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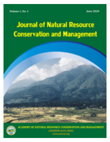

Estimating heat use efficiency in mango under subtropical climate

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ABSTRACT

The subtropical climate in Lucknow, Uttar Pradesh, affects the mango production and heat use efficiency. The latest information on the 2020, 2021, and 2022 fruiting seasons showed the variability in thermal indices like growing degree days, heliothermal unit, and photothermal unit. It was inferred from the scientific analysis that indeed, there was variability in thermal regimes at vegetative, flowering, pea, marble, and maturity phases in mango from 2020 to 2022. Recent data of climatic indicators like maximum and minimum temperatures varied between 16.43 to 44.21°C and 4.00 to 27.21°C respectively. Relative humidity had variations of 64.57 to 95.86 and 34.00 to 78.86 percent; evaporation of 2.53 to 10.06 mm/day with bright sunshine hours of 0.902 to 10.70 h across three seasons. Mean values of GDD, HTU, and PTU at maturity were noted as 1818.47 to 2140.15°Cd, 14332.38 to 17510.49°Cdh, and 30964.82 to 36581.19°Cdh respectively across 2020 to 2022. Considering all these indices, the heat use efficiency was estimated at 1.87 to 6.08 g/m^2/°Cd; 0.23 to 0.77 g/m^2/°Cdh and 0.14 to 0.45 g/m^2/°Cdh at subtropical condition. Such scientific analysis is needed to understand the soil-tree-weather interactions *vis-à-vis* fruit yield in a particular natural resource management zone.

Keywords: Dashehari mango, growing degree days, heliothermal unit, photothermal unit, climatic indicators, heat use efficiency

INTRODUCTION

The energy-matter interaction occurring within an agroecosystem needs to be quantified to have an understanding of climatic responses to the existing production ecosystem. Adak *et al*. (2022) quantified the water use efficiency under subtropical climates to optimize water practices in mango. Knowledge of weather indicators, their dynamics, and their effects on tree functions is of great value for evaluating tree-climate interaction at a particular zonal area. Thus, the variability of weather indicators over the season invariably be assessed to record their dynamic characteristics. Recently, Rötzer *et al.* (2021) quantified 22.8±10.2 to 48.4±17.5 kg CO_2 fixation per year as an ecosystem service by trees. It is often observed that trees respond differently to a weather situation and also found that the phenological characteristics are impacted by climatic vulnerability. The reproductive phase of mango is very sensitive to heat regimes. It is noted that flowering of the same cultivar is different at varied thermal and heat regimes. The rate of fruit set and fruit growth act as a function of thermal indices that prevailed over the period in a particular location. The variability of these indices strongly influences the phenological response and thereby changes in heat use efficiency were observed. Haukka *et al.* (2013) confirmed that soil types and climates had a significant effect on flowering trends. Lorite *et al.* (2020) explained that variability of weather factors had impacts on either advancement or delayed in full bloom in almond or warmer conditions potentially affecting yields also. Benlloch-Gonzalez *et al.* (2018) experimentally recorded that four degrees above the atmospheric temperature, the percentages of fertile flowers were 6.4, 75.6, and 39.5 as compared to the existing atmospheric temperature (23.9, 93.9, and 40.4 percent) with the advancement of flowering timing. Moreover, the fruit set was reduced to the tune of 1.9 to 34 percent. The climate vulnerability is statistically sound to affect the heat or chilling accumulation or hampered flowering in olive due to temperature extremisms as observed by Gabaldón-Leal *et al.* (2017). Further, the chances of seventeen-day advancements in olive flowering timing were also predicted. The rate of heat accumulation at a particular phase again varied due to the ambient situation. Scientific analysis suggested that the weather indicators impact profusely on the net assimilation rate, flowering pattern, pea and marble stage of fruit development. Even, maturity is also affected due to various climatic interactions. All these climatic-tree interactions have immense implications on farm output and the economy of farmers. Even, on a larger scale, over-districts, the farm output, and its associated economy are statistically linked to growers' livelihood. The evapotranspiration in orange orchards was estimated under semi-arid Mediterranean climates to foster growers' precise resource management (Consoli and Papa, 2013) while Pocas *et al.* (2014) generated information on evapotranspiration using satellite-based systems in the super-intensive olive orchard to provide accurate moisture regimes. In a recent analysis, decreasing trends of sensitivity to climate change are observed due to improvements in crop diversification and cropping intensity in a particular district over subsequent years of initiatives. Interestingly, vulnerability trends to climatic change in a particular district may be lowest because of a lower exposure index and statistically lower sensitivity (Chadha and Srivastava, 2022). Rangare *et al.* (2022) recorded 21.6 to 37.6 and 34.1 to 46.0°C low and high maximum temperature during the flowering, pea, and marble to maturity phase in Langra mango. The lowest and highest minimum temperatures and relative humidity of 4.1 to 21.6 and 17.1 to 32.6°C; 76.6 to 28.9 and 100 to 79.4 percent respectively were noted. All these weather interactions had an impact on the flower sex ratio *vis-à-vis* 5 to 7.2 t/ha yield variations in Langra mango. The current study indicated the lack of information on the climatic indicators variability over Lucknow district and its effect on the reproductive phases of mango. Information on thermal indices and heat use efficiency in Dashehari mango was lacking and therefore in the present scientific analysis, the latest information was generated in subtropical zones of Uttar Pradesh.

MATERIAL AND METHODS

The current study of estimating the variability of tree phenophases *vis-à-vis* thermal indices in mango cv Dashehari was quantified following systematic analysis in seasons of 2020, 2021, and 2022 at ICAR-CISH, Rehmankhera, Lucknow, UP. The experimental field consists of Mango cv. Dashehari trees at a spacing of 10×10 m were planted under sandy loam soil conditions. The experimental location had a subtropical climate with dry hot summers and extended cold winter periods. Recent data on climatic indicators were noted down from the agrometeorological observatory and weekly mean data were computed at each vegetative and reproductive phase. Almost all the weather indicators like maximum and minimum temperatures, maximum and minimum relative humidity, bright sunshine hours, wind speed, rainfall, and evaporation were generated and used in the study. Univariate statistical analyses of these data were presented in tabular forms. Three thermal indices growing degree days (GDD), heliothermal (HTU), and Photothermal (PTU) were calculated for this location using information on weather variables from the years 2020, 2021, and 2022 based on standard methodology. Weekly averaged datasets were computed at vegetative, flowering, fruit set and its development. The latest information on flowering, fruit set, pea, and marble stages with maturity was presented in graphs. Variability in reproductive phases was depicted in the Figures. Yields were recorded and heat use efficiency was estimated for 2020, 2021, and 2022. The variability of HUE was also presented in graphical forms. All recent information was employed to find out the responses of climate-tree interactions at the subtropical zone.

RESULTS AND DISCUSSION

Variability of climatic indicators at critical phenophases over mango belt

Analysis of climatic indicators was performed scientifically and showed wider variability over the mango production seasons of 2020, 2021, and 2022 (Table 1). Recent data indicated 18.31±2.78 to 39.17±1.91°C mean weekly T_{max} (maximum temperature) with ranges from 16.43 to 44.21°C (pooled of 2020 to 2022). In the case of T_{min} (minimum temperature) weekly mean of 5.86±1.12 to 26.31±1.23°C having ranges of 4.93 to 27.21°C. It was inferred from the univariate statistical analysis that the maximum and minimum relative humidity (RH) varied between 64.57 to 95.86 and 34.00 to

Table 1. Climatic indicators during mango production seasons (Pooled of 2020, 2021, and 2022) at Rehmankhera, Lucknow, UP

Std	Tmax	Range			Tmin	Range			RH m	Range			RH e	Range		
week	Mean	Max	Min	Skewness	Mean	Max	Min	Skewness	Mean	Max	Min	Skewness	Mean	Max	Min	Skewness
1	21.90±1.45	23.57	21.00	1.71	7.64±0.62	8.07	6.93	-1.63	89.14±2.40	91.00	86.43	-1.40	67.95±6.62	75.57	63.57	1.67
2	19.24±1.84	21.36	18.00	1.66	7.52±1.65	9.43	6.50	1.72	90.86±0.38	91.29	90.57	1.46	67.10±4.08	71.57	63.57	0.99
3	18.31±2.78	21.50	16.43	1.65	6.29±1.66	8.14	4.93	1.23	90.00±0.25	90.14	89.71	-1.73	70.00±8.09	78.86	63.00	0.98
4	19.10±1.65	21.00	18.14	1.73	6.18±0.82	6.90	5.29	-0.92	90.38±4.00	93.43	85.86	-1.44	66.71±3.09	69.57	63.43	-0.61
5	21.99±0.32	22.36	21.76	1.55	5.86±1.12	7.14	5.14	1.70	85.48±0.41	85.71	85.00	-1.73	64.86±2.81	68.00	62.57	1.24
6	23.00±2.03	25.21	21.21	0.91	6.19±1.91	7.50	4.00	-1.63	86.57±2.85	88.29	83.29	-1.73	68.05±7.39	76.57	63.43	1.71
7	25.95±1.17	27.29	25.07	1.48	6.76±0.66	7.14	6.00	-1.73	87.95±5.15	93.29	83.00	0.33	64.81±0.22	65.00	64.57	-0.94
8	27.83±1.49	29.50	26.64	1.29	9.81±1.16	11.07	8.79	0.88	89.19±5.24	92.43	83.14	-1.72	67.52±6.86	75.29	62.29	1.43
9	28.95±2.80	32.00	26.50	0.91	10.31±1.52	11.36	8.57	-1.62	88.71±5.98	92.86	81.86	-1.62	67.14±3.96	71.71	64.86	1.73
10	30.21±3.25	33.00	26.64	-1.02	11.93±1.55	13.36	10.29	-0.61	90.05±6.75	94.57	82.29	-1.66	68.52±4.93	73.86	64.14	0.84
11	31.12±3.88	33.50	26.64	-1.72	13.57±1.18	14.79	12.43	0.27	88.33±9.20	93.71	77.71	-1.73	66.10±6.29	71.00	59.00	-1.38
12	34.45±3.35	37.36	30.79	-0.97	15.50±1.05	16.14	14.29	-1.72	86.52±11.26	94.00	73.57	-1.67	58.90±5.98	62.43	52.00	-1.73
13	35.90±3.18	38.79	32.50	-0.72	15.29±0.50	15.64	14.71	-1.57	83.43±14.96	94.57	66.43	-1.49	50.19±4.86	55.71	46.57	1.49
14	37.93±3.04	40.93	34.86	-0.11	15.26±2.18	17.43	13.07	-0.05	84.10±11.35	94.00	71.71	-0.94	50.10±8.11	57.71	41.57	-0.50
15	39.17±1.91	40.93	37.14	-0.61	18.53±2.25	20.50	16.07	-0.92	79.86±10.60	88.43	68.00	-1.26	47.95±4.52	53.14	44.86	1.64
16	39.07±2.46	41.29	36.43	-0.76	19.43±0.57	19.86	18.79	-1.46	81.48±13.71	92.57	66.14	-1.26	48.48±8.39	56.43	39.71	-0.43
17	38.02±3.90	41.79	34.00	-0.30	18.57±1.43	19.50	16.93	-1.69	81.00±13.75	94.14	66.71	-0.37	48.29±12.68	62.29	37.57	1.09
18	36.95±2.62	38.50	33.93	-1.73	21.93±1.36	23.36	20.64	0.47	82.76±10.55	93.86	72.86	0.50	57.05±1.95	59.29	55.71	1.64
19	36.83±1.73	38.43	35.00	-0.61	22.00±2.00	24.00	20.00	0.00	81.43±9.37	89.14	71.00	-1.19	55.14±5.38	59.86	49.29	-0.91
20	38.24±4.15	42.00	33.79	-0.73	23.02±2.31	25.57	21.07	1.08	81.57±13.53	91.43	66.14	-1.54	49.81±14.39	66.14	39.00	1.47
21	38.24±3.11	41.43	35.21	0.24	23.10±0.68	23.79	22.43	0.16	85.05±16.65	95.57	65.86	-1.71	49.95±9.67	60.00	40.71	0.37
22	36.62±3.44	40.50	33.93	1.37	24.12±1.09	25.36	23.29	1.44	82.48±14.64	94.00	66.00	-1.35	56.14±11.45	64.71	43.14	-1.48
23	38.79±4.96	44.21	34.50	0.98	24.38±0.58	25.00	23.86	0.72	83.33±16.30	94.00	64.57	-1.68	49.57±13.69	59.71	34.00	-1.50
24	37.43±6.12	43.93	31.79	0.62	26.31±1.26	27.14	24.86	-1.68	84.14±16.02	94.71	65.71	-1.68	51.86±15.95	65.43	34.29	-1.06
25	34.88±3.49	38.79	32.07	1.27	25.98±0.54	26.29	25.36	-1.73	83.43±15.82	95.14	65.43	-1.51	60.00±11.26	66.71	47.00	-1.73
26	34.57±1.26	35.50	33.14	-1.51	26.29±0.93	27.21	25.36	0.00	87.67±9.77	95.86	76.86	-1.12	62.90±2.46	65.71	61.14	1.57

76.57 percent respectively. Mean weekly RH values of 79.86±10.60 to 90.86±0.38 and 47.95±4.52 to 70.00±8.09 percent were noted. During the vegetative phase, there was weekly mean rainfall of amount 0.22±0.38 to 2.59±4.49 mm. At the flowering phase, almost no rainfall, and a meager mean weekly rainfall of 1.15±2.00 mm was found. At the later stage of fruit development to maturity, 0.33±0.58 to 6.06±5.28 mm mean weekly rainfall was noted. Pan evaporation of 3.31±0.60 to 9.00±1.06 mm/day and bright sunshine hours of 2.98±2.08 to 9.61±0.58 h were recorded (Table 2). The magnitude of variations in pan evaporation and BSS was recorded from 2.60 to 10.06 mm/day and 0.90 to 10.70 h respectively during vegetative and reproductive phases of mango under subtropical conditions. A wind speed of 0.93 to 10.17 km/h with 1.40±0.43 to 5.54±4.08 km/h was found at this location. The variability of T_{max} and T_{min} during fruit set to development was noted as 30.21±3.25 to 38.79±4.96 and 11.93±1.55 to 24.38±0.58°C. The corresponding RH values lie at 90.05±6.75 to 83.33±16.30 and 68.52±4.93 to 49.57±13.69 percent. Interestingly, high pan evaporation of 6.08±1.51 to 7.75±1.92 mm/day and BSS of 7.62±0.87 to 7.89±0.99 h were recorded. Mean weekly rainfall of 1.00 to 8.63 mm was also observed.

Critical analysis of weather indicators across the mango growing season is an urgent requirement to understand the variability that occurs during phenophases *vis-à-vis* its impact on fruit production. It was observed that the effect of climatic variability in semi-arid regions is of utmost importance to assess the vulnerability of the system (Singh *et al.,* 2019). Sukhvibul *et al.* (1999) found interesting observations of temperature variability and its effect on fruit set, fruit drop, and development in Mango. Salvi *et al.* (2013) reported that the sudden rise of very high temperature at fruit set to marble phase caused a huge fruit drop and low fruit load on mango trees. Moreover, occurrences of spongy tissue have risen by several times. Warm climates showed erratic fruit sets in almond (Kodad *et al.,* 2014). Of course, there may be varietal variations to the temperature response of flower production *vis-à-vis* fruit set. Geetha *et al.* (2016) recorded 15.5 and 16°C lower temperatures in a cultivar of Langra and Amrapali for producing the highest number of hermaphrodite flowers in mango. It was observed that not only temperature, but also other weather factors equally influence the reproductive phases in mango. Recently, Granata and Nunno (2021) opined that deep learning-based models can provide an accurate estimation of evapotranspiration, and the incorporation of location-specific datasets offers better accuracy in perdition. Even, orchard management may influence growth and yield like in persimmon trees. Kanety *et al.* (2014) estimated 0.35 to 1.14 mm/day ET_0 persimmon orchards with a yield of 40 tons/ha. The long-term statistical analysis showed global warming had a potential impact on the advancement of flowering and leaf unfolding (Fu *et al.,* 2016). Based on long-term phenological data of 1729 to 2339 recorded data sets in six angiosperm tree species, Szabó *et al.* (2016) suggested that indeed flowering phenology shifted to climate change. It was confirmed that two to three months before initiation of flowering had a strong influence on flowering timing. Prudencio *et al.* (2018) observed flowering variability in three cultivars of almonds (Desmayo Largueta, Penta, and Tardona) across the 2014 to 2017 seasons.

Variability of thermal indices *vis-à-vis* heat use efficiency during three mango seasons

It was inferred from the analyzed data of three seasons that there was a variation of thermal indices like GDD, HTU, and PTU over the seasons (Fig. 1). Moreover, heat accumulation, heliothermal and photothermal values also varied at vegetative and reproductive phases in Dashehari mango (Fig. 2 to 6). Recent data indicated variability of GDD at the flowering phase to the tune of 765.81 to 917.16 °Cd across the 2020 to 2022 season. The HTU and PTU values had ranged between 1168.68 to 7501.72 °Cdh and 8449.50 to 9615.38 °Cdh respectively across three seasons of flowering. In the pea stage, GDD, HTU, and PTU had variability of 801.09 to 1119.48 °Cd, 4201.63 to 9825.93 °Cdh, and 9136.36 to 13335.67 °Cdh. Moreover, in the marble stage of fruit growth, the variability of three indices were 1016.16 to 1606.444°Cd followed by 8251.02 to 14075.55°Cdh and 12532.53 to 20893.17°Cdh respectively. Of course at the maturity period, initially 1447.95°Cd to approx. 2600°Cd values of GDD were recorded. The critical analysis of stage-wise thermal indicates in mango showed greater variability at each phase and this may be due to changes in weather indicators across three seasons. It was noted that mean GDD of 626.42, 653.88, and 652.62°Cd GDD; 2815.44, 4885.37, and 4208.51°Cdh HTU; 6783.38, 7689.99, and 7063.87°Cdh at 2020, 2021 and 2022 vegetative phase. It was observed that at flowering phase mean

Table 2. Weather indicators during mango production seasons (Pooled of 2020, 2021, and 2022) at Rehmankhera, Lucknow, UP

Std	Rain	Range			Evaporation	Range			BSS (n)	Range			Wind speed	Range		
week	Mean	Max	Min	Skewness	Mean	Max	Min	Skewness	Mean	Max	Min	Skewness	Mean	Max	Min	Skewness
1	0.67±1.15	2.00	0.00	1.73	3.57±0.80	4.40	2.80	0.37	5.01±1.55	6.80	4.00	1.69	1.40±0.43	1.76	0.93	-1.19
2	0.23±0.40	0.69	0.00	1.73	3.55±1.27	4.97	2.53	1.27	4.18±2.17	6.67	2.71	1.65	1.84±0.33	2.23	1.63	1.70
3	2.59±4.49	7.77	0.00	1.73	3.62±1.22	4.97	2.60	1.11	2.98±2.05	5.00	0.90	-0.14	1.86±0.20	2.03	1.64	-1.11
4	0.67±1.15	2.00	0.00	1.73	3.31±0.60	4.00	2.94	1.72	4.90±2.51	7.71	2.89	1.29	1.90±0.40	2.19	1.44	-1.61
5	0.22±0.38	0.66	0.00	1.73	4.10±0.60	4.46	3.40	-1.73	6.11±1.70	7.87	4.47	0.33	2.34±0.99	3.33	1.36	0.04
6	0.00±0.00	0.00	0.00	-	4.61±0.96	5.49	3.59	-0.72	7.19±1.21	7.90	5.79	-1.73	1.92±0.43	2.33	1.47	-0.40
7	0.00±0.00	0.00	0.00	-	5.29±0.93	6.20	4.34	-0.18	8.31±0.40	8.61	7.86	-1.44	1.89±0.60	2.36	1.21	-1.34
8	0.00±0.00	0.00	0.00	-	5.70±1.21	6.91	4.49	0.00	7.38±1.60	8.39	5.53	-1.71	2.69±1.04	3.87	1.91	1.49
9	0.00±0.00	0.00	0.00	-	5.96±1.25	7.06	4.60	-0.89	8.00±1.01	8.90	6.91	-0.80	2.63±0.77	3.43	1.89	0.28
10	0.82±1.42	2.46	0.00	1.73	6.08±1.51	7.27	4.39	-1.34	7.62±0.87	8.16	6.61	-1.72	2.77±0.59	3.37	2.20	0.22
11	1.15±2.00	3.46	0.00	1.73	6.20±2.07	8.11	4.00	-0.61	7.15±1.05	8.33	6.31	1.30	2.60±0.14	2.74	2.46	0.30
12	0.00±0.00	0.00	0.00	-	6.73±1.90	8.86	5.19	1.25	8.09±0.31	8.40	7.77	-0.14	2.37±0.38	2.80	2.07	1.35
13	0.00±0.00	0.00	0.00	-	7.14±1.98	9.31	5.44	1.03	8.58±0.29	8.84	8.27	-0.72	3.28±0.16	3.44	3.11	0.13
14	0.00±0.00	0.00	0.00	-	7.95±1.47	9.31	6.39	-0.61	8.76±0.87	9.43	7.77	-1.41	2.64±0.47	3.01	2.11	-1.28
15	0.00±0.00	0.00	0.00	-	8.92±0.83	9.73	8.07	-0.26	8.84±0.13	8.99	8.74	1.35	2.33±0.60	2.97	1.77	0.56
16	0.00±0.00	0.00	0.00	-	9.00±1.06	9.91	7.83	-0.99	7.48±2.56	9.39	4.57	-1.49	2.46±0.57	3.00	1.86	-0.44
17	0.48±0.82	1.43	0.00	1.73	8.54±1.76	10.01	6.60	-1.12	9.25±1.01	10.13	8.14	-0.95	2.74±0.26	3.00	2.47	-0.24
18	0.55±0.96	1.66	0.00	1.73	8.56±1.58	9.59	6.74	-1.69	8.58±0.55	9.13	8.03	-0.04	3.90±0.77	4.79	3.39	1.65
19	1.38±1.51	3.00	0.00	0.69	8.42±1.61	9.49	6.57	-1.67	9.61±0.58	10.26	9.14	1.22	4.27±1.76	6.29	3.03	1.59
20	3.45±4.57	8.63	0.00	1.46	7.76±1.99	10.06	6.50	1.71	8.33±2.93	10.51	5.00	-1.49	2.38±0.30	2.61	2.04	-1.29
21	0.33±0.58	1.00	0.00	1.73	7.93±1.61	9.17	6.11	-1.40	9.34±1.91	10.70	7.16	-1.58	2.80±0.49	3.30	2.31	0.13
22	1.97±1.73	3.23	0.00	-1.54	8.00±1.86	9.80	6.09	-0.25	8.41±0.70	8.89	7.61	-1.65	5.54±4.08	10.17	2.49	1.48
23	3.30±3.55	7.06	0.00	0.56	7.75±1.92	9.81	6.03	0.77	7.89±0.99	8.47	6.74	-1.73	2.39±0.22	2.59	2.16	-0.59
24	5.77±8.51	15.54	0.00	1.65	7.99±1.67	9.61	6.27	-0.23	7.64±1.73	9.43	5.99	0.36	3.50±0.40	3.91	3.11	0.42
25	1.64±2.84	4.91	0.00	1.73	7.50±2.13	9.50	5.26	-0.51	7.07±2.18	9.40	5.09	0.69	3.58±0.78	4.43	2.90	0.97
26	6.06±5.28	12.09	2.29	1.57	7.30±1.59	9.01	5.89	0.82	5.21±1.91	6.87	3.13	-0.94	3.49±1.42	4.80	1.97	-0.62

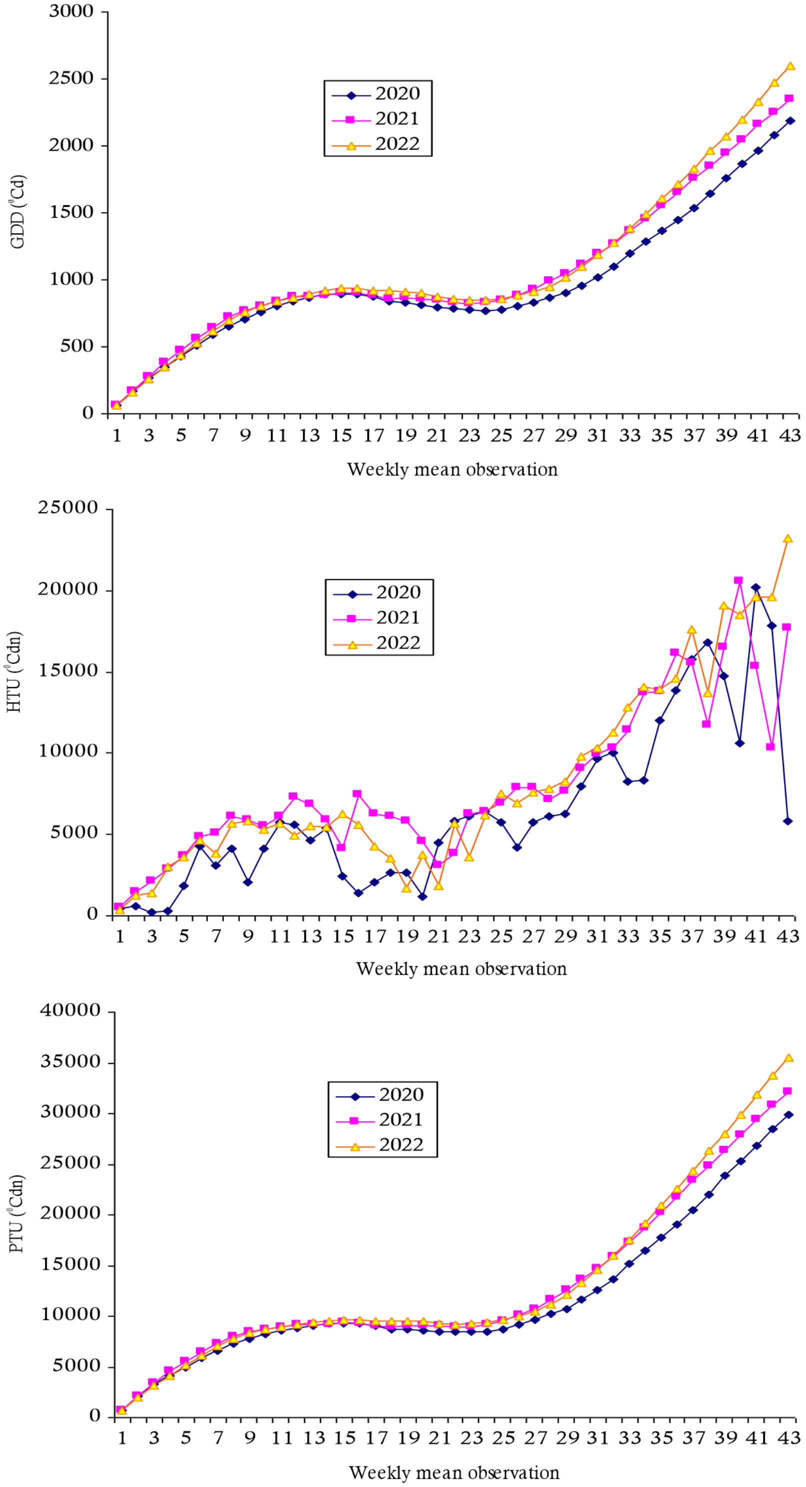

Fig. 1. Variability of thermal indices across 2020, 2021, and 2022 seasons

GDD, HTU, and PTU in the 2020, 2021, and 2022 seasons were of the values of 796.66±23.2, 849.00±18.8, 877.12±24.8°Cd; 4497.19±2320.4, 5592.58±1957.7, 4601.90±2651.9°Cdh; 8621.36±219.2, 9194.42±349.3, 9477.85±230.7°Cdh respectively. At the pea and marble stage, the values of three indices were estimated as 898.47±56.3, 1026.58±82.8, 1001.92±84.8 and 1196.81±114.8, 1358.70±113.8, 1382.36±131.9°Cd in three consecutive seasons. The HTU variability at these

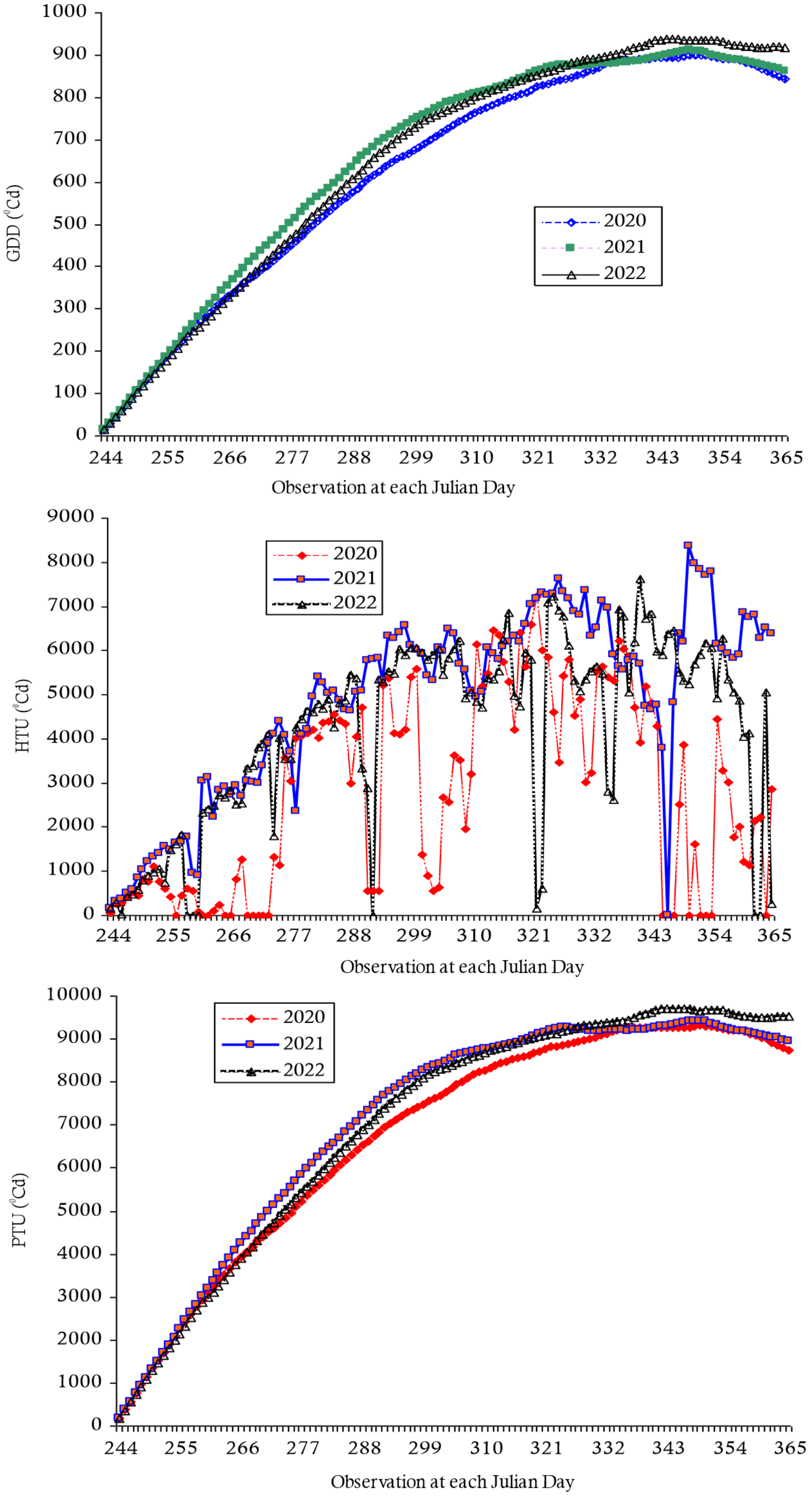

Fig. 2. Variability of thermal indices at the vegetative phase of mango production across the 2020, 2021, and 2022 seasons

stages was 6802.53, 8015.53, 8449.45 9404.50, 12045.31, and 12683.00°Cdh respectively. Changes in bright sunshine hours resulted in the variability of heliothermal values at vegetative and reproductive phases in three seasons. The PTU variability at the pea and marble stage was 10709.51, 12213.66, 11894.39, and 15225.35, 17247.76, and 17517.25 respectively. A broader variability of thermal indices at the maturity period was found. Variability of 1818.47, 1994.46, 2140.15 °Cd GDD; 14332.28,

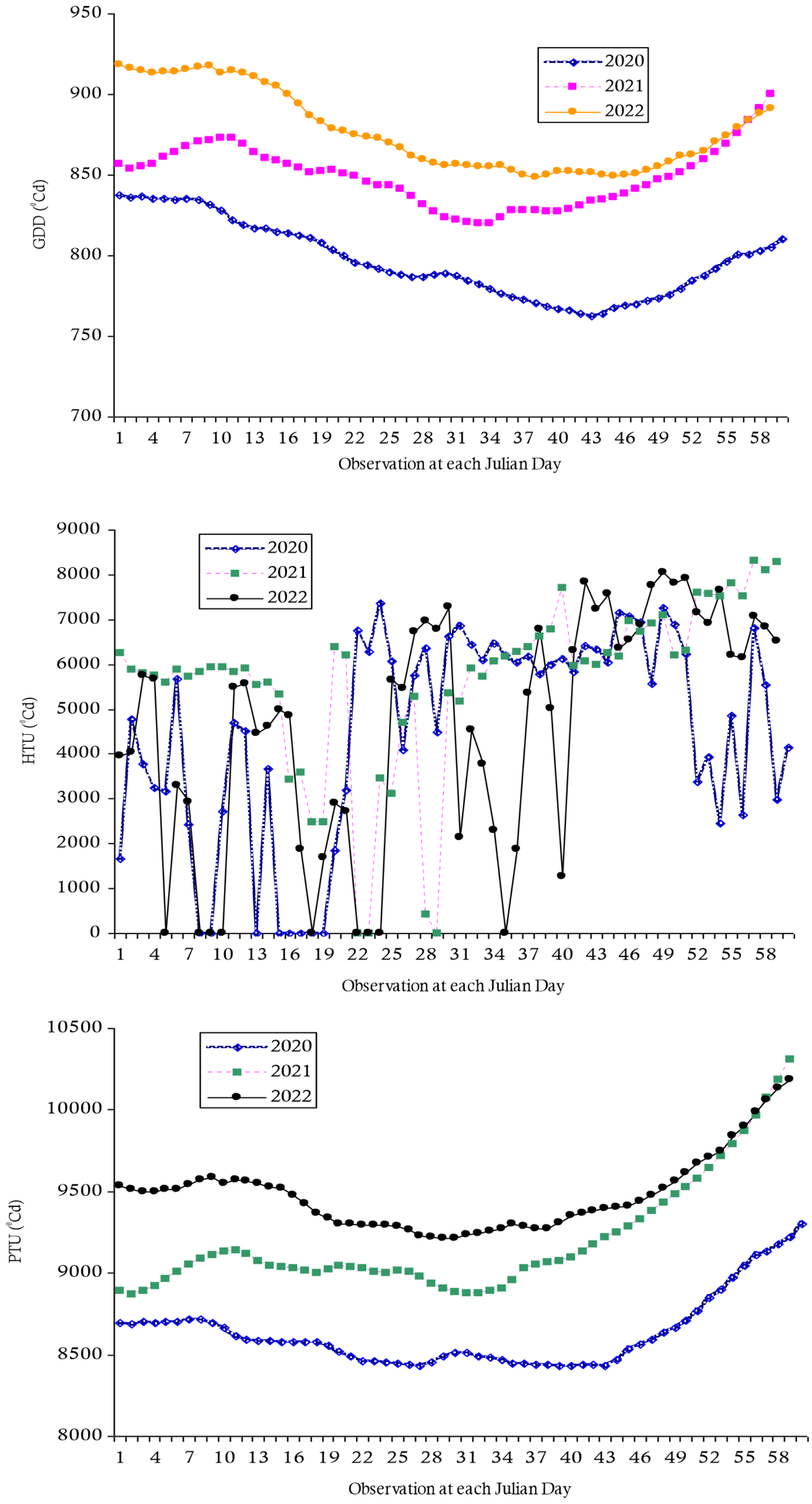

Fig. 3. Variability of thermal indices at the flowering phase of mango production across the 2020, 2021, and 2022 seasons

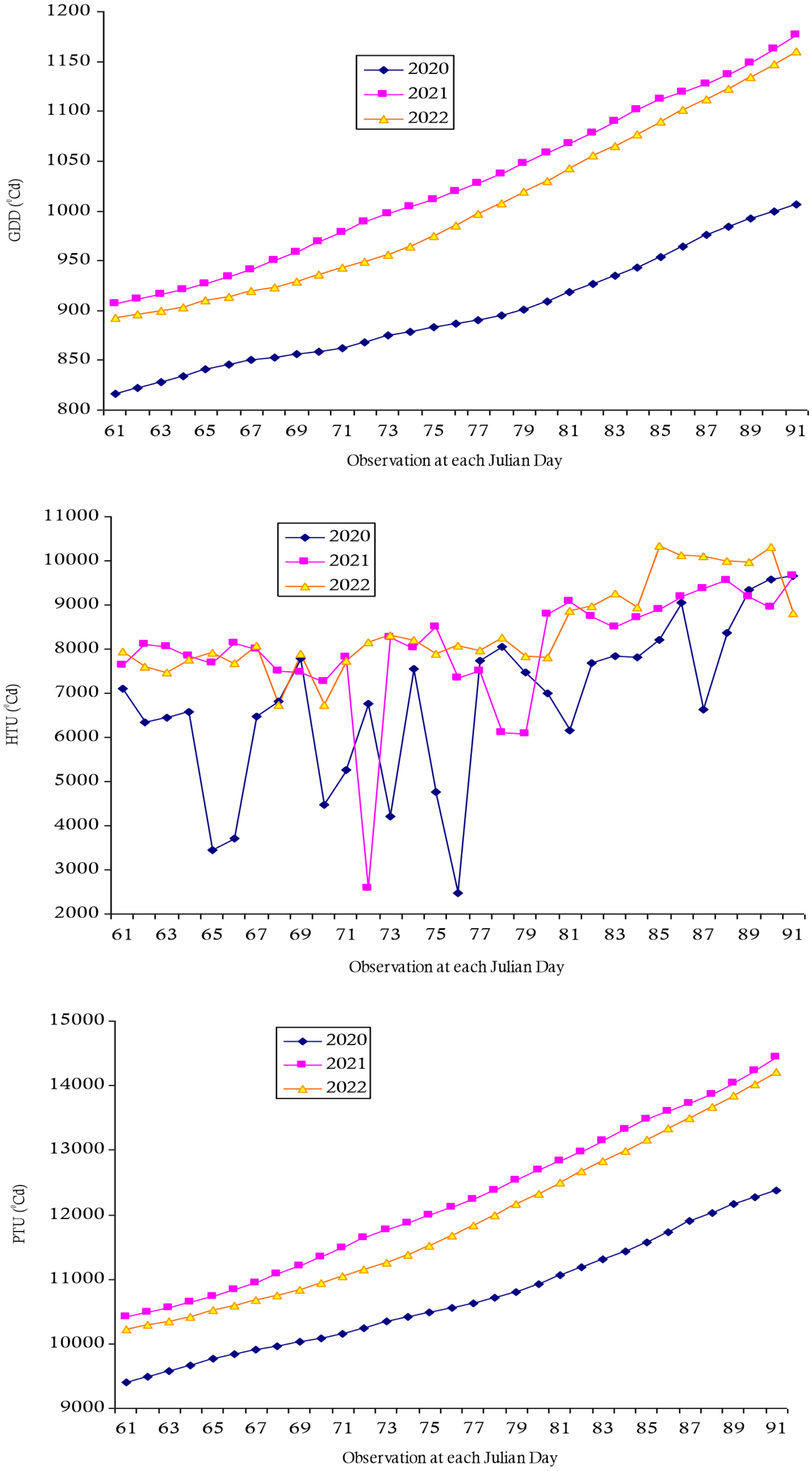

Fig. 4. Variability of thermal indices at the pea phase of mango production across the 2020, 2021, and 2022 seasons

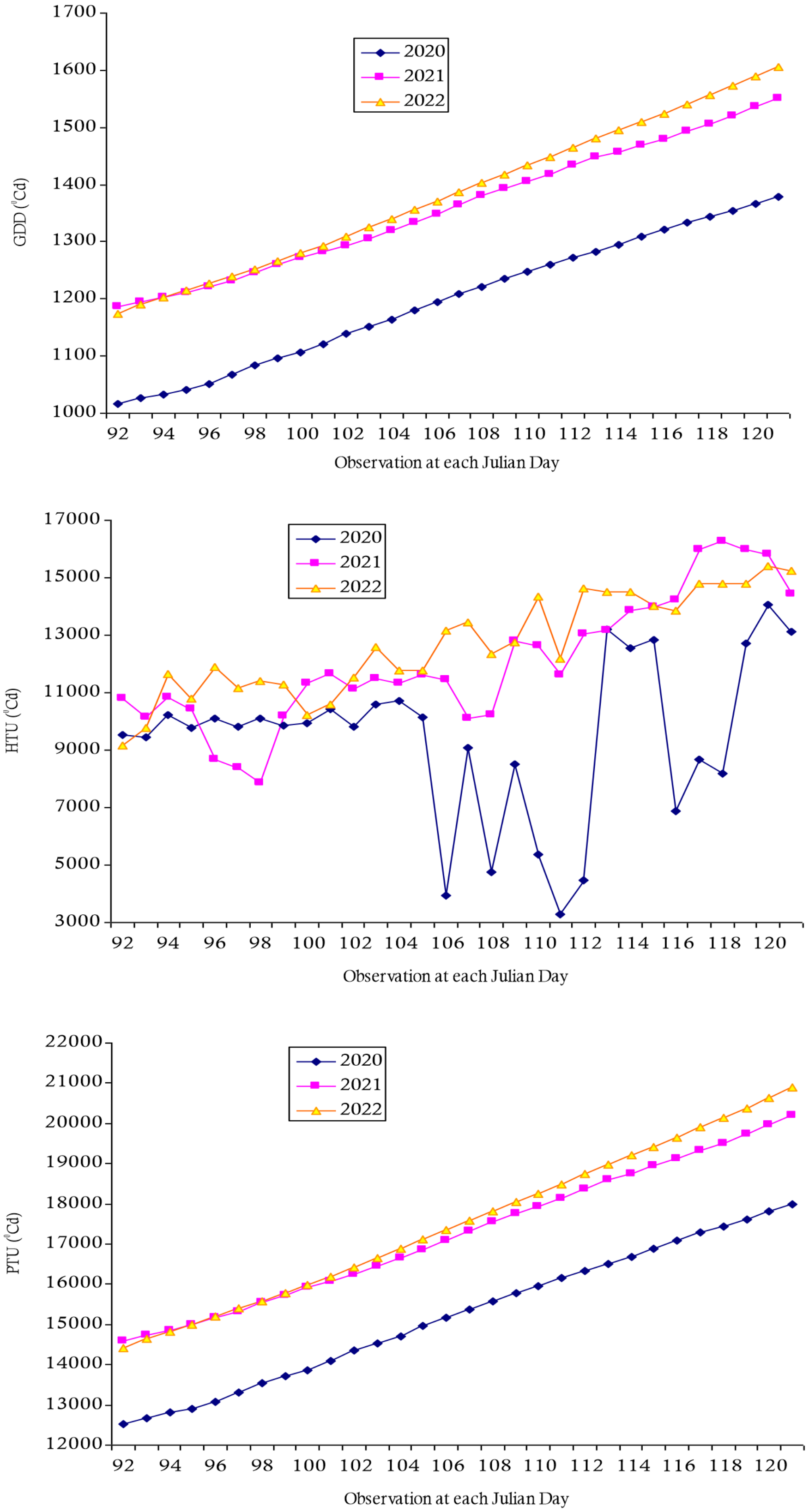

Fig. 5. Variability of thermal indices at the marble phase of mango production across the 2020, 2021, and 2022 seasons

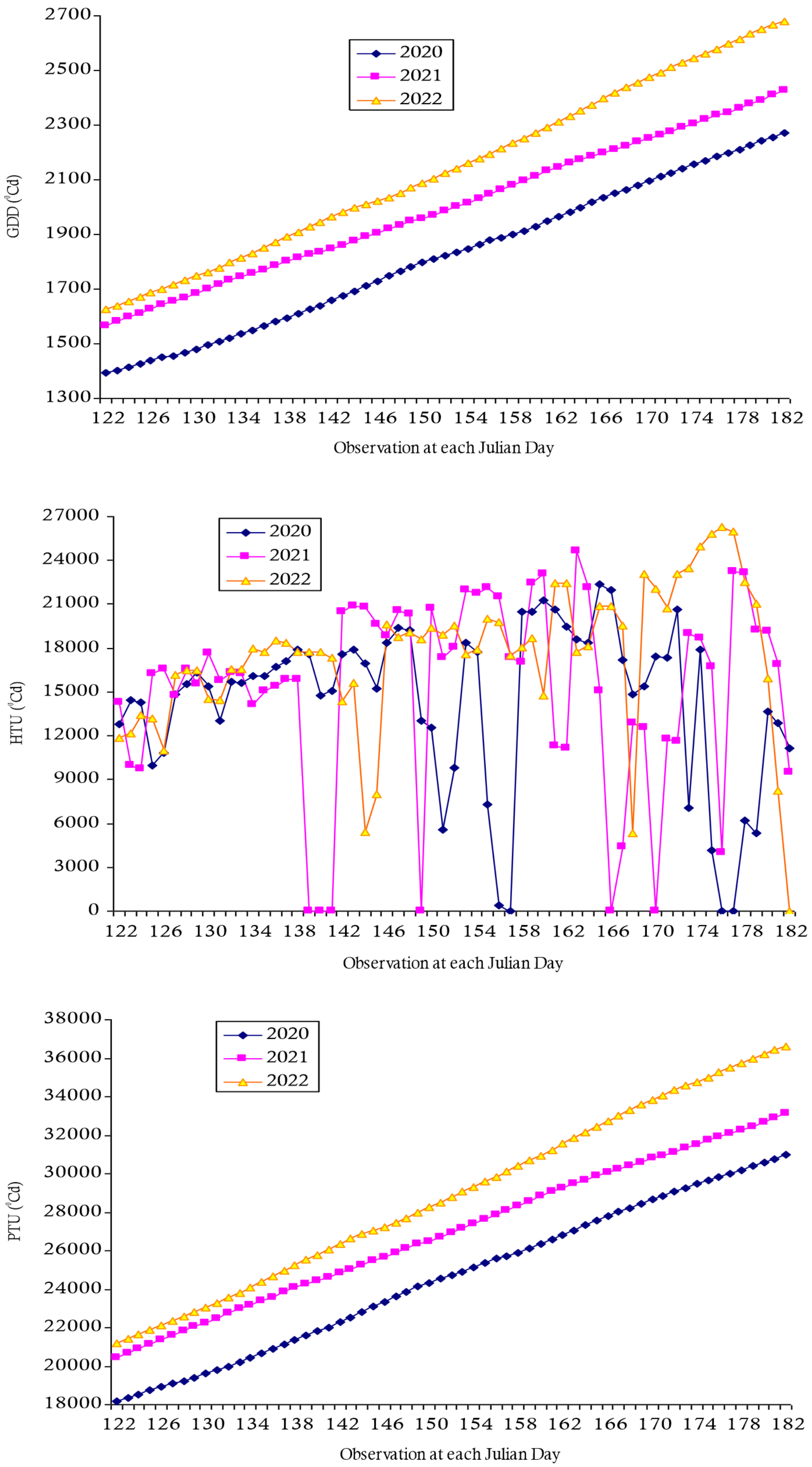

Fig. 6. Variability of thermal indices at the maturity phase of mango production across the 2020, 2021, and 2022 seasons

15212.21, 17510.49 °Cdh HTU and 24589.37, 26944.90, 28902.14°Cdh PTU at 2020, 2021 and 2022 season was observed. Such variability had an impact on the fruit yield of mango trees. It was found that yield of approximately 6 to 11, 5.5 to 11.64, and 4 to 8 t/ha in mango Dashehari in the 2020, 2021, and 2022 seasons. The heat use efficiency varied between 3.30 to 6.08 g/m^2/°Cd in the 2020 season with values of 2.54 to 5.84 g/m^2/°Cd in the 2021 season and 1.87 to 3.74 g/m^2/°Cd in 2022 season (Fig. 7). Considering the HTU values, variability of 0.42 to 0.77, 0.33 to 0.77 and 0.23 to 0.46 g/m^2/°Cdh in three consecutive seasons respectively while ranges of 0.24 to 0.45, 0.19 to 0.43 and 0.14 to 0.28 g/m^2/°Cdh HUE of PTU in 2020, 2021 and 2022 seasons was recorded. Variability of such heat use efficiency acts as a function of climatic indicators thus seasonal variability due to changes in weather data and critical phenophases had impacted by the weather-tree interaction.

The quantification of thermal indices across agro-climatic zones is of great importance and Adak *et al*. (2016) estimated ranges of around 700 to 1600°Cd variations of GDD in Dasherai mango during 2013-15 fruiting seasons. The estimated heat use efficiency was of the order of 3.9 to 5.14 g/m^2/

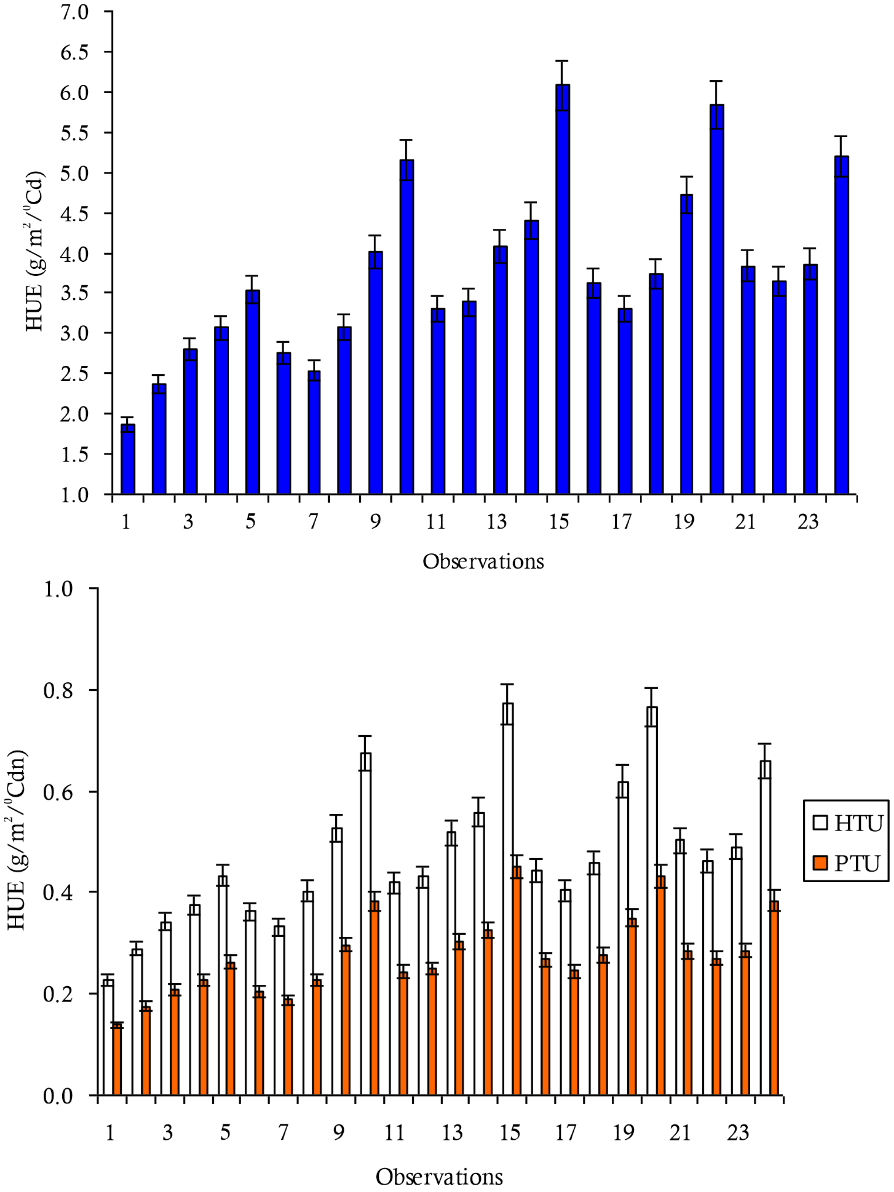

Fig. 7. Variability of heat use efficiency in Dashehari mango across the 2020, 2021, and 2022 seasons

°Cd. Prudencio *et al.* (2018) reported the variability in GDD in three cultivars of almond. Ranges of 4933 to 7770, 7130 to 9166 and 7789 to 9929 in Desmayo Largueta, Penta and Tardona almond cultivars were found during 2014-2017 seasons. The mean temperatures had significant impact on flowering in apricots and heat accumulation as recorded by Guo *et al.* (2015). Based on 30 years of phenological data, Benmoussa *et al.* (2017) estimated the heat requirements for local and foreign almond cultivars in a warm Mediterranean location. Climate change had impacts on fruit phenology *vis-à-vis* fruit productivity and it was observed that extreme climates had threatened nut orchards of central Tunisia (Benmoussa *et al.,* 2018). Gupta *et al.* (2020) quantified the heat accumulation in the grape as 421 to 1617°Cd in fruit set to ripening while the variability of HTU of 2799 to 12578°Cdh and PT U values of 4736 to 20201°Cdh was observed. In our study also variability was recorded and it was found that weather plays significant role in tree phenological response. Actually, the production environment is very pivotal be it atmospheric condition or soil and tree condition. The evapotranspiration also affects the coffee trees during its production (Flumignan *et al.,* 2011) and Pandey *et al.* (2016) evaluated yield, fruit quality and antioxidant potential in Indian gooseberry under field conditions. Information of the sensitivity of the tree to prevailing climatic conditions of very much required and vulnerability may be computed to assess the climate-tree-soil interactions. Poirier-Pocovi and Bailey (2020) scientifically suggested that even crop water stress indices were very much sensitive to environmental conditions and tree phenology. Therefore, systematic data generation for tree-soil-weather response needs to be generated for future climate change study and also to quantify its impact on fruit yield and reproductive phases.

CONCLUSION

The current study encompasses the variability of climatic indicators in mango growing belts of Lucknow, UP. Changes in response of trees to existing weather conditions were recorded. Variability of three thermal indices i.e. growing degree days, heliothermal unit, and photothermal values was recorded. Such variability in each phase of mango reproductive cycles was noted in each season of 2020, 2021, and 2022. Variability of such changes attributed to dynamic variability of weather indicators over the three consecutive seasons. Changes in heat use efficiency were recorded in each season across trees and seasons as well. Tree-climate interaction was thus quantified and growers' need for real-time information on changes would be beneficial. All these datasets may be valuable inputs in simulation modeling for predicting the heat use efficiencies and other vulnerability index calculations for subtropical climates.

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