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PROSPECTS OF PINEAPPLE CULTIVATION UNDER POLYHOUSE IN COASTAL ZONES OF INDIA

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Abstract

The growth and development of pineapple plants and it's response to different flower induction chemicals inside polyhouse microclimatic conditions were studied in hot-humid coastal conditions during 2017-18 at ICAR-CCARI, Goa. The existing naturally ventilated double-span polyhouse was structurally modified to accommodate heavy rainfall, and the additional space created on both sides was utilized to grow pineapple plants with fertigation and flower induction treatment. The day temperature (37.00-42.50ºC) and night temperature (12.16-22.87ºC) inside the polyhouse were higher than the ambient conditions throughout the growing period of the crop (31.94-34.16ºC and 19.65-24.46ºC, respectively). The relative humidity inside the polyhouse ranged from 50.75-97.85%, whereas in ambient conditions, it was 37.75-91.90%. Among the different flower induction treatments, the ethephon 25 ppm+urea 2% + sodium carbonate 0.04% treatment was the most effective with the earliest flowering (33.33 days), which was 15.11 days ahead of the control (48.44 days). Pineapple can be successfully grown inside an existing polyhouse to utilize the additional spaces with fertigation and flower induction with a 50 ml solution of ethephon 25 ppm + urea 2% + sodium carbonate 0.04% with a B: C ratio of 1.15.

Introduction

Protected cultivation or controlled environment agriculture is the intensive production of high-value horticulture crops (Sabir and Singh 2013). It promises the quality production, successful propagation, and hardening of plants along with efficiently utilizing land, water, and nutrients (Singh 2018). Protected cultivation has gained momentum in the past two decades, and presently India has a two-lakh-hectare area under protected cultivation (Singh 2024). The high initial cost of establishment limits the spread of protected cultivation in India (Singh *et al*. 2020). According to Kaur and Ranguwal (2021), an investment of ₹ 37.40 lakhs per acre is required for the establishment of protected structures.

In Goa, conventional protected structures require modifications to suit the agroclimatic situations of the heavy rainfall of the west coast region. High-value vegetables and cut flowers are mostly cultivated in protected structures in western India (Pachiyppan *et al.* 2022). Tropical fruit crops like banana and papaya can be successfully grown inside the polyhouses (Junior *et al.* 2010, Reddy and Gowda 2014, Prakash *et al*. 2015, Darini 2016). Pineapple is another important tropical fruit crop with commercial significance in the coastal regions of India (Priya Devi *et al*. 2013), which is usually cultivated as an intercrop in coconut and arecanut gardens, and unique homestead farms (*kulagars*) (Maneesha *et al.* 2019). The optimum temperature for the growth of pineapple is 25-32°C during the daytime and 15-20°C during the night, and it is generally cultivated in a rainfall range of 600-3500mm (Robert and Odilo 2011). It is a hardy crop; however, open field cultivation is threatened by summer rain, causing price reduction in pineapple at Vazhakkulam, the pineapple hub of Kerala, causing a loss of approximately 200 crores (Thomas and Dinesh 2020).

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Flowering in pineapple is a major problem since natural flowering is not advisable as it leads to a staggered harvest (Cunha *et al.* 2003). In many cases, natural flowering is prevented by spraying chemical analogs of growth hormones, and flower forcing or flower induction is practiced, inducing uniform flowering (Cunha *et al.* 2003, Cunha 2005).

ICAR-CCARI, Goa, recommended structural modifications to overcome the issues due to the heavy rainfall (ICAR-CCARI Annual Report 2013). After the structural modification, the space created on both sides of the polyhouses can be well utilized to cultivate crops other than the main crop, which requires limited resources and less care, and provides high income along with the main crops. Hence, this experiment was conducted to understand the influence of polyhouse microclimate and external application of plant hormones on the earliness and uniformity of flowering, yield, and quality of pineapple crops, along with the economic viability of production practices.

Materials and Methods

The experiment was conducted in ICAR-Central Coastal Agricultural Research Institute, Old Goa (15°48'58" N; Longitude, 73°92'29" E; Latitude, Altitude: 18.60 MSL) during 2017-18. The existing naturally ventilated double-span polyhouse (100 m^2 area in N-S direction, made of UV-stabilized plastic films with 70% light transmission) was structurally modified, and raised beds were prepared in the extra spaces. Pineapple suckers of the variety 'Giant Kew' were planted in double rows with 45 × 45 cm spacing. Plants were fertigated with a recommended dose of fertilizers (12:4:12 g NPK $plant^{-1}cycle^{-1}$). Temperature, humidity, and dew point temperature were recorded by the temperature humidity data logger (EL-USB-2, Lascar Electronics, Essex, UK) installed inside the polyhouse.

Pineapple plant growth parameters were recorded at the early vegetative stage (0-6 months), late vegetative stages (7-9 months), and flowering stage (10- 11 months). The flower induction experiment was designed in a completely randomized design (CRD) with seven treatments *viz.*, T_1: Ethephon 25ppm+ urea 2%+ sodium carbonate (0.04%), T_2: NAA 10 ppm, T_3: NAA.25 ppm, T_4: NAA 50 ppm, T_5: Paclobutrazol 10 ppm, T_6: Paclobutrazol 25 ppm and T_7: Control (water). The treatment solutions (50ml) were poured into the central cup of each plant during evening hours. The number of days taken for flower initiation and development, fruit yield, and quality characters was recorded.

The experimental data were analyzed with a 0.05 probability level using WASP 2.0, a statistical software of ICAR-CCARI, Goa, and the economics of production were calculated based on the operational charges since the experiment was carried out in an existing polyhouse. The amounts in USD were estimated @ 1US $ = ₹86.00. The B: C ratio was calculated as per the standard formulae using gross and net returns and the total cost of production of pineapple under polyhouse conditions.

Results and Discussion

Polyhouse microclimatic conditions varied from the ambient conditions throughout the study during different growth stages of the pineapple crop. The day temperature was higher inside the polyhouse than in the ambient due to the trapping of solar radiation inside the polyhouse (Sharma *et al*. 2024). In naturally ventilated polyhouses, the night temperature was always less than the ambient temperature inside the polyhouse due to the entry of cool air inside (Santhosh and Maitra 2021). During the early vegetative stage, the temperature ranged from 22.87 to 42.5°C (Table 1). Ambient temperature during this period ranged from 24.46 to 31.94°C. Pineapple is a Crassulacean Acid Metabolism (CAM) plant, and photosynthesis happens during the night

(Counto *et al.* 2016). According to Hartwell *et al.* (1999), this temporal control is managed by the nocturnally activated enzyme, Phosphoenolpyruvate carboxykinase (PEPCK). Similarly, during the late vegetative stage, the temperature ranged from 18 to 40.5°C, whereas the ambient temperature was 23.97 to 32.50°C. Flower induction chemicals were applied during the evening hours to ensure effective absorption *via* stomata. During the flowering phase, the temperature range was 12.16 to 37.00°C, and during the fruiting stage, it was 16 to 42.27°C. The corresponding ambient temperature ranges were 19.65 to 33.70°C and 23.18 to 34.16°C, respectively. Hemmings *et al.* (2020) also reported variations in microclimate inside the greenhouse to the ambient conditions during the cropping season.

Table 1. Temperature and humidity inside and outside the polyhouse during the growth stages of the pineapple crop.

Environmental parameters	Temperature (°C)				Relative humidity (%)			
	Inside polyhouse		Ambient condition		Inside polyhouse		Ambient condition	
Crop stages and periods	Min. (night)	Max. (day)	Min. (night)	Max. (day)	7.00 am	2.00 pm	7.34 am	2.34 pm
Early vegetative stage (April-August, 2017)	22.87	42.50	24.46	31.94	96.12	69.79	91.52	71.24
Late vegetative stage (September-November, 2017)	18.00	40.50	23.97	32.50	97.85	66.08	91.90	64.70
Flowering stage (December 2017- January 2018)	12.16	37.00	19.65	33.70	92.31	50.75	82.25	37.75
Fruiting stage (February- June 2018)	16.00	42.27	23.18	34.16	90.95	58.02	86.68	55.55

Relative humidity influences plant growth by regulating stomatal growth and also the uptake of nutrients (Roriz *et al.* 2014). Relative humidity inside the polyhouse was higher than outside during all the stages of pineapple crop growth. During the early vegetative stage, it ranged from 69.79 to 96.12% inside the polyhouse and 71.24 to 91.52% outside the polyhouse. During the late vegetative stage, relative humidity was 66.08 to 97.85% inside and 64.70 to 91.90% outside the polyhouse. During flowering time, relative humidity ranged from 50.75 to 92.31% inside the polyhouse and 37.75 to 82.25% under ambient conditions. Relative humidity ranged from 58.02 to 90.95% inside and 55.55 to 86.68% outside the polyhouse during the fruit developmental stages.

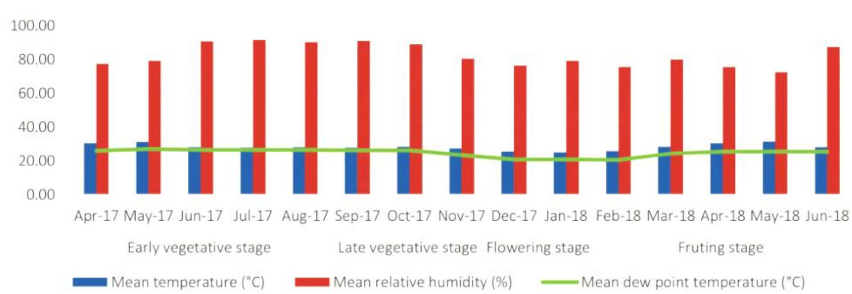

Fig. 1. Monthly mean microclimate conditions inside the polyhouse during the growth stages of the pineapple crop.

The monthly mean temperature during the early vegetative stage of pineapple ranged from 27.92 (July) to 31.23°C (May) and 27.38 (November) to 28.47°C (October) (Fig. 1). During the flowering months, the mean monthly temperature inside the polyhouse was more than 25°C (December 25.68°C, January 25.09°C) but the night temperature was 12.16°C. In the fruiting stage, the lowest monthly mean temperature was 25.77°C (February 2018) and the highest 31.49°C (May 2018). Relative humidity inside the polyhouse ranged from 77.29% (April) to 91.37% (July) during the early vegetative stage, and during the late vegetative stage, it ranged from 80.48% (November) to 90.87% (September). During December- January (flowering period) monthly mean relative humidity was 76.28 to 79.15%. During fruit development, relative humidity was the highest in June 2018 (87.34%) and the lowest in May 2018 (75.64%). The dew point is the temperature at which the air holds the maximum moisture content and beyond which it falls as drops, so it directly affects the relative humidity (Shreshta *et al.* 2019), and high temperature, along with high relative humidity, raises susceptibility to pests and diseases (FAO 2024). The mean monthly dew point temperature during early and late vegetative stages was 25.77 °C (April) to 26.85°C (May) and 23.19 °C (November) to 26.22°C (October). During the flowering stage, it was 20.63 to 20.71°C (December 2017- January 2018). During fruit development, the dew point temperature was the highest in June 2018 (25.47°C) and the lowest in February (20.54°C). The effects of high and low values of temperature, light intensity, and relative humidity on plant growth and metabolism are reviewed by Ferrante and Mariani (2018). The long-term study on the influence of climate parameters on pineapple crop production revealed that temperature and rainfall influenced crop production, but 82% of the yield fluctuation was due to variation in minimum temperature (Williams *et al.* 2017). Plant height was the highest in the late vegetative stage (September-November, 2017) followed by the flowering stage (December, 2017-January, 2018) (Fig. 2). Plant spread (134.38 cm), number of leaves (41.37), and leaf length (103.46 cm) were the highest during the flowering season. Favourable environmental conditions, protection from pests, diseases, and weeds, and fertigation might have helped the luxurious growth of the plants inside the polyhouse. Couto *et al.* (2016) reported the possibility of higher growth of pineapple inside the greenhouse due to the stress factors. The responses of plants to temperature affect the crop duration and yield (Santosh and Maitra 2021), and light mostly affects crop growth (Maitra *et al.* 2020).

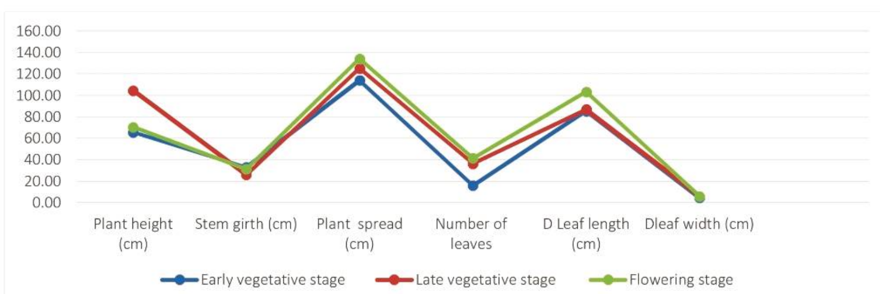

Fig. 2. Biometric parameters of the pineapple crop in different growth stages under polyhouse conditions.

Faster flower initiation inside the polyhouse was observed in pineapple plants treated with Ethephon 25 ppm+ urea 2%+ sodium carbonate (0.04%) (33.33 days), and the longest time was taken in the control (48.44 days) (Table 2). Ethephon treatment induced floral initiation at 49.11 days in open-field pineapple cultivation (Maneesha 2019). In this experiment, all the treatments rendered flowering in pineapple, but ethephon-treated plants induced flowers 15.11 days in advance of the control. Hussain *et al.* (2008) and Maneesha *et al.* (2022) also reported similar effects of ethephon on flower induction in pineapple.

Flower induction in pineapple occurs due to the changes in the endogenous auxin levels, due to the ethylene hormone (Cunha 2005). Ethephon releases ethylene gas when mixed in water along with urea and sodium carbonate. The addition of sodium carbonate and urea helps to adjust the pH of the treatment solution between 8 to 10 for the fast release of ethylene gas and thus improve the effectiveness of flower induction (Cunha *et al.* 2003, Cunha 2005). Ethephon applied in combination with urea and calcium or sodium carbonate speeds up the rate of release of ethylene and induces flowering in pineapple (Dass *et al.* 1976, Balakrishnan *et al.* 1978).

Table 2. Effect of flower induction treatments on the flowering of the pineapple crop.

Treatments	Days for the open heart stage	Days for inflorescence emergence	Days for anthesis	Days for full bloom
T_1: Ethephon 25ppm+ urea 2%+ sodium carbonate (0.04%)	33.33^{d}	41.85^{c}	56.31^{c}	72.90^{b}
T_2: NAA 10 ppm	43.08^{bc}	50.04^{b}	59.58^{bc}	73.77^{b}
T_3: NAA 25 ppm	41.67^{bc}	48.58^{b}	58.63^{bc}	74.83^{b}
T_4: NAA 50 ppm	40.77^{c}	47.54^{b}	56.60^{c}	73.96^{b}
T_5: Paclobutrazol 10 ppm	41.31^{c}	47.00^{b}	56.96^{c}	71.88^{b}
T_6: Paclobutrazol 25 ppm	44.50^{b}	49.67^{b}	61.50^{b}	82.15^{a}
T_7: Control	48.44^{a}	56.04^{a}	66.46^{a}	83.38^{a}
$CD_{(0.05)}$	3.09	3.65	3.68	4.63
MSE	1.78	2.11	2.12	2.67

*Means do not share some letter/s are significantly different.

According to Santhosh *et al.* (2023), crop growth, yield, and productivity can be enhanced by modifying the microclimatic conditions of the polyhouses. In open conditions, pineapple plants treated with ethephon produce significantly higher yields than NAA (Selamat *et al.* 2005, Maneesha *et al.* 2022). In this study, flower induction treatments did not significantly influence fruit weight and crown weight. Among the treatments, fruit weight varied from 1.37 to 1.80 kg, and crown weight varied from 0.35 to 0.58kg (Table 3). The application of flower induction chemicals significantly influenced fruit circumference. Application of NAA 25 ppm increased the fruit circumference to 42 cm. External application of auxins can improve fruit size due to the enlargement of cells (Pattison *et al.* 2014). The T.S.S. was not affected by the treatments, but the acidity was reduced by the application of paclobutrazol 25 ppm (0.55%), which was on par with the application of NAA 10 ppm (0.62%). T.S.S./acid ratio was also the highest in NAA ppm (24.79) and paclobutrazol 25 ppm (23.75). Flower induction treatment had no significant effect on the yield and sweetness of the fruits. Increased vegetative growth and crown growth under the congenial conditions of the polyhouse had affected the fruit size as well as the quality of the fruits. Optimizing the pineapple plant shoot mass can help in managing plant timeline, yield, quality, and market potential (Hung *et al.* 2024).

The operational cost of pineapple cultivation inside an existing polyhouse ($100m^2$) with fertigation facilities consists of the cost of planting materials, fertilizer costs, flower induction treatment charges, and labor charges. The total operational cost was estimated to be ₹10424 ($121.21) (Table 4). The cost of flower induction was ₹1165.84 ($13.56). The total return from polyhouse pineapple production was calculated considering the mean fruit weight, 1.6 kg $plant^{-1}$, and the market price as ₹35.00 kg^{-1}. The gross return from the polyhouse production of pineapple was ₹22400.00 ($260.47), and the net return was ₹11975.45 ($169.25). The B: C ratio was 1.15. Hence, the polyhouse production of pineapple is profitable in an existing polyhouse.

Table 3. Effect of flower induction treatments on fruit yield and quality of pineapple.

Treatments	Fruit weight (kg)	Crown weight (kg)	Fruit length (cm)	Fruit Circ.(cm)	T.S.S. (ºBrix)	Acidity (%)	T.S.S./ acidity
T_1: Ethephon 25ppm+ urea 2%+ sodium carbonate (0.04%)	1.48	0.35	19.02	41.33^{ab}	14.13	0.73^{a}	19.57^{b}
T_2: NAA 10 ppm	1.58	0.48	18.00	38.00^{cd}	15.17	0.62^{b}	24.79^{a}
T_3: NAA 25ppm	1.75	0.52	18.92	42.00^{a}	14.67	0.80^{a}	18.32^{bc}
T_4: NAA 50ppm	1.80	0.53	18.67	40.67^{abc}	13.00	0.81^{a}	16.16^{c}
T_5: Paclobutrazol 10 ppm	1.45	0.58	16.25	36.83^{d}	14.40	0.83^{a}	17.51^{bca}
T_6: Paclobutrazol 25 ppm	1.68	0.55	18.25	38.67^{bcd}	13.00	0.55^{b}	23.75^{a}
T_7: Control	1.37	0.45	18.07	37.17^{d}	12.67	0.78^{a}	16.24^{c}
CD $_{(0.05)}$	NS	NS	NS	3.16	NS	1.00	3.18
MSE	0.23	0.10	0.13	1.82	1.08	0.05	1.83

*Means do not share some letter/s are significantly different.

Table 4. Estimated cost-economics of pineapple cultivation inside an existing 100 m^2 polyhouse.

Expenditure (operating costs)	INR (₹)	USD ($)
i. Pineapple suckers 494 nos. @ ₹5.00 $sucker^{-1}$	2470.00	28.72
ii. Fertilizers (12:4:12 g NPK $plant^{-1}$)		
Urea (46 % N): 26.09kg @ ₹5.36 kg^{-1}	139.83	1.63
Rock phosphate (18 % P_2O_5): 22.22 kg @ ₹8.50 kg^{-1}	188.89	2.20
Muriate of Potash (60 % K_2O): 20 kg @ ₹18 kg^{-1}	360.00	4.29
iii. Flower induction chemical charges	1165.84	13.56
iv. Electricity charges	100.00	1.16
v. Labour charges- 10 man-days @ ₹600 day^{-1}	6000.00	69.77
Total expenditure	10424.00	121.21
Returns		
Yield @ 1.6kg $plant^{-1}$	640.00	7.44
i. Gross return @ ₹35.00 kg^{-1}	22400.00	260.47
ii. Net returns (Gross returns- Total expenditure)	11975.45	139.25
iii. B: C ratio (Net returns/ Total expenditure)	1.15	1.15

Polyhouse microclimatic conditions were favourable for the growth and development of the pineapple crop in Goa. The unexpected rain damage during pineapple harvest and staggered flowering can be managed by polyhouse cultivation of pineapple. Ethephon induced early flowering that was 15.11 days in advance of the untreated control; however, it had no significant effect on the yield and quality of fruits. Polyhouse cultivation of pineapple was economical and can be recommended as an alternative crop to utilize underutilized polyhouses and unused spaces of structurally modified polyhouses.

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