



Effect of Pusa Hydrogel and Plant Growth Regulators on Fruiting, Yield, Fruit Quality and Economics of Strawberry (*Fragaria × ananassa* Duch.) cv. Chandler

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Abstract

A treatment that produces vigorous plants and conserves irrigation water is not automatically the treatment a grower should adopt; that decision ultimately rests on how many fruits reach the crate, how good they taste, and whether the extra input pays for itself. These are the questions the present study addresses. Building on a two-season field trial that has already established the vegetative and water-use responses of strawberry cv. Chandler to Pusa Hydrogel and the plant growth regulators Triacantanol and Cycocel, this paper reports the reproductive, yield, quality and economic outcomes of the same experiment, none of which have been published previously. The trial was conducted during 2021–22 and 2022–23 at the Krishi Vigyan Kendra (KVK), Kotwa, located in Azamgarh, Uttar Pradesh, in a Randomized Block Design with 27 treatments - Pusa Hydrogel at 30 g and 60 g per plant, Triacantanol at 120 ppm and 170 ppm, and Cycocel at 600 ppm and 1200 ppm, applied singly and in combination - replicated three times. Days to first fruit, fruit length and width, fruit set percentage, fruit number, cumulative yield per plant and per hectare, individual fruit weight, four biochemical quality traits (total soluble solids, juice pH, titratable acidity and ascorbic acid), and a full cost–return analysis were recorded, to which a marginal-return comparison not previously applied to this dataset was added. Triacantanol at 170 ppm combined with 60 g Pusa Hydrogel (T20) reached first fruit earliest (71.15 days, pooled), produced the largest fruit (4.83 cm long, 3.49 cm wide), set fruit most efficiently (63.16%), and out-yielded every other treatment on both a per-plant (217.04 g, a 38.7% gain over the control) and per-hectare basis (7.162 t). The same treatment gave the sweetest, most nutritionally rich fruit (TSS 10.54 °Brix; ascorbic acid 52.99 mg per 100 g) and returned the highest net income of the trial (₹ 11,30,324 per hectare; benefit–cost ratio 3.74:1). A partial-budget comparison showed that the additional Triacantanol needed to move from the next-best treatment (T12) to T20 cost roughly ₹ 200 per hectare yet returned an extra ₹ 47,000 - while Pusa Hydrogel used on its own, without a growth regulator, left growers worse off than doing nothing at all. Read alongside the trial's previously reported growth and water-use responses, these results close the loop from field performance to farm income and make a clear case for pairing Pusa Hydrogel with Triacantanol rather than relying on either input in isolation.



Keywords

Strawberry, Pusa Hydrogel, Triacantanol, Cycocel, Fruit Quality, Economic Analysis, Marginal Return

1. Introduction

Few fruit crops reward a grower as quickly as strawberry (*Fragaria × ananassa* Duch.). Its short cycle and strong urban demand make it an appealing option even for farmers working small plots, and this has fuelled its steady spread beyond the traditional hill stations into the plains of northern India. That spread has not been without friction, however. Strawberry roots stay shallow throughout the plant's life, and on the sandy loam soils common to the Middle Gangetic Plain, this shallowness translates directly into vulnerability: a missed irrigation cycle shows up in the crop within days (Sharma et al., 2006). Two rather different kinds of intervention have been proposed to manage this vulnerability. One works on the soil itself - superabsorbent amendments such as Pusa Hydrogel, developed at ICAR-IARI specifically to buffer moisture in coarse-textured soils (Kalhapure et al., 2016). The other works on the plant's internal chemistry - growth regulators such as Triacantanol and Cycocel, which alter hormonal balance rather than the physical growing medium (Kumar et al., 2015).

Whether these two kinds of intervention reinforce each other when applied together is a question this research group set out to answer through a two-season factorial trial spanning 27 combinations of Pusa Hydrogel (30 g, 60 g plant⁻¹), Triacantanol (120 ppm, 170 ppm) and Cycocel (600 ppm, 1200 ppm). Two papers have already come out of that trial. The first showed that pairing 170 ppm Triacantanol with 60 g Pusa Hydrogel - the combination referred to throughout this paper as T20 - produced the tallest, leafiest plants and the earliest flowering of any treatment tested, with the 120 ppm Triacantanol equivalent (T12) close behind (Singh and Bhardwaj, 2025). The second turned to water economy specifically, finding that the same T20 combination raised irrigation water use efficiency by 56% relative to an untreated control (Bhardwaj and Singh, 2025). What neither paper addresses is what happened next - whether the plants that grew best and used water most efficiently also went on to set more fruit, produce better-quality fruit, and earn the grower more money. That is not a foregone conclusion. Vegetative vigour and reproductive output do not always move in step in strawberry; a regulator that pushes canopy growth can, at high enough concentration, delay flowering rather than hasten it, and a soil amendment that saves water will not by itself correct an underlying hormonal imbalance (Roussos et al., 2019).

This paper picks up where the earlier two left off. It reports, for the first time from this trial, how the 27 treatments affected the timing of fruiting, fruit dimensions, fruit set efficiency, fruit number, cumulative yield on both a per-plant and per-hectare basis, individual fruit weight, and four measures of fruit quality - total soluble solids, juice pH, titratable acidity, and ascorbic acid content. It then goes a step further than either previous paper by asking not just which treatment earned the most money in absolute terms, but whether the extra expense of moving to a costlier treatment was actually worth it - a partial-budget, marginal-return question that neither the growth paper nor the water-use paper attempted to answer. Taken together with what is already known about this trial's vegetative and water-use responses, the results presented here complete the chain of evidence from field performance to the figure that matters most to a grower: the money left over at the end of the season.

2. Materials and Methods

Because this paper draws on the same field trial reported in Singh and Bhardwaj (2025) and Bhardwaj and Singh (2025), the experimental setup is described only briefly here; readers are directed to those papers for the fuller agro-climatic and soil profile of the site.



The work was carried out over two rabi seasons, 2021–22 and 2022–23, at the Krishi Vigyan Kendra (KVK), Kotwa, Azamgarh, in the Middle Gangetic Plain (Zone II) of Uttar Pradesh. Soils at the site range from sandy loam to loam, with a near-neutral pH (6.8–7.4), organic carbon and nitrogen on the lower side, and phosphorus and potassium at moderate levels. Winters here are cold enough for occasional frost risk (4–5 °C) and summers hot enough to exceed 42 °C, with almost all of the region's 1000–1200 mm annual rainfall arriving during the June–September monsoon, well outside the strawberry growing season.

Twenty-seven treatments - every combination of Pusa Hydrogel (30 g and 60 g per plant, worked into the soil at transplanting), Triacantanol (120 ppm and 170 ppm), and Cycocel (600 ppm and 1200 ppm), applied alone, in pairs, and all three together, alongside an untreated control - were laid out in a Randomized Block Design with three replications. Foliar sprays of Triacantanol and Cycocel began 30 days after transplanting cv. Chandler runners at 45 cm × 30 cm spacing, with three further applications at fortnightly intervals. All plots received the same recommended fertiliser dose (100:120:80 kg N:P₂O₅:K₂O ha⁻¹).

For the parameters reported in this paper, five plants per plot were tagged at random and tracked through to harvest. Data were subjected to analysis of variance for the Randomized Block Design, following Fisher and Yates (1938), separately for each season and pooled across both; wherever the F-test indicated significance, treatment means were separated using the Critical Difference at the 5% probability level.

3. Observations to be Recorded

- 1) Days taken to first fruit
- 2) Fruit length (cm) and fruit width (cm)
- 3) Number of fruits per plant and fruit set percentage
- 4) Fruit yield per plant (g), individual fruit weight (g) and yield per hectare (t)
- 5) Total soluble solids (°Brix), juice pH, titratable acidity (%) and ascorbic acid content (mg per 100 g)
- 6) Cost of cultivation, gross return, net return and benefit–cost (B:C) ratio, together with a marginal–return comparison between selected treatment pairs

4. Treatment Detail

Notation	Treatment Details
T0	Control
T1	Pusa Hydrogel – 30 g
T2	Pusa Hydrogel – 60 g
T3	Cycocel (600 ppm)
T4	Cycocel (1200 ppm)
T5	Triacantanol (120 ppm)
T6	Triacantanol (170 ppm)
T7	Cycocel (600 ppm) + Pusa Hydrogel 30 g
T8	Cycocel (600 ppm) + Pusa Hydrogel 60 g

T9	Cycocel (1200 ppm) + Pusa Hydrogel 30 g
T10	Cycocel (1200 ppm) + Pusa Hydrogel 60 g
T11	Triaccontanol (120 ppm) + Pusa Hydrogel 30 g
T12	Triaccontanol (120 ppm) + Pusa Hydrogel 60 g
T13	Triaccontanol (120 ppm) + Cycocel (600 ppm)
T14	Triaccontanol (120 ppm) + Cycocel (600 ppm) + Pusa Hydrogel 30 g
T15	Triaccontanol (120 ppm) + Cycocel (600 ppm) + Pusa Hydrogel 60 g
T16	Triaccontanol (120 ppm) + Cycocel (1200 ppm)
T17	Triaccontanol (120 ppm) + Cycocel (1200 ppm) + Pusa Hydrogel 30 g
T18	Triaccontanol (120 ppm) + Cycocel (1200 ppm) + Pusa Hydrogel 60 g
T19	Triaccontanol (170 ppm) + Pusa Hydrogel 30 g
T20	Triaccontanol (170 ppm) + Pusa Hydrogel 60 g
T21	Triaccontanol (170 ppm) + Cycocel (600 ppm)
T22	Triaccontanol (170 ppm) + Cycocel (600 ppm) + Pusa Hydrogel 30 g
T23	Triaccontanol (170 ppm) + Cycocel (600 ppm) + Pusa Hydrogel 60 g
T24	Triaccontanol (170 ppm) + Cycocel (1200 ppm)
T25	Triaccontanol (170 ppm) + Cycocel (1200 ppm) + Pusa Hydrogel 30 g
T26	Triaccontanol (170 ppm) + Cycocel (1200 ppm) + Pusa Hydrogel 60 g

5. Results and Discussion

The experiment ran across two field seasons, 2021-22 and 2022-23, at the Krishi Vigyan Kendra (KVK), Kotwa, Azamgarh (U.P.). The vegetative growth and water-use-efficiency responses of these same 27 treatments have been reported elsewhere (Singh and Bhardwaj, 2025; Bhardwaj and Singh, 2025); everything that follows here - fruiting behaviour, yield, fruit quality, and the economics of cultivation - is being reported for the first time.

5.1 Days to First Fruit, Fruit Length and Fruit Width

How quickly a strawberry plant moves from transplanting to its first ripe fruit, and how large that fruit turns out to be, are captured in Table 1. Plants under T20 reached first fruit noticeably sooner than any other treatment - 71.15 days on a pooled basis, which is more than six days ahead of the untreated control (77.22 days) and over a week ahead of T4, the 1200 ppm Cycocel treatment that lagged behind everything else at 78.52 days. T12 sat between the two, at 73.41 days. The same ranking held for fruit size: T20 gave both the longest fruit (4.83 cm pooled, versus 3.92 cm for the control and just 3.57 cm for T4) and the widest (3.49 cm, against 3.25 cm and 2.95 cm respectively), though on width alone T12 was not statistically distinguishable from it.

It is worth asking why the same treatment leads on both timing and size, since these are, in principle, separate outcomes. Fruit size in strawberry is largely decided early - by how many cortical cells form around fertilisation, and only afterward by how much assimilate is available to expand them. That T20 leads on both counts together points to its advantage starting upstream, at flower initiation, rather than kicking in later during fruit swell. Triaccontanol's known effect on photosynthetic enzyme activity would explain the cellular side of this (Kumar et al., 2015), while Pusa Hydrogel's role in keeping the root zone moist through the pollination window - a stage during which even a short dry spell can knock down both fruit set and eventual fruit size (Pattanaik et al., 2015a) - plausibly explains the rest. Comparable Triaccontanol-linked gains in fruit dimension have turned up before, in mango (Shinde et al., 2008) and, more directly relevant here, in strawberry cv. Chandler grown with organic manure (Khunte et al., 2014).

Table 1. Days to first fruit, fruit length and fruit width in strawberry cv. Chandler as influenced by Pusa Hydrogel and plant growth regulators (pooled data, 2021-22 and 2022-23)

Treatment	Days to First Fruit 2021-22 / 2022-23 / Pooled	Fruit Length (cm) 2021-22 / 2022-23 / Pooled	Fruit Width (cm) 2021- 22 / 2022-23 / Pooled
T0 (Control)	78.43 / 76 / 77.22	3.78 / 4.05 / 3.92	3.17 / 3.33 / 3.25
T4 (Cycocel 1200 ppm)	79.73 / 77.3 / 78.52	3.43 / 3.7 / 3.57	2.87 / 3.03 / 2.95
T12 (Triaccontanol 120 ppm + Hydrogel 60 g)	74.62 / 72.19 / 73.41	4.53 / 4.8 / 4.67	3.39 / 3.55 / 3.47
T20 (Triaccontanol 170 ppm + Hydrogel 60 g)	72.36 / 69.93 / 71.15	4.69 / 4.96 / 4.83	3.41 / 3.57 / 3.49
F-test	S / S / S	S / S / S	S / S / S
SEd	0.463 / - / -	0.437 / 0.707 / 0.57	0.456 / 0.616 / 0.536
CD @5%	0.887 / - / -	0.837 / 1.107 / 0.97	0.902 / 1.062 / 0.982

5.2 Number of Fruits per Plant and Fruit Set Percentage

Fruit count and fruit set percentage together tell us something a little different from fruit size: not how big the harvest was, but how efficiently the plant turned its flowers into something worth picking. On both measures, T20 came out on top - 15.39 fruits per plant and 63.16% fruit set, pooled - with T12 following closely (15.30 fruits; 63.03% set). The control managed 12.13 fruits per plant at 53.80% set, while T4 again brought up the rear, at 10.76 fruits and just 47.47% set.

An extra 3.3 fruits per plant may not sound dramatic, but it was achieved at the same planting density as every other treatment, which means it reflects better use of the flowers the plant already produced rather than simply more flowers to begin with. Indeed, the flower counts reported for these same treatments previously (Singh and Bhardwaj, 2025) do not scale up to fruit number in quite the same proportion across the board, which suggests that what separates the leading treatments from the rest is fruit retention as much as flower production. One plausible explanation lies in the three-to-five-day window right after fertilisation, when a young fruitlet is most likely to abort if it runs short of carbohydrate; if Triaccontanol improves carbohydrate supply through that narrow window, as it appears to in apple (Sharma and Singh, 2008), fewer fruitlets would be lost at exactly the stage where losses matter most.

Table 2. Number of fruits per plant and fruit set percentage in strawberry cv. Chandler - control and key treatments (pooled data, 2021-22 and 2022-23)

Treatment	Fruits/Plant 2021-22 / 2022- 23 / Pooled	Fruit Set (%) 2021-22 / 2022- 23 / Pooled
T0 (Control)	11.66 / 12.61 / 12.13	53.18 / 54.41 / 53.8
T4 (Cycocel 1200 ppm)	10.28 / 11.23 / 10.76	46.85 / 48.08 / 47.47
T12 (Triaccontanol 120 ppm + Hydrogel 60 g)	14.82 / 15.77 / 15.3	62.41 / 63.64 / 63.03
T20 (Triaccontanol 170 ppm + Hydrogel 60 g)	14.91 / 15.86 / 15.39	62.54 / 63.77 / 63.16

Treatment	Fruits/Plant 2021-22 / 2022-23 / Pooled	Fruit Set (%) 2021-22 / 2022-23 / Pooled
F-test	S / S / S	S / S / S
SEd	1.908 / 2.86 / 2.38	0.209 / 1.439 / 0.82
CD @5%	3.634 / 4.58 / 4.11	0.4 / 1.63 / 1.02

5.3 Fruit Yield per Plant, Individual Fruit Weight and Yield per Hectare

Table 3 brings together the three numbers that most directly answer the question a grower actually asks - how much fruit, how big, and how much per hectare. T20 again led on all three: 217.04 g of fruit per plant, an average fruit weight of 26.82 g, and 7.162 t ha⁻¹, all pooled figures. T12 trailed slightly (209.88 g; 24.32 g; 6.926 t ha⁻¹). Set against the untreated control (156.49 g; 19.85 g; 5.176 t ha⁻¹), T20 delivered a 38.7% gain in per-plant yield and a nearly identical 38.4% gain per hectare; against T4, the weakest treatment on record (114.71 g; 14.75 g; 3.785 t ha⁻¹), the margin widened past 89%.

What is more interesting than T20's overall lead is how it compares with T12, since the two treatments are identical except for Triaccontanol concentration - 170 ppm against 120 ppm. The gap between them was small and statistically unremarkable for fruit number (0.09 fruits per plant, well inside the CD of 4.11) but large enough to matter for individual fruit weight (2.50 g, comfortably past the CD of 0.874 g). Read together, this pattern hints that the extra 50 ppm of Triaccontanol in T20 is doing most of its work after fruit set has already occurred, during the phase when each fruit is bulking up, rather than by getting the plant to set noticeably more fruit in the first place. That distinction - dose affecting fruit size more than fruit number - echoes what Khunte et al. (2014) found when combining Triaccontanol with organic manure in this same cultivar, though it had not previously been examined for the present trial.

Table 3. Fruit yield per plant, individual fruit weight and yield per hectare in strawberry cv. Chandler - control and key treatments (pooled data, 2021-22 and 2022-23)

Treatment	Fruit Yield/Plant (g) 2021-22 / 2022-23 / Pooled	Individual Fruit Wt. (g) 2021-22 / 2022-23 / Pooled	Yield (t/ha) Pooled
T0 (Control)	150.3 / 162.67 / 156.49	19.38 / 20.32 / 19.85	5.176
T4 (Cycocel 1200 ppm)	108.52 / 120.89 / 114.71	14.28 / 15.22 / 14.75	3.785
T12 (Triaccontanol 120 ppm + Hydrogel 60 g)	203.69 / 216.06 / 209.88	23.85 / 24.79 / 24.32	6.926
T20 (Triaccontanol 170 ppm + Hydrogel 60 g)	210.85 / 223.22 / 217.04	26.35 / 27.29 / 26.82	7.162
F-test	S / S / S	S / S / S	S
SEd	0.431 / 12.801 / 6.62	0.21 / 1.15 / 0.68	-
CD @5%	0.826 / 13.196 / 7.01	0.404 / 1.344 / 0.874	-

5.4 Fruit Quality: Total Soluble Solids, Juice pH, Titratable Acidity and Ascorbic Acid

Four biochemical traits were assessed at harvest - total soluble solids, juice pH, titratable acidity, and ascorbic acid - and the values for the control and the three treatments discussed throughout this paper appear in Table 4. T20 topped every one of them in the pooled analysis: TSS of 10.54 °Brix, pH of 4.90,

titratable acidity of 0.92%, and ascorbic acid at 52.99 mg per 100 g. T12 was statistically inseparable from it on pH and ascorbic acid (4.90 and 52.74 mg per 100 g). The control sat in the middle on every trait, and T4 finished last on all four, its fruit measuring only 7.41 °Brix TSS, pH 3.57, 0.66% acidity, and 43.02 mg ascorbic acid per 100 g.

What stands out here is that TSS and titratable acidity rose together under T20 rather than one coming at the expense of the other. That is not the usual pattern. Water stress often drives TSS up simply by concentrating fruit solutes, while at the same time suppressing acid accumulation and shrinking the fruit - exactly the disconnect Roussos et al. (2019) documented in strawberry, where certain growth-stimulating treatments boosted fruit number and size without any accompanying improvement in TSS, pH, or acidity. Because Pusa Hydrogel keeps the root zone consistently moist under T20, a concentration effect from water stress can be ruled out here; the more likely explanation is a genuine increase in the fruit's photosynthate supply and its onward transport, which fits with transcriptomic evidence that Triacantanol switches on sugar-metabolism genes in strawberry fruit (Pang et al., 2020). Ascorbic acid and titratable acidity are both metabolically costly for the plant to produce, so seeing both rise alongside TSS under the same treatment points toward an overall lift in the fruit's biosynthetic capacity, rather than a passive concentration artefact.

Table 4. Total soluble solids, juice pH, titratable acidity and ascorbic acid content in strawberry cv. Chandler - control and key treatments (pooled data, 2021–22 and 2022–23)

Treatment	TSS (°Brix) Pooled	Juice pH Pooled	Tit. Acidity (%) Pooled	Ascorbic Acid (mg/100g) Pooled
T0 (Control)	8.48	3.97	0.74	48.99
T4 (Cycocel 1200 ppm)	7.41	3.57	0.66	43.02
T12 (Triacantanol 120 ppm + Hydrogel 60 g)	10.39	4.9	0.88	52.74
T20 (Triacantanol 170 ppm + Hydrogel 60 g)	10.54	4.9	0.92	52.99
F-test	S	S	S	S
SEd	0.521	0.169	0.26	0.885
CD @5%	1.21	0.265	0.46	1.102

5.5 Economics of Cultivation and Marginal-Return Analysis

Table 5 sets out the pooled economics for the control and the key treatments discussed in this paper, worked out at the ₹ 200 per kg farm-gate price that prevailed at the study site across both seasons. T20 came out ahead on both measures that matter most to a grower - net income (₹ 11,30,324 ha⁻¹) and benefit–cost ratio (3.74:1) - with T12 close behind (₹ 10,83,324 ha⁻¹; 3.59:1). The untreated control managed a respectable 2.65:1, while T4 languished at just 1.56:1, the lowest B:C ratio recorded in the trial - and notably, this was not because T4 was an expensive treatment to apply, but because its yield was too poor to justify even ordinary cultivation costs.

Net return on its own, though, does not tell a grower whether spending more to reach a better treatment is actually a good use of money; that calls for a marginal comparison of what the extra input costs against what it brings back. Such an analysis has not previously been applied to this trial, so it is presented here for two pairs of treatments where the question seemed worth asking.

The first comparison, between T12 and T20, isolates the effect of Triaccontanol concentration alone, since the hydrogel dose is held constant at 60 g in both. Moving from 120 to 170 ppm added barely anything to the cultivation bill - about ₹ 200 per hectare, from ₹ 3,01,875.7 to ₹ 3,02,075.7 - yet lifted net return by ₹ 47,000, from ₹ 10,83,324 to ₹ 11,30,324. Dividing one by the other gives a marginal rate of return above 200-fold, which leaves little room for doubt that the higher Triaccontanol dose is worth applying once 60 g of hydrogel is already in the ground.

The second comparison runs in the opposite direction and makes a different point. Applying Pusa Hydrogel on its own, at 60 g per plant (T2), raised cultivation cost by ₹ 14,000 per hectare (from ₹ 2,83,675.7 to ₹ 2,97,675.7) but actually reduced net return, by ₹ 71,400 (from ₹ 7,51,524.3 down to ₹ 6,80,124.3) - a negative return on the investment. The explanation is straightforward once the yield figures are laid alongside the water-use data: hydrogel alone did improve water use efficiency, as reported previously (Bhardwaj and Singh, 2025), but yield under T2 (4.889 t ha⁻¹) was, if anything, slightly below the control's 5.176 t ha⁻¹, so there was no extra output to offset the added cost. In practical terms, this places Pusa Hydrogel firmly in the category of an input that pays off only when paired with something like Triaccontanol to convert the saved water into more fruit - a distinction that only becomes visible once the economics are worked through, and one a grower deciding how to spend a limited budget would want to know.

Table 5. Economic analysis of strawberry cv. Chandler cultivation - control and key treatments (pooled data, 2021-22 and 2022-23; sale price ₹ 200 kg⁻¹)

Treatment	Cost of Cultivation (₹/ha)	Yield (t/ha)	Gross Return (₹/ha)	Net Return (₹/ha)	B:C Ratio
T0 (Control)	2,83,675.7	5.176	10,35,200	7,51,524.3	2.65:1
T4 (Cycocel 1200 ppm)	2,95,675.7	3.785	7,57,000	4,61,324.3	1.56:1
T12 (Triaccontanol 120 ppm + Hydrogel 60 g)	3,01,875.7	6.926	13,85,200	10,83,324	3.59:1
T20 (Triaccontanol 170 ppm + Hydrogel 60 g)	3,02,075.7	7.162	14,32,400	11,30,324	3.74:1

Table 6. Marginal-return comparison between selected treatment pairs (pooled data)

Comparison	Δ Cost of Cultivation (₹/ha)	Δ Net Return (₹/ha)	Marginal Rate of Return
T12 → T20 (Tria 120→170 ppm, Hydrogel 60 g constant)	+200	+47,000	> 200-fold
T0 → T2 (Control → Hydrogel 60 g alone)	+14,000	-71,400	Negative

6. Conclusion

Taken together, these results answer the question that the earlier two papers from this trial left open: yes, the treatment that grew best and used water most efficiently also fruited earliest, produced the largest and best-tasting fruit, yielded the most per plant and per hectare, and put the most money in a grower's pocket. Triaccontanol at 170 ppm combined with 60 g Pusa Hydrogel per plant (T20) led on every parameter examined here, with the 120 ppm equivalent (T12) a close and somewhat more

economical runner-up. The marginal analysis adds a layer of nuance that raw treatment rankings cannot provide on their own: the extra Triacontanol needed to move from T12 to T20 costs next to nothing and returns many times its price, whereas Pusa Hydrogel used without any growth regulator actually loses money relative to doing nothing at all. Read alongside the vegetative and water-use findings already published from this trial, the picture that emerges is a consistent one - from early growth through to the final balance sheet, T20 is the combination that delivers, and it does so specifically because Triacontanol and Pusa Hydrogel are working on different parts of the problem at once. For growers in the agro-climatic conditions of eastern Uttar Pradesh, this points toward pairing the two inputs rather than relying on either alone.

7. Competing Interests

Authors have declared that no competing interests exist.

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