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Evaluation of the Summer Queen Passion Fruit in Bhutan

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Abstract

Passion fruit (Passiflora edulis Sims) is valued for its rich nutritional profile and increasing global demand for both fresh consumption and juice processing. In Bhutan, only the local purple variety has been released for commercial cultivation; however, its small fruit size, low pulp, and limited juice content constrain its consumption as a table fruit and industrial utility. The establishment of Bhutan Agro Industries Limited in Lingmethang has further intensified the demand for passion fruit underscoring the need for improved varieties. To address this gap, the hybrid cultivar 'Summer Queen', a cross between purple and yellow passion fruit introduced from Japan, was evaluated across three research centres (Agriculture Research and Development Centre, Wengkhar, Bajo, and Samtenling) representing diverse agroecological zones. A trial established in 2022 used a Completely Randomized Design with three replications to compare Summer Queen with the local variety. Data on fruit and yield traits, including fruit weight, dimensions, total soluble solids (TSS), pulp content, juice content, number of fruits per vine, and yield per vine, were analysed using ANOVA and Tukey's test in R software. Results consistently demonstrated the superiority of Summer Queen, which produced significantly larger fruits, higher pulp and juice content, and greater yields per vine across locations. On average, Summer Queen yielded 10.7 kg per vine, with 16.3% TSS and 16.8 ml juice per fruit, representing a five-fold increase in yield compared to the local variety. Although agroecological factors influenced specific traits such as fruit size, pulp content, TSS, and juice recovery, Summer Queen outperformed the local variety under both low and mid-elevation conditions, highlighting its adaptability and commercial potential for both fresh consumption and processing. In recognition of its superior performance, Summer Queen was officially released for commercial cultivation during the 27th Variety Release Committee meeting.

Keywords: *Summer Queen; TSS; Yield; Juice content; Processing*

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1 Introduction

Passion fruit (*Passiflora edulis* Sims) is a subtropical perennial vine crop native to South America, widely cultivated for its nutritional and economic importance. The species comprises three main types: the purple passion fruit (*P. edulis Sims f. edulis*), the yellow passion fruit (*P. edulis f. flavicarpa*), and their hybrids. The purple type is generally smaller, sweeter, and richer in flavor, making it suitable for fresh consumption as a table fruit, whereas the yellow type is larger, more acidic, and predominantly used in juice and concentrate production (Ortiz et al., 2012; Viera et al., 2020). Hybrid varieties have been developed to combine desirable traits of both forms. Among them, the Summer Queen passion fruit is a notable hybrid between *P. edulis* and *P. edulis f. flavicarpa.* It was originally developed/hybridized at the Agriculture Experiment Station for Kyushu and Okinawa District. Following its development, it was introduced and widely cultivated in Kagoshima, Japan (Macha et al., 2006). This cultivar is distinguished by its high sucrose and malic acid content, significant levels of α- and β-carotene, and richness in vitamin C (Viera et al., 2025). Furthermore, it thrives in acidic soils and consistently produces large, high-quality fruits (Niwayama & Higuchi, 2019). Beyond its nutritional appeal, passion fruit is valued for its bioactive compounds, which exhibit medicinal properties such as anticancer, anti-inflammatory, and anxiolytic activities (Arabzai et al., 2025).

In Bhutan, passion fruit cultivation remains limited, with a total production of 58.57 MT in 2025, representing only 0.13% of the country's fruit production (National Statistics Bureau, 2025). Until now, only the local purple variety has been officially released for commercial cultivation. Although popular for fresh consumption, this variety is characterized by small fruit size, low pulp, and reduced juice yield, thereby limiting its suitability for large-scale processing. On the other hand, the establishment of Bhutan Agro Industries Limited (BAIL) in Lingmethang, Mongar, has significantly increased the demand for passion fruit for juice processing. The company requires approximately 30 metric tonnes (MT) of fruits annually; however, in 2025, it was able to procure only 7 MT from Zhemgang Dzongkhag due to limited production and a lack of supply from eastern Bhutan.

To address this production gap and provide farmers with a higher-value alternative, the Summer Queen passion fruit hybrid was introduced from Japan in 2019. Compared to the local variety, it produces larger fruits with higher pulp and juice content, while maintaining a rich flavor, attributes that make it well-suited for both processing and fresh consumption.

Recognizing this potential, the Agriculture Research and Development Center (ARDC) Wengkhar initiated multilocation evaluation trials of Summer Queen in 2022 and simultaneously promoted the variety in farmers' fields. At present, five farmers are cultivating Summer Queen passion fruit across 6.31 acres of land in the eastern region under contractual arrangements with BAIL, ensuring assured markets. In addition, trellis systems for passion fruit production have been promoted with funding support from the CARLEP project, as trellis support is essential for optimal vine growth, yield, and fruit quality.

Given the increasing demand for passion fruit, the limitations of the local variety, and the promising attributes of the Summer Queen hybrid, a systematic evaluation of its agronomic and qualitative performance under Bhutanese agroecological conditions was lacking. Therefore, the main objective of the study was to assess the performance of the Summer Queen variety across multi locations, focusing on yield potential, fruit quality parameters, and its suitability for both fresh consumption and industrial processing.

2 Materials and methods

2.1 Study area

The evaluation trial was initiated in 2022 across three locations: ARDC Wengkhar (Latitude- 27.272307, Longitude- 91.270944, Altitude- 1591.8masl) in the eastern region, ARDC Bajo (Latitude- 27.492538, Longitude- 89.9016385, Altitude-1237 masl) in the western region and ARDC Samtenling (Latitude- 26.9084684, Longitude- 90.4321884, Altitude- 375 masl) in the southern region to assess the performance and adaptability of Summer Queen passion fruit under Bhutan's diverse agroecological zones. The experiment was carried out over three consecutive years from 2022 to 2025. Yield and fruit quality parameter data from all three years were included in the analysis. Passion fruit plants typically reach the economic bearing stage between 18 months and three years after planting.

Over the last three years, Wengkhar received an average annual rainfall of 776 mm, with mean maximum and minimum temperatures of 22.4°C and 13.7°C, respectively. Samtenling recorded comparatively higher rainfall, averaging 5080 mm, with mean maximum and minimum temperatures of 29.1°C and 20.7°C (Figure 1). In Bajo, the average annual rainfall was 485.4 mm, accompanied by higher temperatures, with mean maximum and minimum values of 26.6 °C and 15 °C, respectively (National Center for Hydrology and Meteorology [NCHM], 2025).

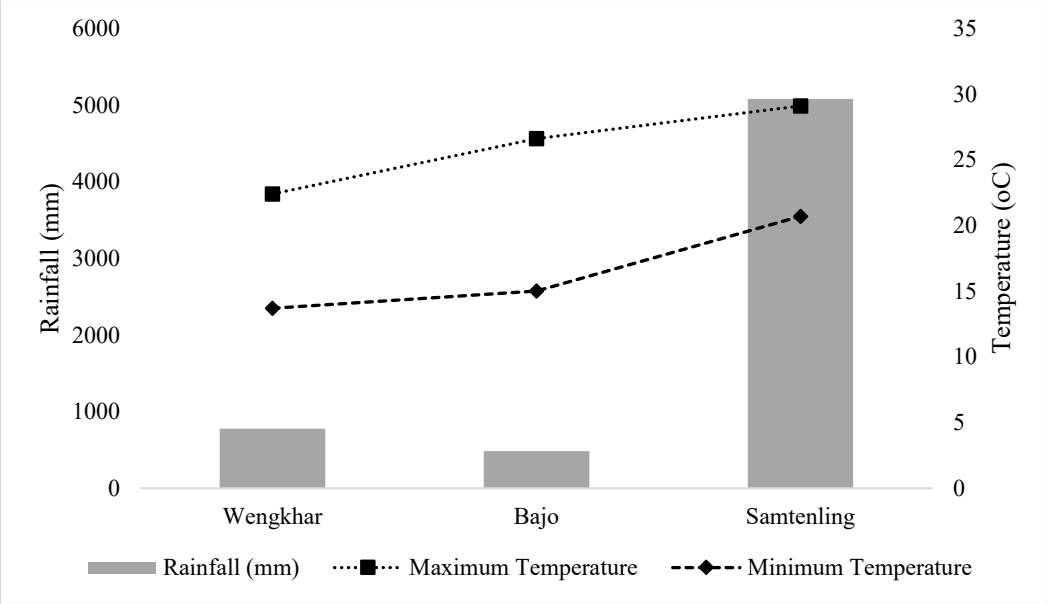

Figure 5. Average rainfall, maximum temperature and minimum temperature of three locations over the last three years (2022-2024)

2.2 Study Design

The experiment was conducted using the Summer Queen and local passion fruit varieties in a Completely Randomized Design (CRD) with three replications across all locations. Seedlings of both varieties were propagated through cuttings. The trial was established using a mound planting system at a spacing of 6 m × 3 m between rows and plants, comprising a total of 36 vines. Each replication consisted of six vines per variety, resulting in 18 vines per variety and 36 vines in total. Planting pits of 40 cm depth were prepared and filled with a mixture of topsoil and farmyard manure (FYM), after which they were raised into mounds 20–30 cm above ground level. Seedlings were planted at the center of each mound. An annual application of 10–20 kg FYM per vine was carried out, and irrigation was provided through a drip irrigation system. To support vine growth and ensure uniform management, a Kniffin trellis system was established across all locations. Under this system, two primary leaders were trained on either side of the main stem, while the lateral shoots arising from these leaders were allowed to hang freely. Pruning was conducted annually between January and February, immediately after the completion of fruit harvest.

Data collection included both fruit quality and yield attributes. Fruit quality parameters included fruit weight, fruit length, fruit diameter, total soluble solids (TSS), pulp content, juice content, and number of seeds per fruit. Yield parameters comprised the number of fruits

per vine and total yield per vine. Yield data were recorded from all vines, while fruit quality parameters were assessed using samples of 10 randomly selected fruits per harvest. A total of seven to eight harvests were conducted between September and February. To minimize variation, a larger sample size was used for both fruit quality and yield assessment by recording observations from 10 fruits in each harvest. For every harvest, the total number of fruits and cumulative fruit weight were also recorded. Fruit weight was measured using a digital weighing balance, fruit dimensions were measured using a vernier caliper, and TSS was determined using a refractometer.

2.3 Data analysis

The average fruit and yield parameters of the Summer Queen passion fruit in three locations were compared using one-way ANOVA in R software at a 95% confidence interval. Similarly, two-way ANOVA was used to assess the interactions between variety and location. For all ANOVA models, the assumptions of normality (Shapiro-Wilk test) and homogeneity of variances (Levene's test) were verified. Where a significant F-test ($p < 0.05$) was found, Tukey's Honest Significant Difference (HSD) post-hoc test was applied for mean separation.

3 Results and Discussion

3.1 Descriptive statistics

3.1.1 Fruit parameters and yield parameters

Overall, the hybrid cultivar Summer Queen outperformed the local variety in both fruit and yield parameters (Table 1). Summer Queen produced larger fruits, with a mean fruit weight of 64.3 g (range: 48.9-82.9 g), compared with 47.7 g (range: 30.1-76.0 g) in the local variety. These results are consistent with the findings of Macha et al. (2006), who reported average fruit weights of 60-100 g for Summer Queen in Japan. In terms of fruit dimensions, Summer Queen recorded mean values of 6.7 cm in height and 5.8 cm in diameter, whereas the local variety produced comparatively smaller fruits, averaging 5.4 cm in height and 4.9 cm in diameter.

For TSS, Summer Queen showed a mean of 16.3% (range: 14.5-17.7%), while the local variety recorded a slightly lower mean TSS of 15.2% (range: 11.9-18.5%). The mean juice content was also higher in Summer Queen with 16.8 ml than in the local variety with 12.4 ml. Similarly, the mean pulp weight of Summer Queen was 31.5 g, which is greater than that of the local variety (21.1 g). Yield components followed a similar trend, with Summer Queen

outperforming the local variety. The average number of fruits per vine was 168.6 for Summer Queen, compared with only 53 fruits per vine for the local variety. Consequently, the mean yield per vine of Summer Queen was substantially higher at 10.7 kg whereas the local variety yielded only 2.4 kg per vine (Figure 2).

Table 1. Descriptive summary of Summer Queen and Local passion fruit

Variety	Descriptive statistics	Fruit weight (g)	Fruit height(cm)	Diameter (cm)	TSS (%)	Juice content (ml)	Pulp weight (g)	Fruits/vine (no)	Yield/vine (kg)
Summer Queen	Mean	64.3	6.7	5.8	16.3	16.8	31.5	168.6	10.7
	Median	59.6	6.8	5.9	16.5	16.8	30.7	168.0	10.2
	Minimum	48.9	5.6	4.8	14.5	13.6	21.4	109.0	6.4
	Maximum	82.9	9.5	6.4	17.7	20.3	47.8	262.0	16.1
	Standard Deviation	11.5	0.7	0.5	1.0	2.1	6.2	33.4	2.7
local	Mean	47.7	5.4	4.9	15.2	12.4	21.1	53.0	2.4
	Median	44.3	5.3	4.7	15.9	11.1	18.9	48.5	2.5
	Minimum	30.1	4.8	4.4	11.9	6.8	13.1	21.0	0.8
	Maximum	76	6.6	6	18.5	25.0	41.0	110.0	4.6
	Standard Deviation	13.6	0.5	0.5	1.9	4.3	7.5	24.8	0.9

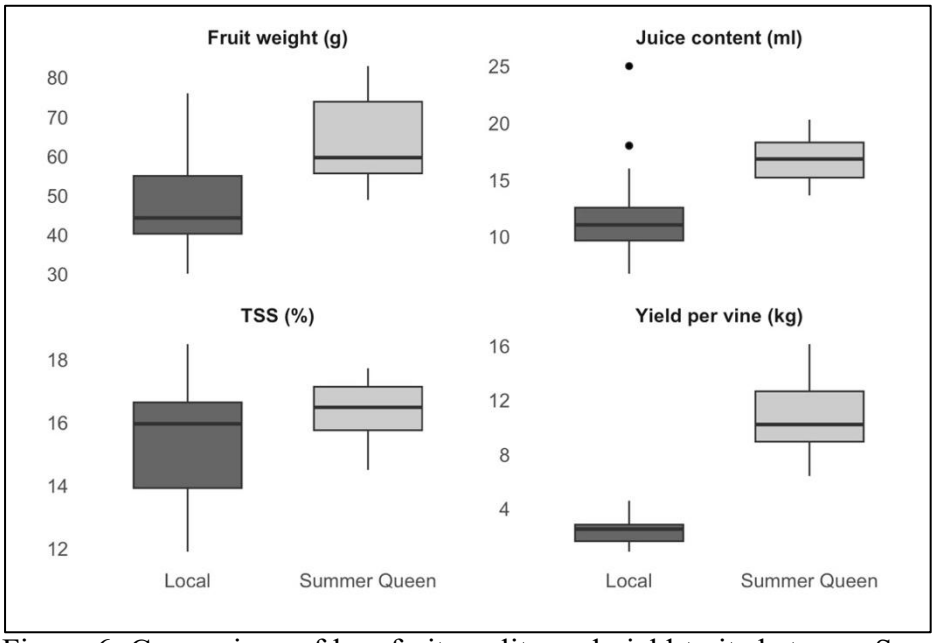

Figure 6. Comparison of key fruit quality and yield traits between Summer Queen and local passion fruit varieties

Overall, the findings demonstrate that Summer Queen consistently outperforms the local variety in fruit size, pulp and juice content, and yield, underscoring its potential as a promising cultivar for both fresh consumption and industrial processing.

3.2 Interactions between locations and treatments

3.2.1 Performance of Summer Queen across three locations

To assess the performance of Summer Queen across three locations, the one-way ANOVA was used. The one-way ANOVA revealed significant differences ($p < 0.05$) among locations for most fruit quality and yield parameters of Summer Queen, except for the number of fruits per vine (Table 2).

At Wengkhar (1591.8 masl), vines produced significantly heavier fruits (78.8 g), along with the highest pulp weight (37.8 g/fruit) and yield per vine (12.7 kg/vine). However, TSS and juice content were comparatively lower, recorded at 15.4% and 15.4 ml/fruit, respectively. The higher yield observed at Wengkhar appears to be associated with the larger fruit size, which supports the findings of Joseph et al. (2021), who reported a significant positive correlation between fruit weight and yield per vine in passion fruit grown in Kerala.

At Samtenling (375 masl), fruits recorded the highest TSS (17.3%) and fruit height (7.2 cm), indicating superior sweetness and flavor intensity. However, this location showed comparatively lower pulp weight (25.7 g/fruit) and yield (9.6 kg/vine). In contrast, Bajo (1237 masl) showed intermediate performance, with moderate fruit size, pulp weight (31.0 g/fruit), and yield (9.8 kg/ vine), while recording the highest juice content per fruit (18.4 ml). The TSS value at Bajo (16.1%) was also higher than that recorded at Wengkhar. The tendency of fruits grown at lower elevations to accumulate higher TSS may be attributed to higher temperatures that enhance sugar accumulation and reduce acidity, compared to fruits grown under cooler and higher elevation conditions as the optimum temperature for Summer Queen is between 18^0C-25^0C (Macha et al., 2006).

The variation in fruit size, physical characteristics, and yield across locations may be attributed to differences in climatic conditions, soil properties, and crop management practices. In addition, fruit set, pulp content, and juice yield are strongly influenced by pollination efficiency. Since passion fruit pollen is sticky, wind pollination is ineffective, and successful pollination largely depends on pollinators such as bumble bees or manual

pollination (Fischer et al., 2018). In terms of fruit color, Summer Queen produced fully developed, vibrant purple fruits at maturity in Bajo and Samtenling, whereas fruits grown at Wengkhar exhibited a slightly tainted purple hue. This observation suggests that the variety may be better adapted to lower elevations for optimal fruit color development. Furthermore, the fruits exhibited a distinct sweet aroma in all the locations, indicating strong potential for processing into juice, jams, desserts, and fermented products (Zheng et al., 2024).

While the data unequivocally demonstrate the superior yield and physical fruit traits of Summer Queen, a critical examination reveals important considerations for its commercial rollout. The significant location-based variation presents not just statistical effects, but practical trade-offs for growers**.** The high-yielding environment of Wengkhar came at the cost of reduced Brix, potentially requiring processors to blend for sweetness. Conversely, the superior TSS at Samtenling aligns with premium fresh market demands, albeit with lower yield. Therefore, the optimal production zone may depend on the target market: mid-elevations for bulk processing contracts, and lower elevations for direct fresh sales where sweetness commands a price premium.

Table 2. Fruit and yield parameters of Summer Queen among three locations

Location	Fruit weight (g)	Fruit height (cm)	Diameter (cm)	TSS (%)	Juice content (ml)	Pulp weight (g)	Fruits/vine (no)	Yield/vine (kg)
Bajo	55.7^{b}	6.0^{b}	5.1^{c}	16.1^{b}	18.4^{a}	31.0^{b}	174.0^{a}	9.8^{b}
Samtenling	58.7^{b}	7.2^{a}	6.3^{a}	17.3^{a}	16.7^{ab}	25.7^{c}	165.0^{a}	9.6^{b}
Wengkhar	78.8a	6.8^{a}	5.9^{b}	15.4^{b}	15.4^{b}	37.8^{a}	167.0^{a}	12.6^{a}
p-Value	***	***	***	***	***	***	NS	*
SD	11.5	0.7	0.5	0.9	2.1	6.2	33.8	2.7

** Means within a column followed by different superscript letters are significantly different according to Tukey's Honestly Significant Difference (HSD) test at *p* < 0.05. NS: not significant; SD: standard deviation. Significance of main effects is indicated as: ***p* < 0.001, **p* < 0.01, *p* < 0.05.*

3.2.2 Interaction analysis of Summer Queen and local passion fruit across two locations

To compare the performance of Summer Queen against the local variety and to test for genotype-by-environment interaction**,** a two-way ANOVA was employed. This model included the fixed effects of Variety (Summer Queen, Local) and Location, as well as their

interaction. Due to insufficient fruiting and yield data for the local variety at the Samtenling site, this analysis was restricted to data from the Bajo and Wengkhar locations only, ensuring a valid and balanced comparison. The local passion fruit at Samtenling had a fewer fruiting as the vines could not grow well which is likely due to excessive heat and rainfall.

The two-way ANOVA revealed significant varietal differences for most fruit quality and yield parameters, except for TSS, which showed no significant difference between varieties ($p = 0.07$). Location had a significant effect on TSS and juice content, while the interaction between variety and location was significant for most fruit physical and yield parameters, indicating differential varietal response across agro-ecological conditions (Table 3).

Across both locations, Summer Queen consistently outperformed the local variety in terms of fruit size, pulp weight, and yield per vine. Although fruit weight was comparable between varieties at Bajo, the substantially higher pulp recovery and fruit number per vine in Summer Queen contributed to its superior yield performance. At Wengkhar, Summer Queen produced significantly larger fruits (78.8 g), higher pulp weight (37.8 g per fruit), and substantially higher yield (12.6 kg per vine) compared to the local variety. Although TSS did not differ significantly between varieties, location had a strong influence on sugar development. Fruits grown at Bajo recorded higher TSS compared to Wengkhar, which may be attributed to higher temperature conditions at lower elevations that promote sugar accumulation and reduce acidity. Juice content was significantly influenced by location and variety. At Bajo, Summer Queen recorded the highest juice content (18.4 ml/fruit), whereas both varieties showed reduced juice content at Wengkhar, possibly due to cooler temperature conditions influencing juice accumulation and fruit water content.

The significant variety × location interaction observed for most fruit quality and yield parameters indicates that varietal performance is strongly influenced by environmental conditions. Summer Queen showed better adaptability across both locations, while the local variety exhibited comparatively lower productivity and fruit quality, particularly at higher elevation. From a utilization perspective, Summer Queen demonstrated strong potential for both fresh consumption and processing while the local variety showed limited commercial processing potential due to lower yield and pulp recovery across both locations.

Overall, the results demonstrate the superior performance and wider adaptability of the Summer Queen variety compared to the local variety across mid to high elevation production

environments. Thus, the Summer Queen variety has been released for commercial production in the 27th Variety Release Committee (VRC) Meeting. One limitation of the present study was the absence of data from farmers' fields for comparison with the on-station results. Future studies should incorporate on-farm data and undertake comparative analyses with on-station findings to ensure greater robustness and external validity of the conclusions.

Table 3. Two-way ANOVA of Summer Queen and Local passion fruit between two locations

Variety	Location	Fruit weight (g)	Fruit height (cm)	Diameter (cm)	TSS (%)	Juice content (ml)	Pulp weight (g)	Fruits/ vine (no)	Yield/vine (kg)
Summer Queen	Bajo	55.7[b]	6.0[b]	5.1[a]	16.1[b]	18.4[a]	31.0[b]	174.0[a]	9.8[b]
Summer Queen	Wengkhar	78.8[a]	6.9[a]	5.9[b]	15.4[b]	15.4[b]	37.8[a]	167.0[a]	12.6[a]
Local	Bajo	54.6[a]	5.8[a]	5.1[a]	16.8[a]	14.9[a]	24.2[a]	33.9[b]	1.8[b]
Local	Wengkhar	40.8[b]	5.0[b]	4.6[b]	13.7[b]	9.9[b]	18.0[b]	72.1[a]	2.9[a]
	Variety	***	***	***	0.07	***	***	***	***
	Location	NS	NS	NS	***	***	NS	NS	0.002
	Variety x location	***	***	***	***	NS	0.002	0.02	NS

** Means within a column followed by different superscript letters are significantly different according to Tukey's Honestly Significant Difference (HSD) test at *p* < 0.05.NS: not significant; SD: standard deviation. Significance of main effects is indicated as: ***p* < 0.001, **p* < 0.01, *p* < 0.05.*

4 Conclusion

This study demonstrated significant variation in fruit quality and yield performance of the Summer Queen passion fruit across different agro-ecological locations. The consistently superior performance of Summer Queen compared to the local variety across locations confirms its higher productivity potential and wider adaptability under mid- to high-elevation growing conditions.

At Wengkhar, Summer Queen produced significantly larger fruits with higher yield per vine but lower TSS and juice content, indicating strong suitability for juice processing at mid evelation. In contrast, Bajo and Samtenling recorded relatively higher TSS and juice content, indicating better suitability for both fresh consumption and juice processing at lower elevation.

Overall, the findings demonstrate that Summer Queen possesses strong commercial potential for both fresh consumption and processing industries and can be recommended for cultivation across mid- to high-elevation production environments.

5 Acknowledgement

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6 Authors' contribution statement

Pema Yangdon was involved in writing the manuscript, trial setup, data collection, and analysis. Mandira Acharja, Kinzang Wangmo, Ngawang Yeshi, Chandra Kumar Monger, and Nangsel Tshomo were involved in data collection and management of the trial block while Thinley Gyeltshen was involved in data analysis and Tshering Penjor was involved in overall guidance for trial set up and data collection.

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