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Differential Response of Sapota Varieties and Hybrids to Chiku Moth, Nephopteryx eugraphella (Ragonot) under High-Density System

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Abstract

Sapota is an economically important tropical fruit crop extensively cultivated in India. Among its biotic constraints, chiku moth, Nephopteryx eugraphella (Ragonot) causes severe damage to buds, flowers and leaves, leading to significant yield loss. An investigation was conducted from 2020-21 to 2024-25 to evaluate eight sapota varieties/hybrids planted at high density spacing (5×5 m) for their tolerance/ susceptibility against chiku moth. Pooled data over five years revealed that Kalipatti exhibited maximum mean (13.69%) and peak bud damage (19.21%) in June, confirming its susceptibility. PKM-1 recorded the lowest mean bud damage (8.24%), being -39.83% less vulnerability than Kalipatti, followed by CO-3 (8.98%) with -34.42% variation. Categorization of varieties on scale basis indicated PKM-1 as Resistant, PKM-3 and CO-3 as Moderately Resistant and Kalipatti as Susceptible. Bud infestation was significantly higher during summer (especially May-June) than winter in all varieties. Correlation analysis revealed that bud diameter (r= 0.739 and 0.735) had a significant positive correlation with bud damage, while total carbohydrate (r= -0.797 and -0.804) and non-reducing sugar (r= -0.732 and -0.714) showed significant negative correlations, suggesting their role in pest resistance mechanism. These findings have significant implications for varietal selection in sapota high density agro-systems.

Introduction

Sapota (*Manilkara achras* (Mill.) Fosberg, syn. *Achras zapota* L.), a member of the family Sapotaceae, is one of the most important commercially grown tropical fruit crops in India. It is cultivated across approximately 75,000 ha with an annual production exceeding 8.98 lakh MT, with India being the largest global producer (Anonymous 2023). In Gujarat, sapota ranks among the most significant fruit crops with major production in districts like Navsari, Surat, Valsad and Bhavnagar. The crop assumes special socio-economic importance as assured income fruit crop for small and marginal farmers of South Gujarat and India.

With rising land values and declining farm sizes, high density planting (HDP) at closer spacing has emerged as a promising strategy to maximize productivity per unit land area, improved fruit quality and early bearing (Patel et al. 2001; Rajasekhar and Ratan 2010 and Kumar et al., 2025). However, the intensification of sapota cultivation under HDP (5 × 5 m) may potentially alter the microclimate in ways that influence pest population dynamics and damage levels.

In India, sapota is attacked by about 33 insect pests and about 23 pests and mites reported in Gujarat (Bisane et al. 2018) and chiku moth, *Nephopteryx eugraphella* (Ragonot) (Lepidoptera: Pyralidae) is recognized as the most serious and economically significant pest. The larvae of this species cause extensive damage by webbing tender leaves, boring into buds and flowers and infesting young shoots, resulting in yield losses estimated up to 30–40% during peak flowering period (Mani and Jayanthi 2022). In another study, chiku moth and bud borer (*Anarsia achrasella*) persists almost throughout the year in sapota and exhibit a significant yield loss to the extent of 25–27% (Bisane 2018).

Incidence study by Shukla and Patel (2011) documented peak pest activity during May-June on buds/flowers. Subsequent investigations by Bisane (2019) elucidated round the year seasonal succession in relation to ecological factors and crop phenology, while Khambhu and Bisane (2017) reported the seasonal occurrence of the pest under HDP. Sapota possess long asymmetrical and overlapping flowering and fruiting bearing tendency, its productivity is largely influenced by insect pest complex during the main flowering and fruiting phase. Amplified canopy density and inter-tree competition in HDP may transform pest pressure differently than in conventional spacing. In this regard, Solanki et al. (2022) noted higher pest status in HDP compared to normal spacing for chiku moth.

However, systematic multi-year studies specifically under high density plantation conditions remain scarce, especially from an agroforestry management perspective with respect to consequence of increased canopy density and altered micro-climate. Few improved hybrids and cultivars from across the country have been released in response to commercial Kalipatti variety limitations in HDP and their field performance with insect resistance are currently being assessed. Among IPM components, host plant resistance is recognized as the most ecologically sustainable and reasonably viable approach, offering durable suppression of pest population without chemical inputs (Johnson et al. 2017).

High density sapota orchards are increasingly promoted as an agroforestry option, often intercropped with shade-tolerant species during the initial years. Understanding varietal performance against key pests in such systems is essential for informed varietal recommendation and integrated pest management (IPM). Therefore, the present investigation was undertaken with the objective to evaluate the varietal tolerance/susceptibility of sapota varieties and hybrids against chiku moth under high density plantation conditions.

Materials and Methods

Experimental Site and Crop Management

The investigation was conducted at Fruit Research Station, Navsari Agricultural University (NAU), Gandevi, Gujarat, India (20.807545º N, 73.022260º E) over five years from 2020-21 to 2024-25. Eight sapota varieties/hybrids (IC numbers), namely PKM-1 (IC-395173), PKM-3 (IC-395181), PKM-4 (Not available), DHS-1 (IC-395174), DHS-2 (IC-395183), Kalipatti as standard check (IC-395179), Cricket ball (IC-395153) and CO-3 (IC-395182) were evaluated. The varieties depicting PKM series has developed at HCRI, TNAU, Periyakulam; CO series at TNAU, Coimbatore (Tamil Nadu) and naming DHS developed at UHS, Bagalkot (Karnataka), while others are commercial cultivars.

The trees were planted during June, 2009 at high density spacing of 5 × 5 m and 11 years old at the commencement of the study. The experiment was laid out in a Randomized Block Design (RBD) with three replications and two trees per replication per variety. Uniform agronomic practices were followed throughout the experimental period. Each tree received 100 kg farmyard manure (FYM) and a fertilizer dose of N:P_2O_5:K_2O at 1000:500:500 g per tree per annum. Irrigation was provided at regular intervals.

Critically, all trees were kept free from insecticide spray throughout the study period to enable natural pest expression and unbiased varietal comparisons.

Pest Observations

Observations were recorded monthly during the summer season (March-June) and winter season (October-January) of each year. From each variety, 10 twigs were randomly selected encompassing all four cardinal directions of the canopy. Total number of buds as well as buds damaged by chiku moth was counted on each twig. Per cent bud damage was calculated as: % Bud damage = No. of damaged buds / Total buds × 100.

Peak damage was identified as the maximum monthly mean across the observation period. Both yearly average and peak damage intensity were considered to decide the tolerance and susceptibility intensity. Also, varietal damage reaction over standard check (Kalipatti) was calculated to check the susceptibility/tolerance level as given below:

% Variation = % Damage in variety – % Damage in std. check/% Damage in std. check ×100

In results, negative values indicate superiority over the susceptible check.

Categorization of Susceptibility/Resistance

Varieties/hybrids were categorized into six susceptibility/resistance classes based on the statistical formula, using mean per cent bud damage (X_i), grand mean ($\bar{X}$) and standard deviation (SD) (Gupta and Kapoor, 1997).

Sr. No.	Category	Code	Statistical formula
1.	Highly Resistant	HR	$X_i \leq (\bar{X} - 2SD)$
2.	Resistant	R	$(\bar{X} - SD) \geq X_i > (\bar{X} - 2SD)$
3.	Moderately Resistant	MR	$\bar{X} \geq X_i > (\bar{X} - SD)$
4.	Moderately Susceptible	MS	$\bar{X} < X_i \leq (\bar{X} + SD)$
5.	Susceptible	S	$(\bar{X} + SD) < X_i \leq (\bar{X} + 2SD)$
6.	Highly Susceptible	HS	$X_i > (\bar{X} + 2SD)$

Morphological, Biochemical and Nutritional Analysis

For correlation analysis, 10 buds were randomly selected from each variety/hybrid and bud length (mm) and diameter (mm) were measured using a digital Vernier caliper. Biochemical analysis of bud for eight parameters *viz.*, crude protein, total carbohydrate, reducing sugar, non-reducing sugar, total soluble sugar, crude fiber, total phenol and lipid were conducted using standard protocols (Thimmaiah 1999) at Food Quality Testing Laboratory, N. M. College of Agriculture, NAU, Navsari. As well, 11 nutritional attributes *viz.*, nitrogen, phosphorous, potassium, sulphur, calcium, magnesium, boron, iron, manganese, zinc and copper were estimated from leaf using standard protocols at Department of Soil Science, NAU, Navsari.

Statistical Analysis

Data were subjected to analysis of variance (ANOVA) appropriate for RBD with factorial arrangement over months and years. Per cent damage data were square root transformed before analysis for homogeneity of variance. Pooled analysis was performed across five years. Pearson correlation coefficients between pest damage and morpho-biochemical and nutritional parameters were computed using standard methods.

Results and discussion

Year-wise Varietal Performance

The significant differences ($p < 0.05$) were observed among varieties/hybrids for per cent bud damage in all five years (Tables 1-3; Fig. 2-3).

Year I (2020-21): Annual Mean bud damage (Table 1) was lowest in PKM-1 (9.16%) and PKM-3 (10.18%) and highest in Kalipatti (16.48%), followed by Cricket Ball (13.41%) and DHS-1 (13.04%). Peak damage occurred in May (PKM-4, 18.87%), December (Kalipatti, 20.21%) and January (Cricket Ball, 18.79%) (Fig. 2). PKM-1 and PKM-3 were -38.19-44.41% less susceptible than Kalipatti (Fig. 3).

Year II (2021-22): Kalipatti recorded the highest mean damage (12.14%) (Table 1), followed by DHS-2 (10.41%) and PKM-4 (10.02%), while CO-3 (7.66%), PKM-3 (7.77%) and PKM-1 (7.79%) showed the lowest infestation (-35.80 to -36.89% reduction over Kalipatti) (Fig. 2). Peak damage was observed in May (PKM-4: 13.11%) and June (Kalipatti: 16.25%, DHS-2: 15.34%) (Fig. 3).

Year III (2022-23): Minimum damage estimated in PKM-1 (9.01%) and CO-3 (9.67%) (Table 2), showing -32.74-37.32% lower susceptibility than Kalipatti, respectively (Fig. 2). The higher incidence was recorded in Kalipatti (14.38%) and DHS-2 (13.32%), with peaks in June (22.14% and 21.15%, respectively) (Fig. 3).

Year IV (2023-24): PKM-1 (8.25%) and CO-3 (8.55%) was least affected (-35.49–37.79% reduction), whereas Kalipatti (13.26%) and DHS-2 (12.12%) showed higher damage (Table 2; Fig. 2). Peak damage occurred in June (Kalipatti: 20.09%, DHS-2: 19.45%) (Fig. 3).

Year V (2024-25): PKM-1 recorded the lowest damage (6.98%), with -42.82% reduced susceptibility (Table 3; Fig. 2). The highest mean damage was observed in Kalipatti (12.21%) and DHS-2 (11.19%), with June peaks (19.94% and 18.66%, respectively) (Fig. 3).

Kalipatti consistently recorded the highest bud damage across all years, while PKM-1 and CO-3 showed the lowest damage levels. Among all 5 years, summer season damage (March-June) was slightly higher than winter (October-January) across all varieties/hybrids, wherein bud damage peaked in May-June during summer and in December-January during winter. March-June phase, which was 47.47% higher than October-January during 2022-23, the widest seasonal disparity and noted only 2.93% during 2020-21 across five years. The interaction between treatment and month (T×M) was non-significant in individual years, representing a standard competent rank of varieties across the flowering season.

Pooled of Five Years (2020-25)

The pooled analysis over five years (Table 3; Fig.1) demonstrated highly significant differences among varieties and PKM-1 (8.24%), CO-3 (8.98%) and PKM-3 (9.08%) exhibited the lowest damage. Kalipatti recorded the highest mean bud damage of 13.69%, followed by DHS-2 (11.84%) and DHS-1 (11.29%). Summer season damage was significantly greater (32.27%) than winter damage. The peak damage month was predominantly June for most varieties except PKM-4, DHS-1 and CO-3 (May) under pooled data, aligning with peak summer flowering.

The per cent variation in bud damage over Kalipatti showed that PKM-1 had the maximum reduction (-39.83%), followed by CO-3 (-34.42%) and PKM-3 (-33.66%) and slightly nearer to DHS-1 (-17.51%) and DHS-2 (-13.51%) (Fig. 3). These data clearly indicate that all tested varieties were less damaged than Kalipatti, with substantial variation between groups. The interaction of varieties with month of summer and winter (T×M) was significant, indicating variety-specific seasonal responses among them. The interaction of varieties with years (T×Y) was also significant, indicating that the relative varietal performance was influenced by year-to-year variation, possibly driven by inter-annual variation in flowering phenology and ecological circumstances.

Monthly Trend in Bud Damage

Monthly analysis (Fig. 4) revealed a progressive increase in bud damage from March to June during the summer season. In June, Kalipatti recorded the highest damage (19.21%), followed by DHS-2 (17.56%) and DHS-1 (15.68%). During winter, damage escalated from October to December, peaking in December before declining in January. The early-flowering varieties (PKM-4, DHS-1, DHS-2, Kalipatti, Cricket ball and CO-3) initiated flowering from March/October (co-incident with higher pest pressure), while PKM-1 and PKM-3 commenced flowering in April/November, when moth populations were building but not yet at peak (Table 4).

Categorization on Resistance/Susceptibility

Based on average bud damage (Fig. 5), pooled categorization placed PKM-1 as Resistant (R); PKM-3 and CO-3 as moderately resistant (MR); PKM-4, DHS-1, DHS-2 and Cricket ball as moderately susceptible (MS) and Kalipatti as susceptible (S). None of the varieties was categorized as highly resistant (HR) or highly susceptible (HS). The categorization based on peak bud damage (Fig. 6) yielded broadly similar results with PKM-1 and CO-3 as resistant; PKM-3 as moderately resistant; PKM-4, DHS-1, DHS-2 and Cricket ball as moderately susceptible and Kalipatti as susceptible, confirming robustness of findings.

Morphological, Biochemical and Nutritional Correlation

The correlation analysis (Table 5) revealed that bud diameter showed a significant positive correlation with both average ($r = 0.739$ at $p < 0.05$) and peak ($r = 0.735$ at $p < 0.05$) bud damage, suggesting that varieties (DHS-1, DHS-2 and Kalipatti) with wider buds (6.47 to 6.85 mm) are more susceptible. PKM-3, PKM-1 and CO-3 had lower bud diameter (5.91 to 6.04 mm) were less susceptible. Total carbohydrate content showed the highest significant negative correlation with both average ($r = -0.797$ at $p < 0.01$) and peak ($r = -0.804$ at $p < 0.01$) bud damage, indicating that varieties (PKM-1, PKM-3 and CO-3) with higher total carbohydrate (38.44 to 43.35%) concentrations in buds suffered less damage. Non-reducing sugar content also showed significant negative correlation ($r = -0.732$ at $p < 0.05$ for average; $r = -0.714$ at $p < 0.05$ for peak damage), signifying that varieties (CO-3, PKM-4 and PKM-3) with more non-reducing sugar (1.39 to 1.65%) concentrations in buds infested chiku moth damage. In contrast, bud length, crude protein, reducing sugar, total soluble sugar, crude fiber, total phenol and lipid did not show statistically significant correlation with bud damage.

In correlation matrix between leaf nutritional attributes and bud infestation (Table 6), phosphorus exhibited a significant negative correlation with both average ($r = -0.734$) and peak bud damage ($r = -0.724$) at $p < 0.05$, indicating that more phosphorus content may be associated with lessen susceptibility. Resistant varieties like PKM-1, CO-3 and PKM-3 had higher phosphorus content in leaf ranging from 0.22 to 0.31%, while Kalipatti, DHS-2 and DHS-1 possessed 0.12 to 0.19% phosphorus. Conversely, magnesium had highly significant positive correlation with both average ($r = 0.864$) and peak bud damage ($r = 0.838$) at $p < 0.01$ level. This indicates that varieties with higher leaf magnesium levels are considerably more susceptible to bud borer infestation. Kalipatti (0.38%), DHS-2 and DHS-1 (0.24%) had the elevated magnesium, while PKM-1 and CO-3 possessed lower content (0.14%), representing a remarkable part in chiku moth defenselessness. None of the other estimated micronutrients showed a significant correlation with either average or peak bud damage.

Discussion

The present multi-year investigation provides strong evidence for differential varietal susceptibility of sapota to chiku moth under HDP circumstances. The consistent superiority of PKM-1 in terms of lowest

bud damage across all five years and both seasons confirms its potential as a resistant variety for HDP agroforestry systems. These findings corroborate earlier reports from normal plantations (10×10 m) by Bisane and Naik (2016) and Bisane et al. (2026), indicating that the escape type resistance mechanism of PKM-1 is robust and not substantially influenced by planting density. They revealed differential susceptibility among varieties, with Kalipatti being consistently most susceptible and PKM-1 least susceptible under conventional planting. Our results corroborated those of Khambhu and Bisane (2017), who found in HDP (5×5 m) that DHS-2 and Kalipatti were considerably impacted, while PKM-1, PKM-4 and CO-3 showed lesser vulnerability. Additionally, they verified that summer time is when activity peaks.

Furthermore, PKM-1 was shown to be less sensitive to chiku moth in Saurashtra region of Gujarat, while Cricket ball were found to be very susceptible under normal spacing (Vaja et al. 2018). Similarly, Solanki et al. (2022) demonstrated that PKM-1 and CO-3 were showed comparatively lower damage, while Kalipatti and Cricket ball had higher susceptibility under both normal and HDP conditions, which aligns well with the present findings. Although HDP generally exacerbate infestation, varietal genetics again seem to be a decisive factor. The susceptibility of Kalipatti is consistent across all above mentioned reports in the literature and the current five-year pooled data further substantiate this. The high pest pressure on Kalipatti is of practical concern, as it remains the most widely cultivated commercial variety in Gujarat and western region of India. The findings suggest that Kalipatti-dominated high density orchards would require more intensive pest management interventions, particularly during peak activity months of May-June and December.

The higher summer season damage compared to winter, observed consistently across varieties, is attributable to peak month activity during the primary (summer) flowering flush when higher temperatures accelerate larval development and increase moth generations, as documented by Shukla and Patel (2011) who reported peak activity in May-June on flowers/buds. Furthermore, chiku moth activity has increased recently in South Gujarat region, especially in Kalipatti, where there are now two distinct infection peaks: May–June and December (Bisane 2019). In middle Gujarat, the higher incidence noticed between July to November on leaf and bud (Chaudhary et al. 2017). While earlier under North Gujarat condition, the infestation was appeared minimum in May, it increased gradually and reached maximum in September and then dropped down gradually (Hajare et al. 2012). The bud infestation was appeared more or less throughout the year in Chhattisgarh, wherein the minimum was observed during August, it increased gradually and reached maximum in October (Ghirtlahre et al. 2015).

Phenological synchrony has been shown to be a major component in seasonal damage variance and the alignment of sensitive bud/flower flush phenology with peak pest numbers appears to be the main cause of summer season harm. It's interesting to note that spacing seemed to have little impact on varietal sensitivity in the present situation, supporting the notion that genetic resistance is more important. June emerged as the primary peak activity month in the pooled analysis, which coincides with the late-summer primary flowering flush and transitional weather conditions (pre-monsoon heat and humidity) that favour rapid pest multiplication. This is consistent with observations by Sran and Sandhu (1979) who documented maximum larval infestation during the summer months in Punjab.

Cricket balls were found to be only moderately susceptible in the current study, despite earlier reports that they were more vulnerable in North Gujarat with common spacing (Patel 1996). According to a varietal study on leaf damage in Karnataka by Vijayaraghavendra and Basavanagoud (2017), the incidence of chiku moths was higher in Cricket Ball and Kalipatti and lower in DHS-1 and DHS-2. Damage was more common from August to November and less common from December to July. Localized pest dynamics or environmental interactions may be the cause of this geographical difference.

An intriguing morphological discovery is the strong positive connection between bud diameter and insect damage. For newborn larvae, wider bud widths may indicate a more accessible and resource-rich feeding location, making entry and establishing simpler. A morphological basis for differential resistance is supported by the fact that varieties with broader buds (DHS-1 and Kalipatti) were more vulnerable to damage than those with narrower buds (PKM-3 and CO-3). The susceptibility towards higher bud diameter in present investigation is demonstrated by Bisane et al. (2026) under normal spacing cultivation, wherein Cricket ball, DHS-1, DHS-2, Kirthibharti and Kalipatti varieties with advanced bud diameter were more susceptible to chiku moth, whereas Mohangootee, Chala collection-1, 2, 3 and Zumakhiya possessing comparatively smaller bud diameters were identified as tolerant. The mechanical benefit provided by a bigger bud size may offer easier entrance or a more encouraging micro-habitat for the caterpillar of chiku moth.

The significant negative association between total carbohydrate content and bud damage is remarkable from a host-plant resistance perspective. CO-3, PKM-3 and PKM-1 which had the higher total carbohydrate content in bud, while Kalipatti with the lowest total carbohydrate was most susceptible. This inverse relationship may specify that high carbohydrate concentrations alter osmotic potential or nutritional profile of buds in ways unfavourable to larval nutrition or survival. Higher carbohydrate content in plant may serve as an antibiosis/antixenosis mechanism against the pest. As reported earlier, flavonoid content, ascorbic acid, free amino acid, tannins content and phenols content were dependable variables for characterization of resistance in ridge gourd against melon fruit fly (Haldhar et al. 2015). The role of carbohydrates may be indirect through their impact on plant vigour and overall health. Non-reducing sugars, which also showed significant negative connection, include sucrose and certain oligosaccharides that may be indigestible or inhibitory to lepidopteran larvae. These findings provide a biochemical basis for resistance that warrants further investigation through feeding choice and larval performance assays.

Crude protein, reducing sugar, total soluble sugar, crude fiber, total phenol and lipid content did not show significant correlations with either average or peak bud damage. This advocates that the biochemical composition of bud is not a primary variable of susceptibility to chiku moth in the varieties investigation. This result is analogous with the findings of Bisane et al. (2026) revealed that there was non-significant correlation between eight biochemical contents and bud damage by chiku moth in sapota under normal spacing condition. This may be due to small margin in biochemical contents amongst hug 23 varieties/hybrids of sapota.

The notable strong positive association was observed with magnesium against chiku moth, being as a foliage feeder also. Magnesium as a micro-nutrient is a crucial constituent of the chlorophyll molecule and is key factor for plant photosynthesis. High magnesium intensity may boost leaf quality and lusciousness, making the plant more attractive to insect pests. Excess amount of magnesium may persuade imbalance with calcium and potassium uptake, excessive vegetative growth and can sometimes increase defenselessness by producing succulent tissues preferred by boring insects. Guo et al. (2024) expressed that magnesium deficiency induced leaf chlorosis and affected fruit quality in pomelo trees and that leaf magnesium concentration had the strong positive correlation with SPAD value. This depicts that magnesium is a decisive micro-nutrient for plant health point of view and its unevenness can have spilling effects on crop pest susceptibility.

The negative correlation between phosphorus and damage could be connected to its involvedness in energy transfer and the synthesis of secondary metabolites, some of which may act as feeding deterrents. Ample amount phosphorus level drives sturdy root initiation, cellular growth and the structural thickening of flower bud tissues. Yadav et al. (2020) demonstrated significant positive correlation with fruit size, average fruit weight, pulp:stone ratio, total soluble solids and Vitamin C, while negatively correlated with fruit firmness, acidity content and total phenolic content. This indicated that nutritional attributes play an important role in determining host plant resistance.

The non-significant relationship of bud damage with most of biochemical parameters slightly was unforeseen, as secondary metabolites such as phenolics are commonly accounted for host plant resistance (HPR) against herbivorous insects (War et al. 2012). Though, it is possible that the concentration levels in sapota buds are not within the effective range for resistance expression in present investigation. Future research targeting enzyme activity may provide deeper approach into the biochemical basis of resistance.

In the same way, non-significant association between bud damage and micro-nutrients, revealing that the intensity of these micro-nutrients in the leaf are not directly linked with susceptibility against chiku moth, but these elements are essential for plant health and various metabolic processes. This is related with findings from other plant-pest systems, where mineral nutrition may have a marginal role in determining susceptibility. Garantonakis et al. (2016) demonstrated that Bactrocera oleae damage caused significant modifications in phosphorus, potassium, iron and magnesium concentration in olive fruits, while an overall decreasing trend was observed for nitrogen. This exhibits that pest infestation can alter nutrient dynamics in plants, creating a response loop that may further influence susceptibility.

The commencement of delayed flowering in PKM-1 and PKM-3 during April vs. March for PKM-4, DHS-1, DHS-2, Kalipatti, Cricket ball and CO-3 may partly elucidate their relatively lower total bud damage, as chiku moth damage build-up during early March may not fully coincide with their peak flowering. Similar phenological escape mechanism has been noted in host-plant resistance study of Bisane et al. (2026) for chiku moth under normal spacing. Nevertheless, the consistently lesser infestation in CO-3 despite its early October flowering beginning, suggests that morphological and biochemical factors also play a

mix component, as evidenced by the correlation data. However, the current finding revealed that varietal grouping for chiku moth resistance/susceptibility was not changed by HDP circumstances compared to conventional spacing, signifying that host-associated resistance mechanisms are stout across planting spacing compactness. This has imperative and convenient implications for advocating resistant varieties in HDP orchards.

The year-to-year fluctuation in absolute damage levels (significant V×Y interaction) imitates the influence of annual ecological variability on chiku moth infestation. Year 2020-21 showed the higher cumulative damage, possibly reflecting more sympathetic pest circumstances, while forthcoming 2021-22 year showed the lowest. This chronological variability emphasizes the need for multi-year data to establish stable varietal rankings, which the present 5-year data set provides strongly.

PKM-1 and CO-3 were consistent performer as resistant varieties over a 5-year period justifies their recommendation for HDP systems where chiku moth management is a priority concern, the lack of any variety achieving highly resistant (HR) status highlights the need for ongoing germplasm evaluation and breeding efforts to identify or develop varieties with higher levels of chiku moth resistance. Unlike traditional 8 × 8 m or 10 × 10 m spacing, HDP at 5 × 5 m spacing produces a denser canopy that may alter the microhabitat for insect accumulation as stated by Solanki et al. (2022), sapota HDP suffer slightly higher due to chiku moth than conventional planting system. Given that even the most vulnerable variety (Kalipatti) did not attain highly susceptible cataloging, the current data point out that this possible HDP-associated risk can be managed by suitable variety selection. For farmers considering HDP-based sapota agroforestry, this is a positive outcome. Dhakar et al. (2023) also noted that multi-year varietal evaluation is crucial for consistent variety recommendations in sapota, which is borne out by the present 5-year dataset that reveals year-to-year variation in absolute damage levels while retaining consistent relative rankings.

Conclusion

This extensive five-year systematic study of eight sapota varieties/hybrids against chiku moth, *N. eugraphella* under HDP indicated PKM-1 as consistently the least susceptible variety, categorized as resistant and is recommended for HDP systems. CO-3 and PKM-3 were moderately resistant and can serve as alternate preference. Kalipatti, though commercially important was the most susceptible and may necessitate additional IPM interventions in HDP sapota orchard. Summer season (March-June) consistently exhibited higher bud damage than winter (October-January), with June and December as the peak activity month. Bud diameter was positively linked with damage, pointing to a structural vulnerability factor in sapota. Correspondingly, chiku moth damage was negatively associated with total carbohydrate and non-reducing sugar content of buds as well as phosphorus nutrition in leaf, while positively allied to magnesium micro-nutrient, signifying biochemical and nutritional mechanisms of resistance that merit further exploration. These long phase data-set endorse a scientific basis for variety-specific pest management recommendations in high density sapota agroforestry systems in tropical fruit-growing regions.

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Tables

Tables 1 to 6 are available in the Supplementary Files section.

Figures

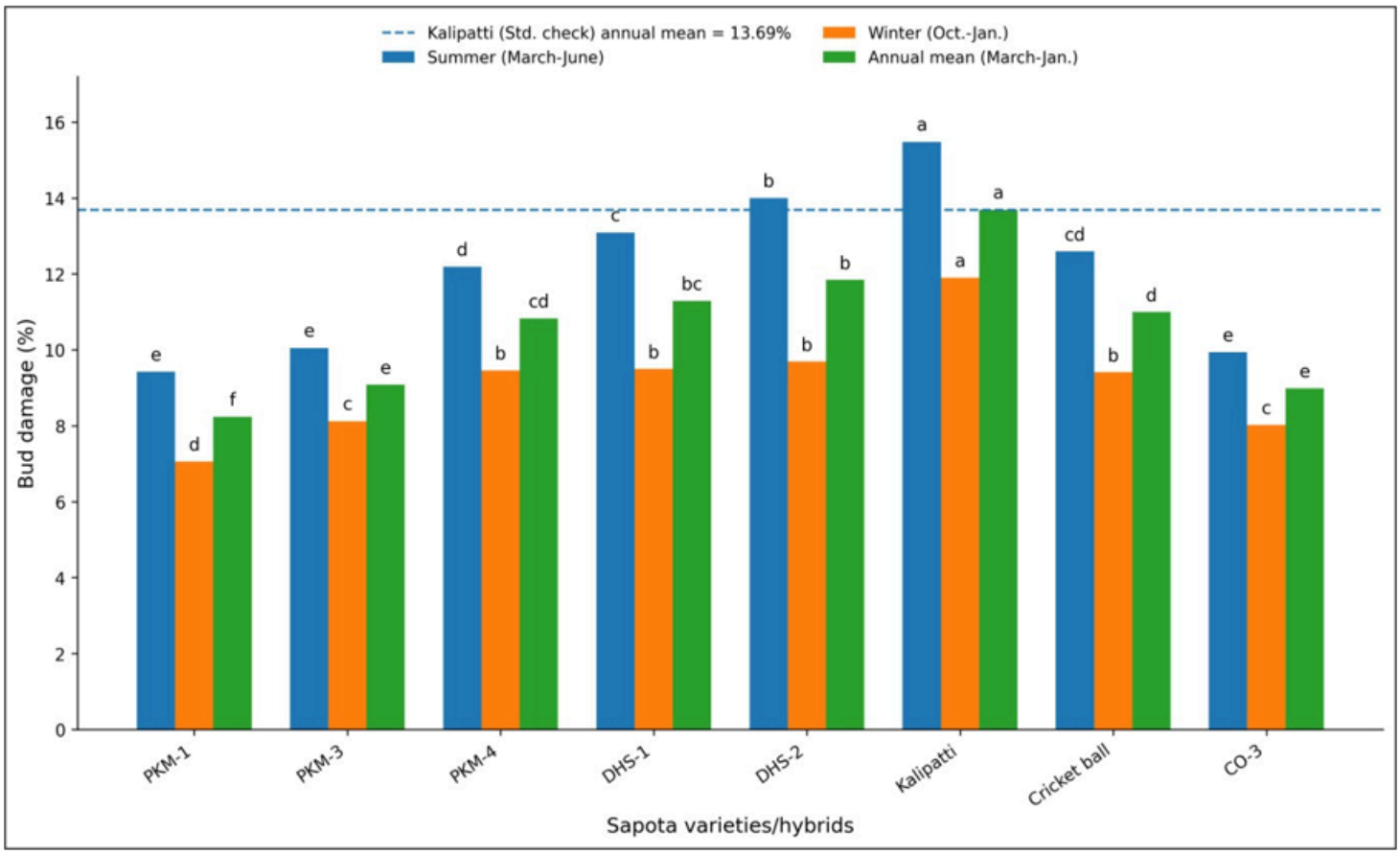


Figure 1

Cumulative per cent bud damage by chiku moth in different sapota varieties/hybrids under HDP (2020-25)

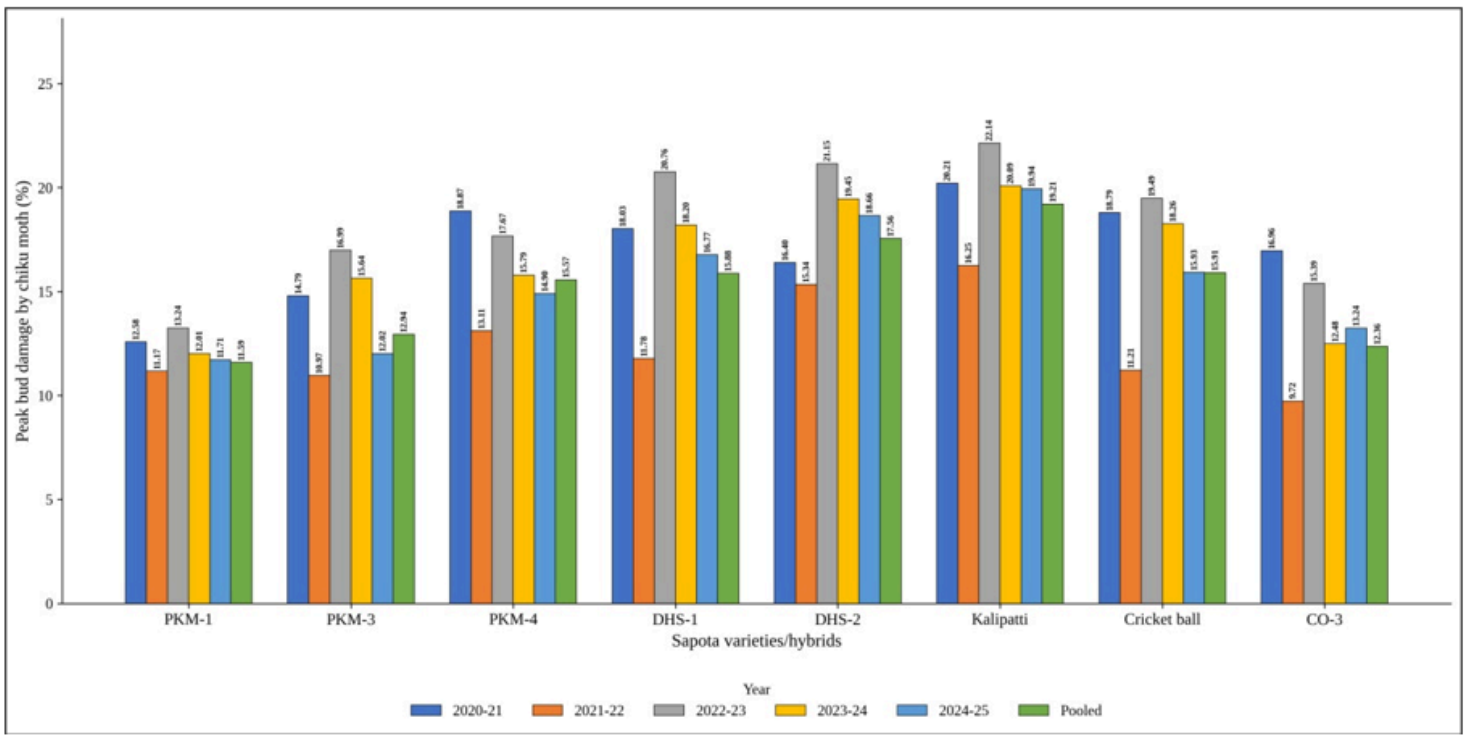


Figure 2

Peak per cent bud damage by chiku moth in different sapota varieties/hybrids under HDP (2020-25)

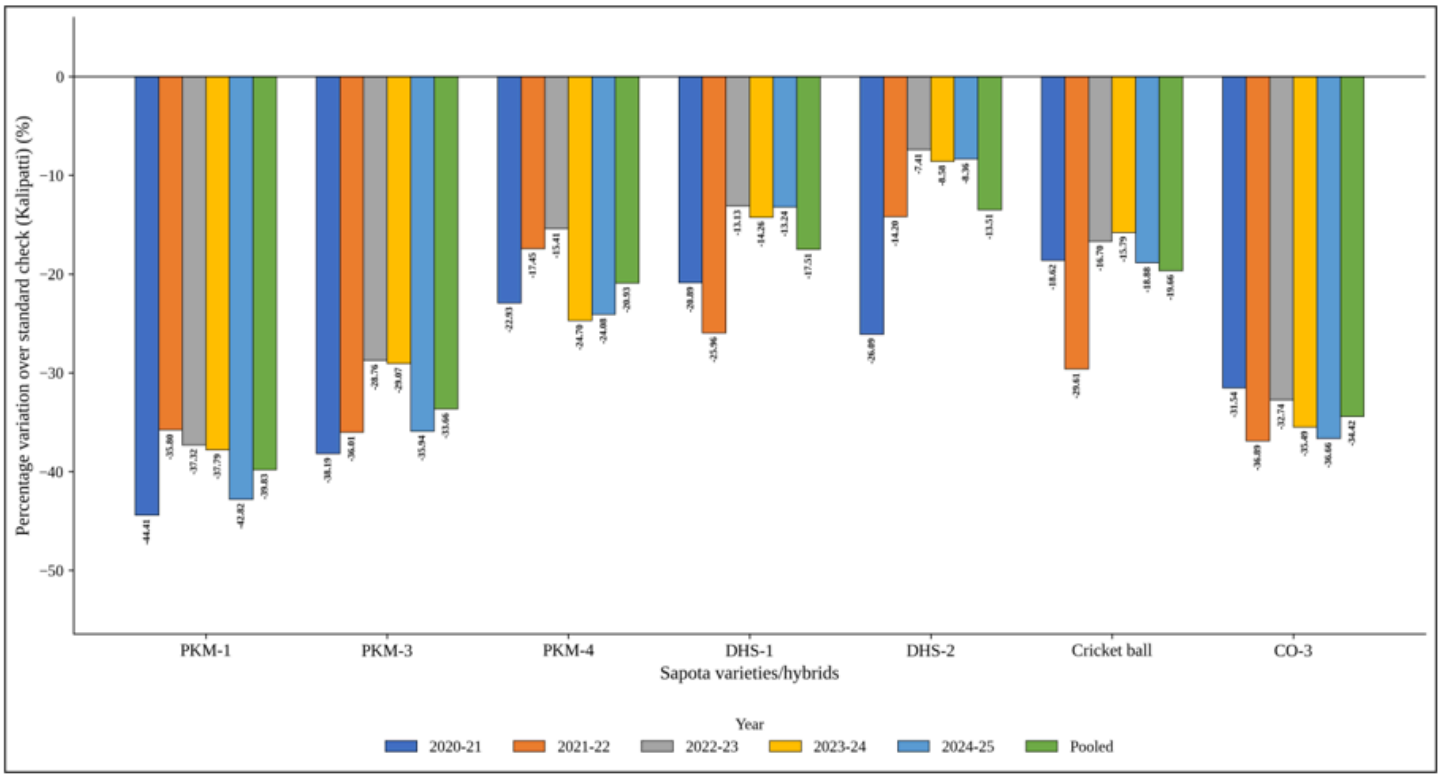


Figure 3

Percent variation in bud damage over Kalipatti (Standard check) by chiku moth in different sapota varieties/hybrids under HDP (2020-25)

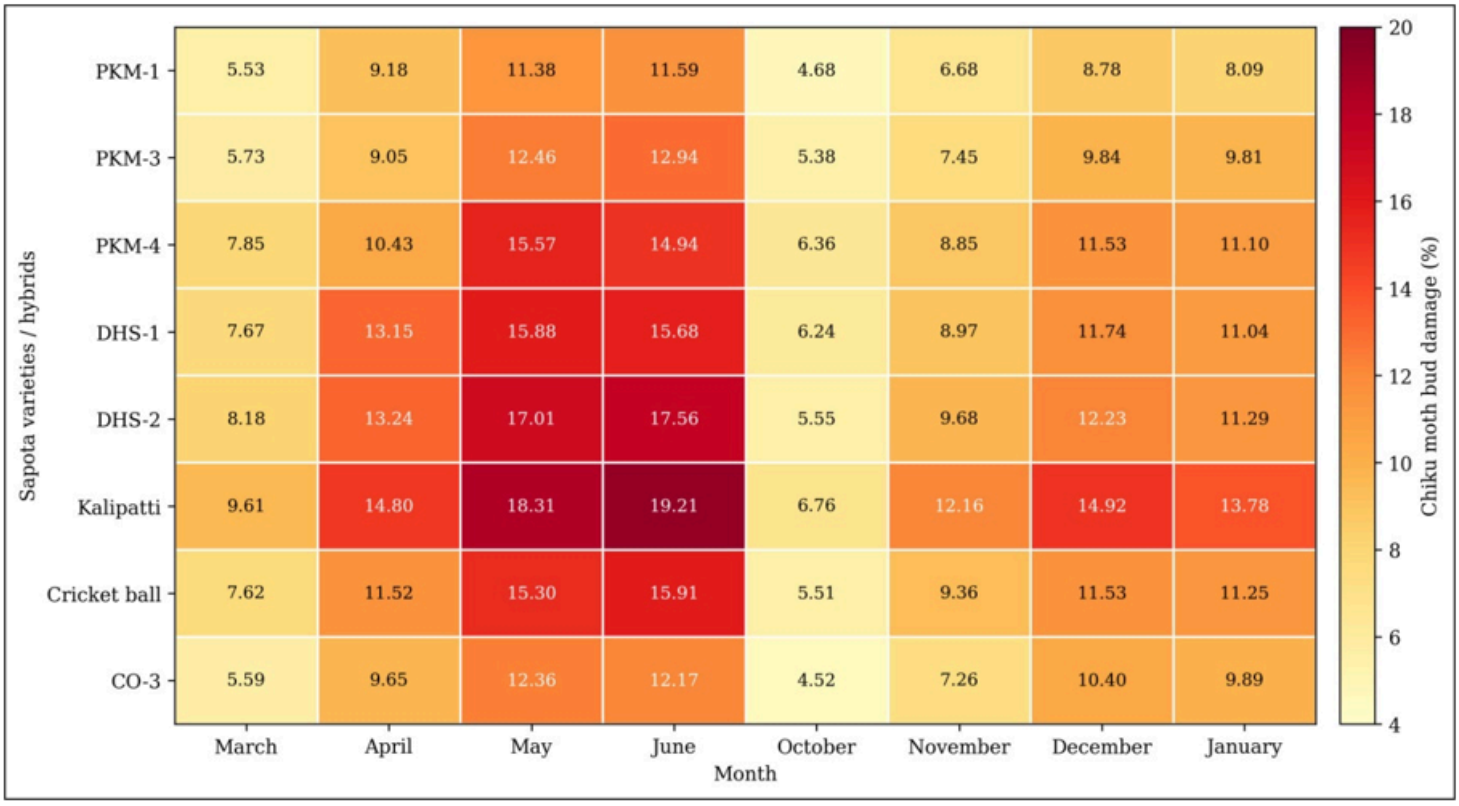


Figure 4

Monthly trend of cumulative per cent bud damage by chiku moth in different sapota varieties/hybrids under HDP (Pooled of 5 Years)



Figure 5

Categorization map of different sapota varieties/hybrids against chiku moth based on average bud damage under HDP (2020-25)



Figure 6

Categorization map of different sapota varieties/hybrids against chiku moth based on peak bud damage under HDP (2020-25)

Supplementary Files

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