needed.

Plant biostimulants offer one such option. A biostimulant is defined as any substance or micro-organism applied to plants with the aim of enhancing nutrient use efficiency, abiotic stress tolerance and crop quality traits, regardless of its own nutrient content (du Jardin, 2015) [6], a definition since embodied in European Union Regulation 2019/1009, which recognises biostimulants as a distinct category of agricultural input separate from fertilizers and plant protection products (Caradonia *et al.*, 2018) [7]. Unlike conventional inputs, a single biostimulant may act through several concurrent pathways: direct stimulation of carbon and nitrogen metabolism, and indirect enhancement of nutrient acquisition through modulation of root morphology and membrane transport (Rouphael *et al.*, 2018; Yakhin *et al.*, 2017) [8, 9]. Because these effects are mediated by

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physiological regulation rather than by nutrient supply, biostimulants are applied in minute quantities and are increasingly viewed as a route to maintaining yields under reduced fertilizer inputs (Quille *et al.*, 2025) [10].

Seaweed-derived biostimulants are among the most widely commercialised of these. Seaweed contains essential mineral elements, vitamins, fatty acids, amino acids, polysaccharides, phenolics and growth-regulating hormones including auxins, cytokinins, gibberellins and abscisic acid, and its extracts influence root and shoot growth, photosynthesis, stomatal conductance and stress tolerance (Hariharan *et al.*, 2024; Thamei *et al.*, 2024) [11, 12]. Work on the mode of action in rice has shown that foliar application of a *Kappaphycus alvarezii* extract raises photosynthetic efficiency and alters the expression of genes governing potassium and nitrogen transport, plasma-membrane H⁺-ATPases and oxidative-stress defence enzymes, increasing leaf dry mass by about 19 per cent and sheath nitrogen content by up to 50 per cent (van Tol de Castro *et al.*, 2024) [13]. This provides a physiological basis for the growth and yield responses reported at the field scale. Zymegold® is a seaweed-derived formulation containing cytokinin, hydrolysed protein complexes, enzymes, amino acids and minerals.

The agronomic evidence for seaweed extracts is substantial but variable. A meta-analysis of 198 peer-reviewed studies comprising 2021 treatment-control comparisons placed the mean yield increase at 16.3 per cent, with cereals among the most responsive crop groups and the largest effects in tropical regions (Perez-Onate *et al.*, 2026) [14]. In rice, reported grain yield gains range from about 11 to 18 per cent under blended *Gracilaria-Sargassum* extracts in the Lower Gangetic and Eastern Coastal Plains of India (Munisamy *et al.*, 2026) [15], and *Sargassum* sap with full recommended fertilizer gave the highest grain and straw yield and a benefit-cost ratio of 1.83 in the New Alluvial Zone of West Bengal (De *et al.*, 2026) [16]. A leaf area index of 4.85 and a grain yield of 4552 kg ha⁻¹ were recorded when seed presoaking was combined with foliar sprays at panicle initiation and flowering (Elamparithi *et al.*, 2025) [17].

That variability is itself informative. The same meta-analysis found response magnitude to depend strongly on application strategy, timing and formulation rather than on the extract alone (Perez-Onate *et al.*, 2026) [14], and inconsistent field results have been attributed to application schedules chosen without reference to crop phenology (Surma

et al., 2025) [18]. Dose is equally unsettled: in transplanted Aman rice no additional yield advantage was obtained above 400 ml ha⁻¹, implying a saturating rather than a linear response (Liza *et al.*, 2026) [19], while sprays timed early in the crop cycle outperformed later ones at an identical rate (Surma *et al.*, 2025) [18]. Dose and schedule therefore interact, and an optimum established for one agro-ecology cannot be transferred to another.

No such optimisation has been reported for the mid-hill sub-humid zone of the north-western Himalayas, where a short monsoon growing season, acidic soils and a state mean productivity well below the national average together define conditions unlike those of the alluvial and coastal rice tracts in which most Indian seaweed-extract trials have been conducted. The present investigation was therefore undertaken to quantify the response of transplanted rice to graded doses of a seaweed-based biostimulant applied either once at tillering or twice at the tillering and boot-leaf stages, with the specific objective of identifying the dose and schedule at which the growth and yield response saturates under these conditions.

Materials and Methods

Experimental site and season

The experiment was conducted during the *kharif* season of 2022 at the Experimental Farm of the Department of Agronomy, College of Agriculture, CSK Himachal Pradesh Krishi Vishvavidyalaya, Palampur, situated in the north-western Himalayas at 32°09' N latitude, 76°54' E longitude and 1290 m above mean sea level. The site lies in the mid-hill sub-humid zone of Himachal Pradesh, which receives 2000–2500 mm of rainfall annually, about 80 per cent of it during the monsoon (June–September).

Monthly meteorological data for the cropping season are presented in Table 1 and Figure 1. Mean weekly maximum temperature ranged from 34.2 °C in the 23rd standard week (4–10 June) to 24.2 °C in the 41st standard week (8–14 October), and mean weekly minimum temperature from 21.8 °C to 13.4 °C over the same period. Mean relative humidity ranged between 30.5 and 91.2 per cent. Total rainfall during the crop season was 1852.6 mm, of which 77.1 per cent was received in July and August alone; October was almost dry, receiving only 26.6 mm. Temperature and humidity remained within the range reported as favourable for rice (Yoshida, 1978; Reddy, 2004) [20, 21].

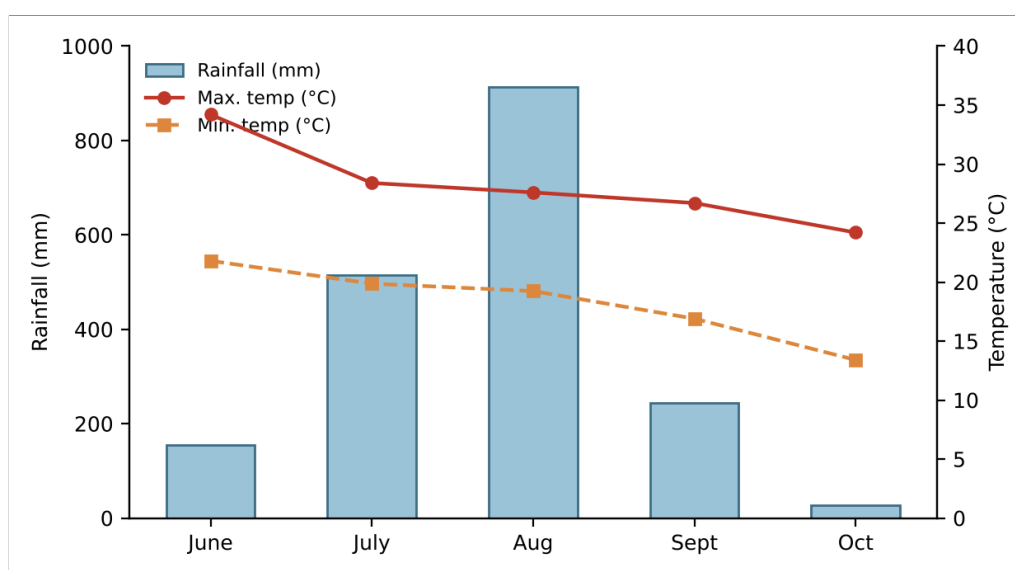


Figure 1. Monthly rainfall and mean maximum and minimum temperature at Palampur during *kharif* 2022

Soil properties and cropping history

Composite soil samples were drawn from the 0–15 cm layer before the start of the experiment and analysed for physico-chemical properties (Table 2). The soil was a silty clay loam, acidic in reaction

(pH 5.34) and medium in available nitrogen, phosphorus and potassium. The field had been under a rice (*kharif* 2021)–wheat (*rabi* 2021–22) sequence in the preceding year and was uniformly fertilized.

Table 1. Monthly meteorological data at Palampur during *kharif* 2022

Month	June	July	August	September	October	Total / Range
Total rainfall (mm)	155.4	514.6	912.8	243.2	26.6	1852.6
Mean maximum temperature (°C)	34.2	28.4	27.6	26.7	24.2	24.2–34.2
Mean minimum temperature (°C)	21.8	19.9	19.2	16.9	13.4	13.4–21.8

Table 2. Physico-chemical properties of the soil (0–15 cm) of the experimental site

Soil property	Value	Method of analysis
Sand (%)	20.2	International pipette method ²²
Silt (%)	43.4	International pipette method ²²
Clay (%)	36.4	International pipette method ²²
Textural class	Silty clay loam	—
pH (1 : 2.5 soil : water)	5.34	Glass electrode pH meter ²³
Organic carbon (g kg ⁻¹)	7.20	Rapid titration method ²⁴
Available nitrogen (kg ha ⁻¹)	337.2	Alkaline permanganate method ²⁵
Available phosphorus (kg ha ⁻¹)	24.8	0.5 M NaHCO ₃ extraction ²⁶
Available potassium (kg ha ⁻¹)	279.5	Neutral normal ammonium acetate extraction ²⁷

Treatments and experimental design

Eleven treatments were evaluated in a randomized block design with three replications (Table 3). Four doses of Zymegold liquid (500, 750, 1000 and 1250 ml ha⁻¹) were applied as a single foliar spray at the tillering stage; six doses (500, 750, 1000, 1250, 1500 and 2000 ml ha⁻¹) were applied as two foliar sprays, one each at the tillering and boot-leaf stages; and an unsprayed control received a water spray at the same two stages. Gross and net plot sizes were 2.2 m × 4.2 m (9.24 m²) and 1.4 m × 3.6 m (5.04 m²), respectively. Zymegold® liquid, a seaweed-derived biostimulant containing cytokinin, hydrolysed protein complexes, enzymes, amino acids and minerals, was supplied by [name of manufacturer or supplier, city, country].

Crop husbandry

The nursery was raised by the dry-bed method on raised seedbeds of 8.5 m × 1.25 m × 10 cm using a seed rate of 25 kg ha⁻¹ of rice variety PAC 807⁺, sown in rows 10 cm apart. Each bed received a basal dose of 65 g urea and 150 g single super phosphate, followed by a top dressing of 45 g urea per bed a fortnight after sowing. After preparatory tillage, bunds 40 cm wide and 30 cm high were raised around each plot and the plots were hand puddled (Figure 2). Seedlings were transplanted at a spacing of 20 cm × 15 cm with two seedlings per hill (Figure 3). The crop was fertilized with 90 kg N, 40 kg P₂O₅ and 40 kg K₂O ha⁻¹ through urea, single super phosphate and muriate of potash. Half the nitrogen and the entire phosphorus and potassium were applied as a basal dose before transplanting; the remaining nitrogen was applied in two equal splits at tillering and panicle initiation. Butachlor was applied as a pre-emergence herbicide at 3 litre ha⁻¹ in 800 litres of water. A general view of the experimental field is shown in Figure 4. The crop was harvested on 21 October 2022, sun-dried in the field for 3–4 days and threshed.

**Figure 2.** A general view of puddling of the experimental plots**Figure 3.** A general view of transplanting of rice seedlings**Figure 4.** A general view of the experimental field

Observations recorded

Plant height was measured on ten randomly selected and tagged hills per net plot at 30-day intervals and at harvest, from the ground surface to the tip of the uppermost leaf before panicle emergence and to the panicle tip thereafter. Tillers were counted on the same ten tagged hills at 30-day intervals and at harvest, averaged and multiplied by 33.33 to express tiller density per m². For dry matter accumulation, all shoots of four hills were cut at ground level from the second row at either end of each plot at 30-day intervals and at harvest, oven-dried at 70 °C for five days, and the dry weight multiplied by 8.33 to express accumulation per m².

Table 3. Details of treatments

Treatment	Dose (ml ha ⁻¹)	Application stage
T ₁ : Zymegold	500	Tillering
T ₂ : Zymegold	750	Tillering
T ₃ : Zymegold	1000	Tillering
T ₄ : Zymegold	1250	Tillering
T ₅ : Zymegold	500	Tillering and boot leaf
T ₆ : Zymegold	750	Tillering and boot leaf
T ₇ : Zymegold	1000	Tillering and boot leaf
T ₈ : Zymegold	1250	Tillering and boot leaf
T ₉ : Zymegold	1500	Tillering and boot leaf
T ₁₀ : Zymegold	2000	Tillering and boot leaf
T ₁₁ : Control (water spray)	—	Tillering and boot leaf

Crop growth rate (CGR, g m⁻² day⁻¹) was computed as $(W_2 - W_1) / (T_2 - T_1)$ (Radford, 1967) [22], and relative growth rate (RGR, mg g⁻¹ day⁻¹) as $(\log_e W_2 - \log_e W_1) / (T_2 - T_1) \times 1000$ (Blackman, 1919) [23], where W_1 and W_2 are total plant dry weights at times T_1 and T_2 . CGR₁ and RGR₁ refer to the 30–60 days after transplanting (DAT) interval and CGR₂ and RGR₂ to the 60–90 DAT interval.

Days to 50 per cent flowering were recorded from the date of sowing, when 50 per cent of the shoots in the area marked for shoot counting had produced panicles. Days to physiological maturity were counted from transplanting, when 85 per cent of the plants had turned golden yellow and the grains could no longer be crushed with the nails. Effective tillers were counted on the ten tagged hills and expressed per m². Panicle length was measured from base to apex on ten randomly chosen panicles per plot at harvest. Grains per panicle and

grain weight per panicle were determined on ten threshed panicles per plot. Thousand-grain weight was recorded on a composite sample from each net plot and adjusted to 14 per cent moisture. Grain yield per net plot was recorded after cleaning and winnowing, standardised to 14 per cent moisture and converted to q ha⁻¹. Straw yield was obtained by deducting grain weight from total produce. Harvest index was computed as the ratio of grain yield to biological yield, expressed as a percentage.

Phytotoxicity was assessed in a separate trial comprising two sprays of Zymegold at 1000, 1500 and 2000 ml ha⁻¹ at the tillering and boot-leaf stages, with an unsprayed control. Epinasty, hyponasty, chlorosis, necrosis, leaf injury, vein clearing and stunting were rated visually on ten plants per plot at 0, 1, 3, 5, 7, 10 and 14 days after each spray on a 0–10 scale, where 0 indicates complete safety and 10 complete injury.

Statistical analysis

Data were subjected to analysis of variance appropriate to a randomized block design. Treatment means were compared using the least significant difference (LSD) at the 5 per cent level of probability; differences that were not significant are reported as NS.

Results and discussion

Plant height

Plant height was not significantly influenced at 30 DAT (Table 4), as the first spray was applied at 27 DAT and the observation was recorded only three days later. From 60 DAT onwards the treatments separated clearly. At 60 DAT, two applications of Zymegold each at 1250 ml ha⁻¹ recorded significantly taller plants, although it remained at par with a single spray at 1250 ml ha⁻¹ and with double sprays at 1000, 1500 and 2000 ml ha⁻¹. At 90 DAT and at harvest the same treatment was again significantly superior, remaining at par with double sprays at 1000, 1500 and 2000 ml ha⁻¹ and reaching 104.9 cm at harvest. Significantly shorter plants were recorded in the control at 60 DAT, 90 DAT and at harvest (89.0 cm at harvest), at par with a single spray at 500 ml ha⁻¹.

The gain in plant height may be ascribed to the auxins, gibberellins, cytokinins and macro- and micro-elements present in seaweed extract, which together elicit a strong physiological response (Deepana *et al.*, 2021) [24]. Comparable increases in the plant height of rice following seaweed extract application have been reported elsewhere (Khan *et al.*, 2013; Satapathy *et al.*, 2014; Sunarpi *et al.*, 2011) [25, 26, 27].

Applied at tillering stage; * applied at tillering and boot-leaf stages. DAT = days after transplanting; NS = not significant.

Table 4. Effect of Zymegold on plant height (cm) of rice

Treatment	30 DAT	60 DAT	90 DAT	At harvest
T ₁ : 500 ml ha ⁻¹ *	53.1	76.7	88.7	92.4
T ₂ : 750 ml ha ⁻¹ *	53.5	79.6	92.6	97.3
T ₃ : 1000 ml ha ⁻¹ *	54.9	82.5	94.5	97.9
T ₄ : 1250 ml ha ⁻¹ *	55.0	84.7	96.2	99.2
T ₅ : 500 ml ha ⁻¹ **	53.5	80.3	95.7	98.0
T ₆ : 750 ml ha ⁻¹ **	54.9	81.7	96.3	100.0
T ₇ : 1000 ml ha ⁻¹ **	55.5	84.7	98.6	102.2
T ₈ : 1250 ml ha ⁻¹ **	55.6	86.5	101.9	104.9
T ₉ : 1500 ml ha ⁻¹ **	55.0	84.9	99.8	103.9
T ₁₀ : 2000 ml ha ⁻¹ **	55.1	85.8	100.6	104.0
T ₁₁ : Control (water spray)	53.4	74.5	84.5	89.0
SEm ±	0.9	1.0	1.6	1.7
LSD (p = 0.05)	NS	3.0	4.7	4.9

(continued on next page)

Number of tillers m^{-2}

Tiller density did not differ significantly among treatments at 30 DAT but was significantly influenced at 60 DAT, 90 DAT and at harvest (Table 5). At all three stages the highest tiller density was recorded under a double spray of Zymegold at 1250 ml ha^{-1} (237.2 tillers m^{-2} at 60 DAT), which remained at par with single sprays at 1000 and 1250 ml ha^{-1} and with double sprays at 1000, 1500 and 2000 ml

ha^{-1} . The control recorded the lowest tiller density (219.6 tillers m^{-2} at 60 DAT), at par with a single spray at 500 ml ha^{-1} . Tiller density declined between 60 DAT and harvest in every treatment, reflecting the normal mortality of late and non-productive tillers. Similar increases in tiller number in rice following seaweed extract application have been reported previously (Sunarpi *et al.*, 2020; Ghodake *et al.*, 2022) [28, 29].

Table 5. Effect of Zymegold on the number of tillers m^{-2} of rice

Treatment	30 DAT	60 DAT	90 DAT	At harvest
T ₁ : 500 ml ha^{-1} *	126.2	224.5	214.3	207.7
T ₂ : 750 ml ha^{-1} *	127.4	226.3	215.6	212.1
T ₃ : 1000 ml ha^{-1} *	129.2	230.6	218.4	214.2
T ₄ : 1250 ml ha^{-1} *	131.7	232.9	221.4	215.8
T ₅ : 500 ml ha^{-1} **	127.9	225.6	215.3	212.2
T ₆ : 750 ml ha^{-1} **	128.3	228.1	217.5	213.3
T ₇ : 1000 ml ha^{-1} **	131.0	231.2	220.4	216.3
T ₈ : 1250 ml ha^{-1} **	132.3	237.2	224.8	219.6
T ₉ : 1500 ml ha^{-1} **	130.5	236.7	220.6	217.4
T ₁₀ : 2000 ml ha^{-1} **	132.0	235.2	221.0	217.8
T ₁₁ : Control (water spray)	126.2	219.6	208.5	203.7
SEm $\pm$	1.80	2.7	2.4	2.1
LSD ($p = 0.05$)	NS	7.9	7.0	6.1

Applied at tillering stage; * applied at tillering and boot-leaf stages. DAT = days after transplanting; NS = not significant.

Dry matter accumulation

Dry matter accumulation followed the same pattern (Table 6): non-significant at 30 DAT and significantly influenced at 60 DAT, 90 DAT and at harvest. A double spray of Zymegold at 1250 ml ha^{-1} accumulated the greatest dry matter at harvest (1098.9 g m^{-2}), remaining at par with double sprays at 1000, 1500 and 2000 ml ha^{-1} . The control

accumulated the least (868.2 g m^{-2}), a difference of 26.6 per cent at harvest. The divergence between treatments widened progressively with crop age, being 10.8 per cent at 60 DAT and 19.6 per cent at 90 DAT, indicating that the benefit of the second spray at boot leaf was expressed mainly during the reproductive phase. The higher dry matter accumulation reflects the cumulative improvement in all vegetative growth characters, in agreement with earlier reports (Abdel-Megeed *et al.*, 2021; Arun *et al.*, 2019; Devi *et al.*, 2015) [30, 31, 32].

Table 6. Effect of Zymegold on dry matter accumulation (g m^{-2}) of rice

Treatment	30 DAT	60 DAT	90 DAT	At harvest
T ₁ : 500 ml ha^{-1} *	57.8	393.0	864.3	908.6
T ₂ : 750 ml ha^{-1} *	59.5	402.3	881.2	942.7
T ₃ : 1000 ml ha^{-1} *	60.5	408.8	888.5	961.8
T ₄ : 1250 ml ha^{-1} *	59.9	418.8	914.9	990.2
T ₅ : 500 ml ha^{-1} **	56.6	395.9	903.3	992.5
T ₆ : 750 ml ha^{-1} **	59.4	406.0	931.5	1026.4
T ₇ : 1000 ml ha^{-1} **	59.0	414.1	991.5	1087.4
T ₈ : 1250 ml ha^{-1} **	59.8	419.7	1001.7	1098.9
T ₉ : 1500 ml ha^{-1} **	59.2	415.6	982.6	1080.8
T ₁₀ : 2000 ml ha^{-1} **	59.9	416.2	992.7	1089.1
T ₁₁ : Control (water spray)	58.4	378.8	837.8	868.2
SEm $\pm$	2.4	7.3	11.0	14.2
LSD ($p = 0.05$)	NS	21.6	32.4	41.8

Applied at tillering stage; * applied at tillering and boot-leaf stages. DAT = days after transplanting; NS = not significant.

Growth indices

Crop growth rate was consistently higher during 60–90 DAT than during 30–60 DAT in all treatments (Table 7), coinciding with the period of maximum canopy expansion. CGR₁ was significantly highest under a double spray of Zymegold at 1250 ml ha^{-1} (12.00 g m^{-2} day⁻¹), at par with all other treatments except a single spray at 500 ml ha^{-1} and the control. CGR₂ was likewise significantly highest under

the same treatment (19.40 g m^{-2} day⁻¹), remaining at par with double sprays at 1000, 1500 and 2000 ml ha^{-1} and exceeding the control (15.30 g m^{-2} day⁻¹) by 26.8 per cent.

Relative growth rate was not significantly influenced during 30–60 DAT but was significant during 60–90 DAT. RGR₂ was significantly higher under a double spray at 1000 ml ha^{-1} (29.12 mg g⁻¹ day⁻¹) than in T₅, T₆, T₈, T₉ and T₁₀. RGR declined sharply between the two intervals in every treatment, as expected, since RGR expresses dry matter gain relative to existing biomass and therefore falls as the crop accumulates mass.

The dose–response relationship for CGR_2 is shown in Figure 5. The response rose steeply up to 1000–1250 ml ha⁻¹ under the double-spray schedule and then plateaued, with 1500 and 2000 ml ha⁻¹ giving no further advantage. Single sprays produced a much flatter response across the same dose range, confirming that the timing of the second application at boot leaf, rather than the total quantity applied,

governed the growth response. The increase in CGR and RGR following Zymegold application may be attributed to the supply of macro- and micro-nutrients together with growth-promoting hormones such as gibberellins and cytokinins (Colla *et al.*, 2014) [33], and comparable results have been obtained with seaweed-based biostimulants (Devi *et al.*, 2015; Layek *et al.*, 2018; Nayak *et al.*, 2020) [32, 34, 35].

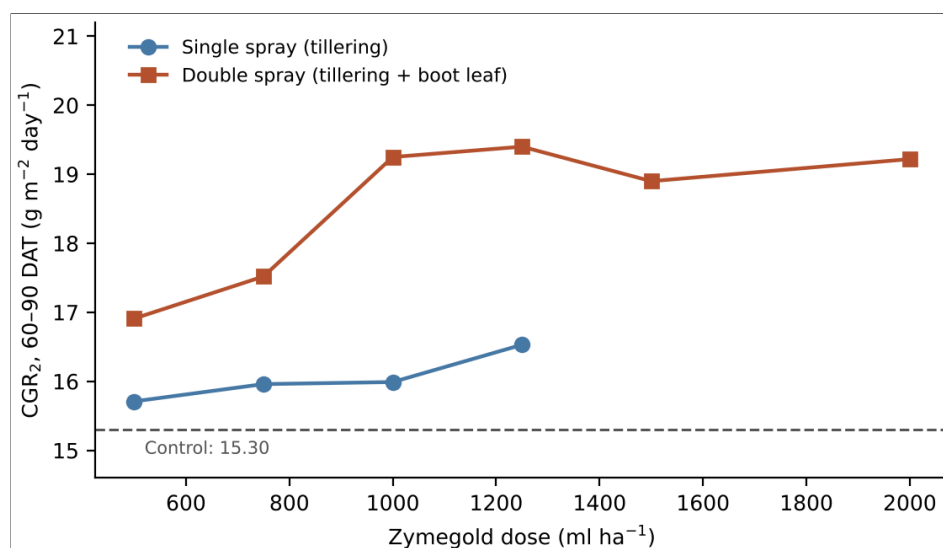


Figure 5. Dose–response relationship for crop growth rate during 60–90 DAT (CGR_2) under single and double foliar sprays of Zymegold. The broken line denotes the water-spray control

Developmental studies

Neither days to 50 per cent flowering nor days to physiological maturity were significantly influenced by Zymegold application (Table 8). Numerically, a double spray at 1250 ml ha⁻¹ took the fewest days to 50 per cent flowering (96.2) and to physiological maturity (126.3),

while the control took the most (99.9 and 130.5 days respectively), suggesting a slight advancement of phenology of about three to four days under biostimulant application. The absence of statistical significance indicates that phenology in this variety is governed primarily by genotype and thermal environment rather than by foliar nutrition.

Table 7. Effect of Zymegold on growth indices of rice

Treatment	CGR_1	CGR_2	RGR_1	RGR_2
T ₁ : 500 ml ha ⁻¹ *	11.17	15.71	63.88	26.27
T ₂ : 750 ml ha ⁻¹ *	11.43	15.96	63.73	26.14
T ₃ : 1000 ml ha ⁻¹ *	11.61	15.99	63.64	25.88
T ₄ : 1250 ml ha ⁻¹ *	11.97	16.53	64.85	26.06
T ₅ : 500 ml ha ⁻¹ **	11.31	16.91	64.84	27.49
T ₆ : 750 ml ha ⁻¹ **	11.55	17.52	64.06	27.68
T ₇ : 1000 ml ha ⁻¹ **	11.84	19.25	65.23	29.12
T ₈ : 1250 ml ha ⁻¹ **	12.00	19.40	64.93	29.02
T ₉ : 1500 ml ha ⁻¹ **	11.88	18.90	64.96	28.70
T ₁₀ : 2000 ml ha ⁻¹ **	11.88	19.22	64.60	28.97
T ₁₁ : Control (water spray)	10.68	15.30	62.34	26.46
SEm ±	0.24	0.36	0.44	0.61
LSD ($p = 0.05$)	0.71	1.11	NS	1.79

CGR = crop growth rate (g m⁻² day⁻¹); RGR = relative growth rate (mg g⁻¹ day⁻¹). Subscript 1 denotes the 30–60 DAT interval and subscript 2 the 60–90 DAT interval. Applied at tillering stage; * applied at tillering and boot-leaf stages. DAT = days after transplanting; NS = not significant.

Applied at tillering stage; * applied at tillering and boot-leaf stages. DAT = days after transplanting; NS = not significant.

Yield attributes

All yield attributes were significantly influenced by Zymegold application (Table 9). Two applications each at 1250 ml ha⁻¹ produced the highest number of effective tillers (207.1 m⁻²), the longest panicles

(24.16 cm), the most grains per panicle (164.20), the greatest grain weight per panicle (3.68 g) and the highest thousand-grain weight (22.38 g). For every attribute this treatment remained at par with double sprays at 1000, 1500 and 2000 ml ha⁻¹; for effective tillers it was additionally at par with single sprays at 1000 and 1250 ml ha⁻¹. The control recorded the lowest value of every attribute, in each case at par with a single spray at 500 ml ha⁻¹.

Table 8. Effect of Zymegold on the developmental stages of rice

Treatment	Days to 50 % flowering	Days to physiological maturity
T ₁ : 500 ml ha ⁻¹ *	99.8	130.2
T ₂ : 750 ml ha ⁻¹ *	99.7	129.5
T ₃ : 1000 ml ha ⁻¹ *	99.2	129.0
T ₄ : 1250 ml ha ⁻¹ *	98.5	128.5
T ₅ : 500 ml ha ⁻¹ **	97.2	129.8
T ₆ : 750 ml ha ⁻¹ **	96.9	128.8
T ₇ : 1000 ml ha ⁻¹ **	96.4	126.5
T ₈ : 1250 ml ha ⁻¹ **	96.2	126.3
T ₉ : 1500 ml ha ⁻¹ **	96.2	126.7
T ₁₀ : 2000 ml ha ⁻¹ **	97.9	127.9
T ₁₁ : Control (water spray)	99.9	130.5

Table 9. Effect of Zymegold on the yield attributes of rice

Treatment	Effective tillers m ⁻²	Panicle length (cm)	Grains panicle ⁻¹	Grain weight panicle ⁻¹ (g)	1000-grain weight (g)
T ₁ : 500 ml ha ⁻¹ *	196.6	21.20	145.70	3.02	20.75
T ₂ : 750 ml ha ⁻¹ *	200.4	21.98	147.30	3.09	20.98
T ₃ : 1000 ml ha ⁻¹ *	202.8	22.26	149.80	3.16	21.12
T ₄ : 1250 ml ha ⁻¹ *	204.1	22.57	152.80	3.24	21.18
T ₅ : 500 ml ha ⁻¹ **	198.9	22.74	155.60	3.28	21.05
T ₆ : 750 ml ha ⁻¹ **	202.4	23.18	158.70	3.40	21.45
T ₇ : 1000 ml ha ⁻¹ **	203.2	23.71	162.90	3.62	22.25
T ₈ : 1250 ml ha ⁻¹ **	207.1	24.16	164.20	3.68	22.38
T ₉ : 1500 ml ha ⁻¹ **	203.6	23.92	163.89	3.60	21.95
T ₁₀ : 2000 ml ha ⁻¹ **	202.9	24.02	163.56	3.63	22.18
T ₁₁ : Control (water spray)	188.9	20.84	142.20	2.91	20.43
SEm ±	1.51	0.29	1.55	0.05	0.23
LSD (p = 0.05)	4.47	0.85	4.57	0.17	0.60

Applied at tillering stage; * applied at tillering and boot-leaf stages. DAT = days after transplanting; NS = not significant.

Grain, straw and biological yield and harvest index

Grain yield was significantly influenced by Zymegold application (Table 10, Figure 6). The highest grain yield of 56.08 q ha⁻¹ was obtained with two applications each at 1250 ml ha⁻¹, which remained at par with double sprays at 1000 ml ha⁻¹ (55.49 q ha⁻¹), 1500 ml ha⁻¹ (54.94 q ha⁻¹) and 2000 ml ha⁻¹ (55.85 q ha⁻¹). The lowest grain yield was recorded in the water-spray control (43.38 q ha⁻¹), at par with a single spray at 500 ml ha⁻¹ (46.08 q ha⁻¹). Double application at 1250 ml ha⁻¹ thus increased grain yield by 29.3 per cent over the control; the corresponding increases under double sprays at 2000, 1000 and 1500 ml ha⁻¹ were 28.7, 27.9 and 26.6 per cent respectively. The absence of any further gain above 1250 ml ha⁻¹ mirrors the plateau observed for crop growth rate and confirms that the yield response to this biostimulant saturates once the canopy required to intercept available radiation has been established.

Straw yield followed the same pattern. The highest straw yield (57.22 q ha⁻¹) was recorded under a double spray at 1250 ml ha⁻¹, at par with double sprays at 750, 1000, 1500 and 2000 ml ha⁻¹. The control recorded the lowest straw yield (46.00 q ha⁻¹), at par with a single

Treatment	Days to 50 % flowering	Days to physiological maturity
SEm ±	1.23	1.64
LSD (p = 0.05)	NS	NS

The improvement in effective tiller number may be attributed to better utilisation of resources in plots receiving growth hormones, micronutrients, enzymes, amino acids and vitamins through Zymegold. The increase in grains per panicle is likely mediated by cytokinin, which enhances the translocation of sucrose into the spikelet and thereby improves grain set in rice. These results accord with earlier findings for effective tillers (Satapathy *et al.*, 2014; Devi *et al.*, 2015; Mitra *et al.*, 2012; Ishwarya *et al.*, 2019) [26, 32, 36, 37], for panicle length (Glaser *et al.*, 2015; Akhter *et al.*, 2015; Olmo *et al.*, 2016) [38, 39, 40] and for grains per panicle (Huang *et al.*, 2019; Mannan *et al.*, 2020; Yuan *et al.*, 2021) [41, 42, 43].

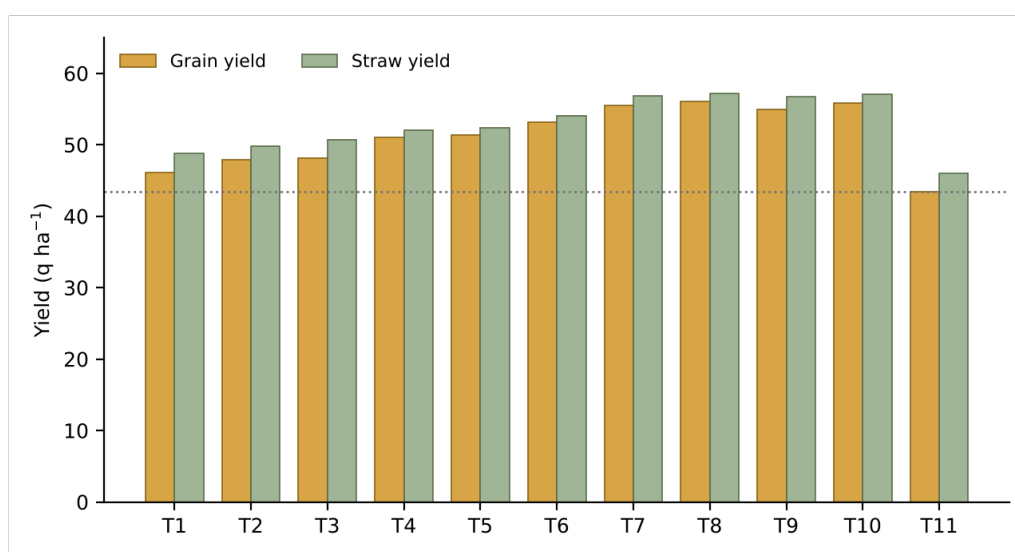
spray at 500 ml ha⁻¹ (48.79 q ha⁻¹). Biological yield ranged from 89.38 q ha⁻¹ in the control to 113.30 q ha⁻¹ under the best treatment. Harvest index was not significantly influenced by the treatments, ranging narrowly from 48.56 to 49.59 per cent, since harvest index is governed largely by the genetic constitution of the variety and is little affected by cultural practices.

Grain yield is the integrated expression of the yield-attributing characters, and the present results show clearly that it varied in step with those characters under the different biostimulant doses. The positive effect of biostimulants containing phytohormones, betaines, cytokinins, minerals, vitamins, amino acids and enzymes on the yield and yield attributes of rice has also been reported previously (Khan *et al.*, 2009; Jadhao *et al.*, 2015; Pal *et al.*, 2015; Hidangmayum *et al.*, 2017; Trivedi *et al.*, 2018) [44, 45, 46, 47, 48]. The increment in straw yield may be explained by the supply of macro- and micro-nutrients together with appreciable quantities of cytokinins, auxins and betaines, which raise chlorophyll production, enhance photosynthesis and thereby stimulate vegetative growth (Satapathy *et al.*, 2014; Khan *et al.*, 2009; Bastia *et al.*, 2013; Rathore *et al.*, 2009) [26, 44, 49, 50].

Applied at tillering stage; * applied at tillering and boot-leaf stages. DAT = days after transplanting; NS = not significant.

Table 10. Effect of Zymegold on the yield and harvest index of rice

Treatment	Grain yield (q ha ⁻¹)	Straw yield (q ha ⁻¹)	Biological yield (q ha ⁻¹)	Harvest index (%)
T ₁ : 500 ml ha ⁻¹ *	46.08	48.79	94.87	48.58
T ₂ : 750 ml ha ⁻¹ *	47.93	49.78	97.71	49.07
T ₃ : 1000 ml ha ⁻¹ *	48.12	50.64	98.76	48.73
T ₄ : 1250 ml ha ⁻¹ *	50.98	52.03	103.01	49.49
T ₅ : 500 ml ha ⁻¹ **	51.40	52.38	103.78	49.52
T ₆ : 750 ml ha ⁻¹ **	53.17	54.07	107.24	49.59
T ₇ : 1000 ml ha ⁻¹ **	55.49	56.87	112.36	49.38
T ₈ : 1250 ml ha ⁻¹ **	56.08	57.22	113.30	49.55
T ₉ : 1500 ml ha ⁻¹ **	54.94	56.74	111.68	49.19
T ₁₀ : 2000 ml ha ⁻¹ **	55.85	57.04	112.89	49.47
T ₁₁ : Control (water spray)	43.38	46.00	89.38	48.56
SEm ±	0.94	1.26	1.89	0.83
LSD (<i>p</i> = 0.05)	2.82	3.74	5.60	NS

**Figure 6.** Grain and straw yield of rice under graded doses and application schedules of Zymegold. T₁–T₄ single spray at tillering; T₅–T₁₀ double spray at tillering and boot leaf; T₁₁ water-spray control. The broken line denotes the grain yield of the control

Phytotoxicity

No phytotoxic symptoms of any kind were observed at any observation date, even at the highest doses of 1500 and 2000 ml ha⁻¹ applied twice. All ratings remained at zero on the 0–10 scale, indicating complete safety of this seaweed-based biostimulant to rice across the dose range tested.

Conclusion

Foliar application of the seaweed-based biostimulant Zymegold® significantly improved the growth and yield of transplanted rice under the mid-hill sub-humid conditions of the north-western Himalayas. Two applications of 1250 ml ha⁻¹, one each at the tillering and boot-leaf stages, gave the highest plant height, tiller density, dry matter accumulation, crop growth rate and yield attributes, and raised grain yield by 29.3 per cent over the water-spray control. The response saturated beyond this dose, so that 1500 and 2000 ml ha⁻¹ conferred no additional benefit, and the two-spray schedule was consistently superior to a single spray at the same dose. Phenology and harvest index were unaffected, and no phytotoxicity was detected at any dose. A double foliar spray of Zymegold at 1250 ml ha⁻¹ at the tillering and boot-leaf stages is therefore recommended for transplanted rice in this agro-ecological zone.

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