Journal of Applied and Natural Science
15(1), 340 - 348 (2023)
ISSN : 0974-9411 (Print), 2231-5209 (Online)
journals.ansfoundation.org

Research Article

Evaluating the seasonal accumulation of Heat units as an agroclimatic indicator on Baby corn (*Zea mays* L.) under different sowing windows

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Article Info
https://doi.org/10.31018/jans.v15i1.4273
Received: December 11, 2022
Revised: February 21, 2023
Accepted: March 3, 2023

How to Cite
Sankar, T. *et al.* (2023). Evaluating the seasonal accumulation of Heat units as an agroclimatic indicator on Baby corn (*Zea mays* L.) under different sowing windows. *Journal of Applied and Natural Science*, 15(1), 340 - 348. https://doi.org/10.31018/jans.v15i1.4273

Abstract
Temperature determines the plant's growth and development, which decides the onset of different phenophasic stages of the Baby corn. This study aimed to evaluate the phenological behaviour and yield of Baby corn (*Zea mays* L.) influenced by sowing windows and heat units with the field investigations carried out during winter (January – April) and *kharif* (June – September) 2022 at Eastern Block Farm of Tamil Nadu Agricultural University, Coimbatore. Growing Degree Days (GDD), Photo Thermal Units (PTU), Helio Thermal Units (HTU), Relative Temperature Disparity (RTD), Heat Unit Efficiency (HUE) and seasonal efficiency were calculated at different phenological stages. The results revealed that early attainment of phenophases was noticed during winter (62.5 days - January 21st to 27th April) than *kharif* (77.1 days – 15th June to 4th October). Among seasons, higher accumulation of GDD (1553) and PTU (19099) was observed during *kharif* 2022, whereas maximum accumulation of HTU (9923) and RTD (2146) was observed in winter 2022. Seasonal efficiency was higher during *kharif* (118) than during the winter season (81). The sowing windows significantly influenced the higher accumulation of heat units and yield attributes. Hence, higher yield (11922.7 kg ha^{-1}) and HUE (7.3) were obtained during *kharif* than in winter 2022 (yield – 7849 kg ha^{-1} and HUE – 5.8). Weather parameters showed a negative correlation except RH-I, WS, SR and HUE during winter 2022 (R^2=0.802) and RH-II, WS, RF, Daylength, HUE during *kharif* 2022, which had a positive correlation (R^2=0.795). Baby corn is highly sensitive to increasing temperature. Hence, the study expresses the effect of varying ambient temperature on the duration between the phenological stages and yield.

Keywords: Baby corn, Cob yield, Phenology, Sowing windows, Seasonal heat units

INTRODUCTION

Baby corn (*Zea mays* L.), also known as mini corn or candle corn, is cultivated for unfertilized young ears, harvested after silks have turned pinkish colour just after emergence. The crop is newly evolved, most importantly dual purpose (vegetable and fodder) crops grown round the year in India (Kumar *et al.,* 2015) and popular among domestic and foreign market values both processing and export potential (Das *et al.,* 2008). At present, the Indian states of Meghalaya, Uttar Pradesh, Haryana, Maharashtra, Karnataka and Andhra Pradesh are growing Baby corn (Ranjan and Sow, 2021). Depending upon agro-climatic conditions, 3 to 4 crops of Baby corn can be taken up in a single year. Furthermore, it produces higher green fodder per unit area than normal maize (Nataraj *et al.,* 2011). The increase in the production of Baby corn is necessary to meet the demand for vegetables for the burgeoning population of both humans and animals (Kumar *et al.,* 2015).

Baby corn cultivation is highly seasonal bound and the crop is highly sensitive to increasing temperature. Also, Baby corn yield significantly decreases with increasing temperature. So, the growth and yield of the crop are highly affected by the changes in daily temperature (Hatfield and Prueger, 2015). Consequently, successful growth requires an optimum temperature of 22°C to 28° C. Crops get injured if the daytime temperature exceeds 30°C reducing the yield (Ben-Asher *et al*., 2008). Hence, optimum sowing can improve crop yield significantly and make crops fit in existing cropping patterns (Choudhury *et al.,* 2021). Usually, plants require a certain growing degree day (GDD) to attain the phenological stages, depending on daily temperature and sowing windows (Dahmardeh, 2012). Since the environment is changing daily, sowing windows have a profound influence on both the growth and yield of the crop (Iizumi and Ramankutty, 2015). Sharma *et al.* (2021) reported that delayed sowing reduced the hybrid maize yield by about 55% under rainfed conditions, whereas yield reduction was only 21% in irrigated condition. The reduction in the accumulation of heat units was due to a reduction in the number of days taken to attain the physiological maturity of crop. The phenological development and yield of Baby corn is highly temperature dependent. Hence, the study was conducted to examine the relationship between yield and thermal units influenced by sowing windows during winter and *kharif* 2022 in the western region of Tamilnadu.

MATERIALS AND METHODS

Study location

Coimbatore district was chosen for conducting the experimental trails. Coimbatore is called Manchester of South India and it is situated on the banks of the river Noyyal. It is one of the western agro-climate zone districts, between 10º to 11º N latitude and 76º to 77º E longitude. The soil characteristics of the experimental plot are described in Table 1.

Experimental details

The variety F1 Sundar of Baby corn (*Zea mays* L.) was used as test crop to conduct the field experiments during winter (January – April) and *kharif,* (June – September) 2022. Sowing windows taken as main plot and crop geometries, with mulching taken as a subplot, which was laid out in a split-plot design and replicated thrice. All the packages of practices were followed as per the Tamil Nadu Agricultural University crop production guide for Agriculture (CPG, 2020). The crop was harvested after the silk colour turned pinkish from milky white by leaving border sample rows. Details of the sowing windows for both seasons are given in Table 2.

Weather parameters

The occurrence of Baby corn phenophases viz., plant emergence (PE) to 50% flowering (P_1), 50% flowering to cob emergence (P_2), cob emergence (CE) to harvesting (P_3), plant emergence (PE) to cob emergence (P_4), 50% flowering to harvesting (P_5) and plant emergence (PE) to harvesting (P_6) were recorded after the plants reached 50% of respective crop stages. Simultaneously, weather parameters and heat units viz., Growing Degree Day (GDD) with a base temperature (Tb) of 6.6^{o}C (Borowiecki, 1992) and Photo Thermal Unit (PTU), Helio Thermal Unit (HTU), Relative Temperature Disparity (RTD), Seasonal Efficiency (SE) and Heat Use Efficiency (HUE) were also studied to examine the growth and yield of the crop. All the heat units were measured as per the following relationships shown in the Table 3.

The day length details were collected from http://www.world-timedate.com/astronomy/sunrise_sunset/sunrise_sunset_calendar.php?city_id=257. The daily weather data, viz., maximum and minimum temperature, wind speed, rainfall, bright sunshine hours and relative humidity during the crop season (winter and *kharif* 2022), were retrieved from Agro Climate Research Centre, Tamil Nadu Agricultural University, Coimbatore. The daily data were converted into standard meteorological weekly data during crop growing period (4th standard week - 21st January to 16th standard week – 22 April and 24th standard week – 15 June to 39th standard week – 30th standard week, respectively). From the meteorological data, the weather prevailed during winter 2022 with a maximum temperature (29 ºC to 36.5 ºC), minimum temperature (25.5 ºC to 26 ºC), total rainfall (49.4 mm), relative humidity (44 % to 82%), wind speed (2.8 km/hr to 9.8 km/hr) and sunshine hours (upto 10.2 hours) and daylength (11.35 to 12.24 hours) (Fig. 1). Likewise, the weather prevailed during *kharif* 2022 were maximum temperature (25.5 ºC to 34 ºC), minimum temperature (21 ºC to 24.5 ºC), total rainfall (273 mm), relative humidity (53 % to 82.5%), wind speed (3.4 km/hr to 19.4 km/hr) and sunshine hours (upto 11 hours) and daylength (12.01 to 12.46 hours) (Fig 2).

Statistical analysis

Correlation between Baby corn yield and heat units was done and step-wise regression techniques were performed to investigate the effect of heat units on phenology and yield through R software.

Table 1. Soil characteristics of the experimental plot

Parameters	Value	Methodology/ Reference
Texture	Clay loam	-
Type	Black	-
Lime status	Calcareous	-
Organic Carbon	Low (0.45 %)	Chromic acid wet digestion method (Walkley and Black, 1934)
pH	Slightly alkaline (8.36)	Potentiometry (Jackson, 1973)
EC	Non saline (0.37 Ds m^{-1})	Conductometry (Jackson, 1973)
Available N	Low (213 Kg ha^{-1})	Alkaline Permanganate method (Subbiah and Asija, 1956)
Available P (Olsen's)	High (31.0 Kg ha^{-1})	Olsen method (Olsen *et al.,* 1954)
Available K	High (640 Kg ha^{-1})	Flame Photometry (Stanford and English, 1949)

RESULTS AND DISCUSSION

Baby corn phenophases duration

The variabilities of different phenophases duration across the sowing windows were summarized and presented in Table 4. From the tabulated data, the mean phenological duration of plant emergence to 50% flowering (P_1), 50% flowering to cob emergence (P_2) and cob emergence to harvest (P_3) were 47.1, 3.5 and 3.4 days during winter, while they were 50.1, 9.3 and 8.2 days during *kharif* seasons respectively. The early attainment of different phenophases was also noticed during winter 2022 (62.5 days) and it was 77.1 days during
kharif 2022. As expected, the amount of solar radiation (360.3 cal/cm^2/day) and daily maximum temperature (34 ºC) received were higher during winter sowing towards summer growing. This weather phenomenon accelerated the physio-chemical process of crops, so enhanced their growth and development. This was in line with the findings of Thavaprakaash *et al.* (2007), who noted that the baby corn crop attained phenophases early during the summer season and delayed during the late *rabi* season in Coimbatore, Tamilnadu. They also reported that the increasing temperature significantly lowered the time to 50% flowering and total crop duration.

Among the different sowing windows of winter 2022, the quick attainment of phenophases was noticed in late sowing (D_3 – 58 days) followed by mid-sowing (D_2 - 62.8 days) and early sowing (D_1 -66.6 days), respectively. From the experimental data, the different phenological days indicated that the crop duration was reduced with delayed planting during the winter season. Also, it was noted that the cob matured quickly (7.5 days) during late winter sowing (D_3- 20th February), mainly due to the higher ambient temperature (35.1 ºC) regime. Bairagi *et al.* (2020) observed that the early to mid-winter sowed baby corn plant cobs took longer days to attain maturity, whereas late winter to early summer sowed plant cobs took fewer days to mature in Nadia, West Bengal. They also indicated that the possible reason could be prevailing high temperatures during the pre-flowering stage leading to the early maturity of the crop.

The results of *kharif* 2022 sowing window revealed that the early attainment of phenophases was noticed during mid *kharif* sowing (D_2 – 83.8 days), followed by early sowing (D_1 – 77.8 days) and late sowing (D_3 – 69.7 days) correspondingly. This was also supported by Shrestha *et al.* (2016), who mentioned that the duration to attain different phenological stages of maize decreased with late sowing due to the mean ambient temperature (26.9 ºC) increased with delayed sowing in Nawalparasi District, Nepal.

Heat units

Growing degree days

The accumulated Growing Degree Days (GDD) are represented in Table 5 which shows that the accumulation of heat units (GDD – 1553 ºC days) required to attain the various phenological stages was higher during *kharif* 2022 than GDD (1342 ºC days) required to attain all the phenological stages during winter 2022. Among the sowing windows of winter 2022, higher accumulation of GDD was noted in the early sowing window (D_1 -1392 ºC days) followed by mid and late sowing windows (D_2- 1360 and D_3-1275 ºC days), respectively. Furthermore, the delayed sowing during the winter reduced the required GDD for attaining physiological maturity by up to 116ºC days. This was due to maximum temperature that supported the accumulation of

Table 2. Details of the sowing windows for the cropping seasons

Sowing windows	Winter 2022	*Kharif* 2022
Early sowing	21st January	15th June
Mid sowing	5th February	30th June
Late sowing	20th February	15th July

Table 3. Weather parameters and their heat unit relationships

Parameter	Relationships		Reference
GDD	$GDD = \sum_{i=1}^{n}((\mathrm{Tmax} + \mathrm{Tmin}/2)) - Tb$	Eq. 1	Iwata, 1984
HTU	$HTU = \sum_{i=1}^{n}(GDD * SSH)$	Eq. 2	Rajput, 1980
PTU	$PTU = \sum_{i=1}^{n}(GDD * Day\ length)$	Eq. 3	Major *et al.,* 1975
RTD	$RTD = \sum_{i=1}^{n}((\mathrm{Tmax} - \mathrm{Tmin}/\mathrm{Tmax})) * 100$	Eq. 4	Rajput, 1980
HUE	$\mathrm{HUE} = \mathrm{Yield}/\mathrm{GDD}$	Eq. 5	Haider *et al.,* 2003
Seasonal Efficiency	SE = Yield of crops in a season Mean yield of all seasons *100	Eq. 6	Thavaprakaash *et al.,* 2007

required GDD earlier, accelerating the physiological growth and development of the plant. The higher amount of Growing Degree Days (GDD) was required for attaining physiological maturity in mid sowing window (D_2 -1690 ºC days) followed by early and late sowing windows (D_1- 1576 and D_3-1395 ºC days), respectively, during *kharif* 2022. Girijesh *et al.*(2011) observed that the first fortnight of July recorded the maximum heat units (1768.8 degree days) to attain physiological maturity and it reduced in June's first fortnight and July's second fortnight sowing. Also, longer phenophasic days accumulated a higher amount of GDD during early sowing in baby corn, which might be attributed to variation in temperature prevailed under different sowing dates, as stated by Dar *et al. (*2018).

Helio thermal unit

The Helio thermal unit (HTU) required to attain different phenophases was higher during winter than in the *kharif* 2022 season (Table 5). This might be due to the maximum sunshine hours prevailing during the cropping period. The similar results obtained by Thavaprakaash *et al.,* 2007 found that the HTU requirement of baby corn was lower during the late *rabi* and *kharif* seasons in Coimbatore, Tamilnadu. Among the winter sowing windows, early sowing achieved the highest HTU (D_1 -10314 ºC day hour) during the entire crop duration, followed by mid and late sowing (D_2-9881 and D_3 -9572 ºC day hour), respectively. Among the *kharif* 2022 sowing windows, the highest HTU was found during mid-sowing (D_2- 9141 ºC day hour) followed by late and early sowing (D_3 - 8408 ºC day hour and D_1 - 7511 ºC day hour) correspondingly. Higher phenophasic duration during early sowing accumulated higher HTU than mid and late sowing.

Photo thermal unit

The accumulated Photothermal unit (PTU) is represented in Table 6. Higher PTU value was attained during *kharif* (19099 ºC day hour) than winter season (15936

Table 4. Different phenophases duration of Baby corn during winter and *kharif* 2022 influenced by sowing windows

Phenophases	winter 2022					*kharif* 2022				
	D_1	D_2	D_3	Mean	CV (%)	D_1	D_2	D_3	Mean	CV (%)
P_1	48.6	46.8	46.0	47.1	2.8	50.1	51.7	48.6	50.1	3.1
P_2	4.3	3.8	2.5	3.5	25.8	9.2	10.9	7.7	9.3	17.6
P_3	4.8	3.3	2.0	3.4	40.9	7.9	9.7	6.9	8.2	17.0
P_4	52.8	50.5	48.5	50.6	4.3	59.3	62.6	56.3	59.4	5.3
P_5	9.0	7.1	4.0	6.7	37.7	17.1	20.6	14.6	17.4	17.3
P_6	57.6	53.8	50.5	54.0	6.6	67.2	72.3	63.2	67.5	6.7
1st to final Harvest	9.0	9.0	7.5	8.5	10.2	10.7	11.5	6.5	9.6	28.0
Total duration	66.6	62.8	58.0	62.5	6.9	77.8	83.8	69.7	77.1	9.2

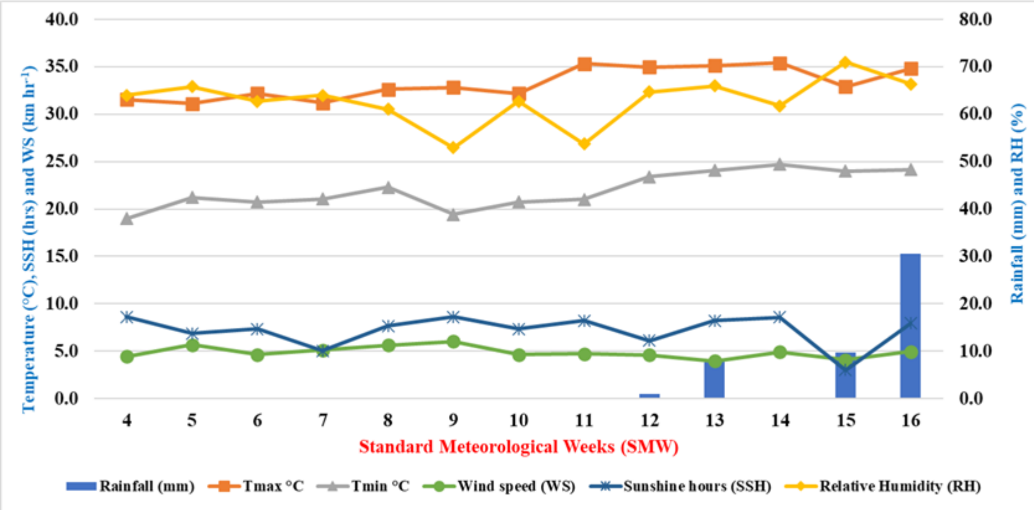

Fig. 1. *Meteorological data during winter 2022 cropping season*

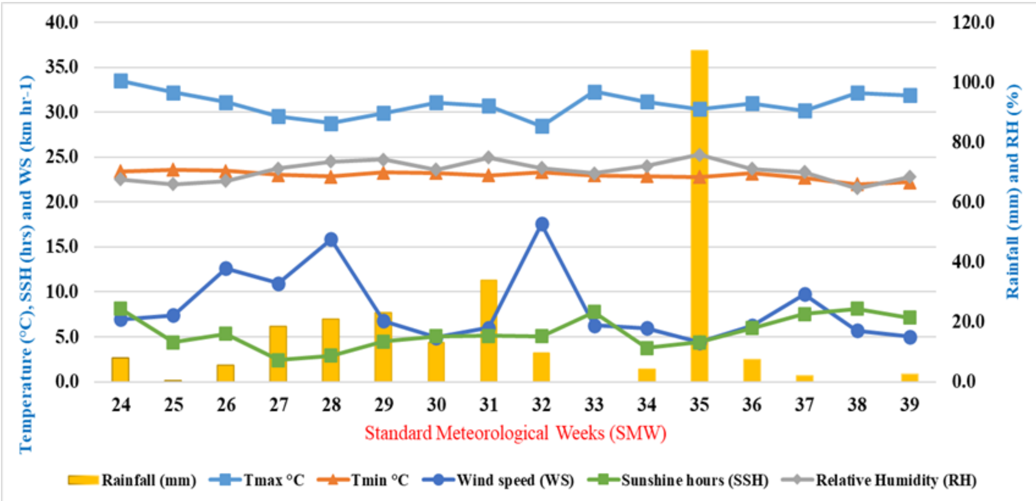

Fig. 2. *Meteorological data during kharif 2022 cropping season*

ºC day hour). It was due to the higher day length during July-September months that accumulated higher PTU in *kharif* season. During the winter, early sowing accumulated the higher PTU (D_1 – 16302 ºC day hour). Consequently, the accumulation of PTU was reduced towards the delay in sowing windows (D_2 - 161555 and D_3 – 15350 ºC day hour), respectively which indicated the number of days required to attain physiological harvest was reduced towards summer months crop growing. This was also stated by Jan *et al.* (2022), who reported that PTU values decreased consistently with an increase in the age of sweet corn (*Zea mays saccharata* L.) seedlings in Jammu and Kashmir. Among the *kharif* sowing windows, the higher PTU was obtained during mid-sowing (D_2 – 20750 ºC day hour) followed by respective early and late sowing (D_1 - 19469 and D_3 – 17077 ºC day hour).

Relative temperature disparity

The accumulated Relative temperature disparity **(**RTD) values are represented in Table 6, which shows that the higher accumulation was during winter than *kharif* season. Since the RTD values are more dependent on daily maximum and minimum temperatures, higher temperature during winter, sowing accumulated more RTD than *kharif*. Sowmiya *et al.* (2022) also observed that lower RTD was acquired by the *kharif* season to reach different phenophases stage than summer. Table 6 depicts that the accumulated higher RTD values to attain each phenophases during winter season during early sowing (D_1 -2330) followed by mid and late sowing dates (D_2 - 2166 and D_3 -1942) correspondingly. *kharif* sowing windows showed the higher RTD during mid sowing (D_2 – 2058) followed by early and late sowing (D_1 - 1854 and D_3 – 1747) respectively.

Seasonal efficiency

The seasonal efficiency was higher in the *kharif* season (118) followed by the winter season (81). Hence, *kharif* season was more suitable for growing Baby corn than the winter season. The similar outcome was observed by Thavaprakaash *et al.* (2007) and Sowmiya *et al.,* 2022 who reported that the seasonal efficiency was more than 100 in *kharif* and it was less than 100 in the late *rabi* season. It indicated the suitability of Baby corn cultivation during *kharif* season.

Yield and Heat use efficiency (HUE) of Baby corn

The yield of Baby corn varied significantly under different seasons and sowing windows (Fig.3). Among the seasons, the maximum yield (11471.2 kg ha^{-1}) and HUE (7.3) were obtained during *kharif* 2022 than winter 2022 yield (7849 kg ha^{-1}) and HUE (5.8). Among winter sowing windows, early sowing achieved highest yield (D_1 -9810 kg ha^{-1}) and HUE (7.1), followed by mid (7445.3, 5.5) and late sowing (6291.7, 4.9), respectively. The optimum temperature (27.5°C) and mean day length (11.7 hours) during early sowing helped to obtain the maximum yield than mid and late sowing. The result was also corroborated by Hemalatha *et al.* (2013), who found that the higher accumulation of heat units increased the yield in maize and vice-versa. Among *kharif* 2022 sowing windows, the highest yield (14142 kg ha^{-1}) and heat use efficiency (8.4) were obtained during the early sowing followed by mid (10918.3, 6.9) and late sowing (9353.3, 6.7) respectively. This relationship was also substantiated by Naveen *et al.* (2020), who found that the higher accumulation of heat units with respect to long phenophasic duration of early sowing increased yield in green gram and vice-versa.

Correlation and regression analysis

The correlation relationship of Baby corn yield and weather parameters for winter (Fig. 4.) and *kharif* (Fig. 5) seasons revealed that most of the meteorological parameters had a negative correlation with the Baby corn yield, except RH-I, WS, SR and HUE during winter 2022. In contrast weather parameters viz., RH-II, WS, RF, Daylength and HUE showed positive correlation during *kharif* 2022 with respect to crop yield. Similarly, the correlation analysis between various thermal indices and yield revealed that there was a negative relationship among GDD, HTU, PTU and RTD during both

Table 5. Growing Degree Days (GDD) and Helio Thermal Unit (HTU) of Baby corn during winter and *kharif* 2022

Phenophases	GDD						HTU					
	Winter			*Kharif*			Winter			*kharif*		
	D_1	D_2	D_3	D_1	D_2	D_3	D_1	D_2	D_3	D_1	D_2	D_3
P_1	971	974	1006	1018	1034	1027	7292	7141	7714	4227	4873	5479
P_2	99	87	53	187	225	153	686	749	159	1428	1194	817
P_3	107	78	44	164	194	141	686	664	287	811	1159	1198
P_4	1068	1061	1059	1205	1255	1141	7965	7887	7874	5655	6048	6296
P_5	204	157	97	353	381	294	1359	1343	454	2241	2149	2015
P_6	1175	1139	1103	1373	1553	1282	8651	8551	8168	6475	7704	7494
1st to final Harvest	209	223	172	206	235	155	1593	1295	1404	1044	1908	1206
Total	1392	1360	1275	1576	1690	1395	10314	9881	9572	7511	9141	8408

Table 6. Photo Thermal Unit (PTU) and Relative Temperature Disparity (RTD) of Baby corn during winter and *kharif* 2022

Phenophases	PTU						RTD					
	Winter			*Kharif*			Winter			*kharif*		
	D_1	D_2	D_3	D_1	D_2	D_3	D_1	D_2	D_3	D_1	D_2	D_3
P_1	11216	11466	12054	12638	12785	12155	1721	1666	1596	1156	1196	1198
P_2	1190	1056	651	2305	2750	1854	159	116	66	234	281	174
P_3	1294	950	534	2009	2354	1707	159	101	62	213	232	206
P_4	12385	12521	12705	14943	15475	14008	1877	1782	1662	1390	1470	1372
P_5	2462	1911	1184	4333	4637	3561	316	207	129	449	465	380
P_6	13678	13471	13239	16991	19125	15715	2036	1883	1725	1607	1837	1578
1st to final Harvest	2530	2723	2111	2518	2839	1874	284	286	217	251	348	231
Total	16302	16155	15350	19469	20750	17077	2330	2166	1942	1854	2058	1747

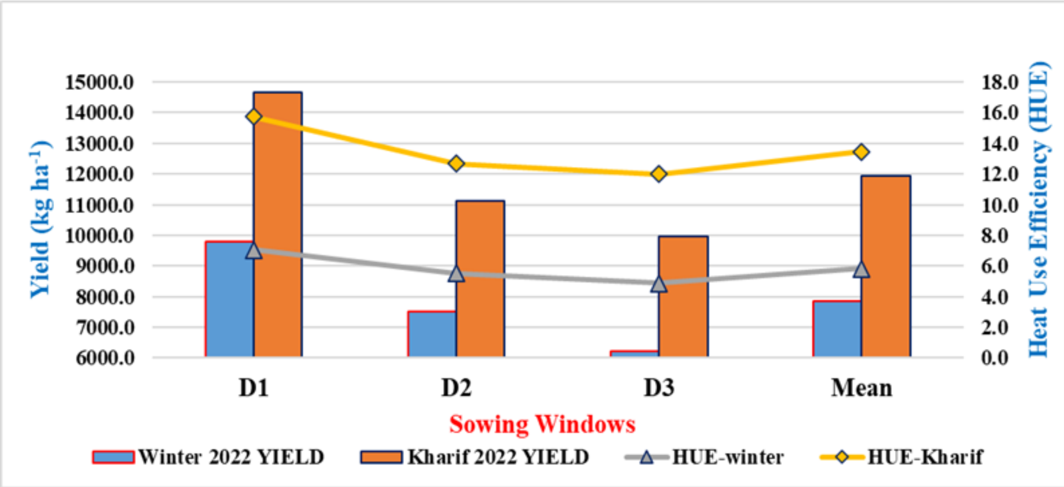

Fig. 3. *Yield and Heat use efficiency of Baby corn during winter and kharif 2022*

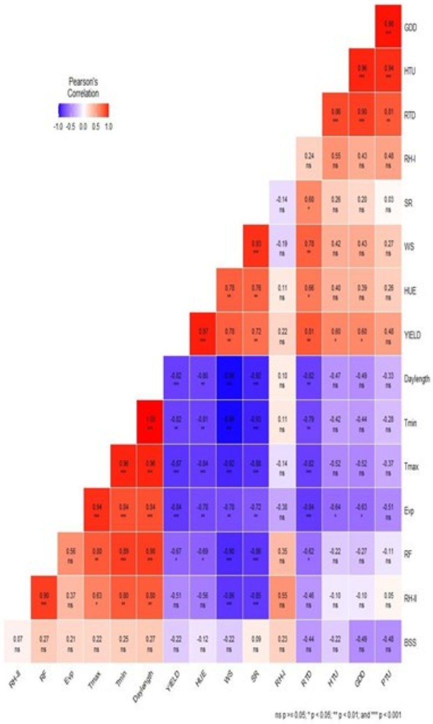

Fig. 4. *Correlation coefficient between yield and weather parameters during winter 2022*

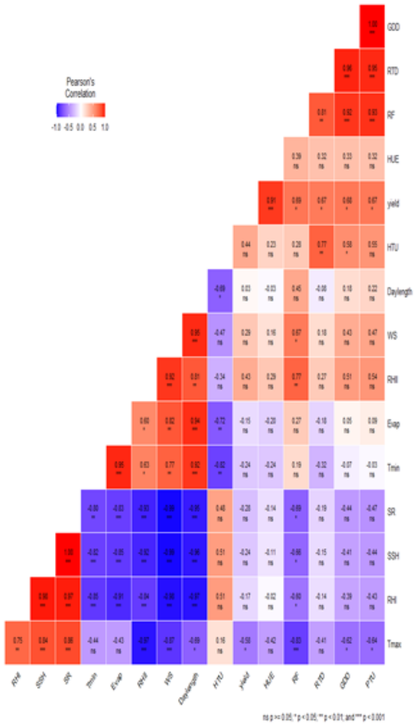

Fig. 5. *Correlation coefficient between yield and weather parameters during kharif 2022*

the cropping seasons. Based on the significant correlation, step wise regression was used to develop a regression model as given below:

Model 1 (winter, 2022) - Y= 805270 -3615 (Tmax) -3803 (RH-I) -2430 (RH-II) -22287(WS) -4424 (SSH); R^2=0.802

Model 2 (*kharif*, 2022) - Y= 5977321- 53432 (RH-I) -1681 (RH-II) -33772 (WS)-20917 (SSH)- 68.8 (RF); R^2=0.795

The above model determined that the higher temperature during late winter sowing (34°C) and during late kharif sowing (30.9°C) was not conducive for higher cob yield than early sowing.

Conclusion

This research study concluded that the seasonal efficiency was higher during *kharif* season cultivation than during winter. Hence, the *kharif* season was highly suitable for Baby corn cultivation in the western agro-climatic zones of Tamilnadu. In terms of duration, quick attainment of phenophases was noticed during the late sowing of both winters and *kharif* 2022. Early sowing increased the duration of the crop and accumulated a higher amount of heat units, viz., GDD, HTU, PTU, RTD and HUE, due to longer phenophasic duration than other sowing windows. Optimum date of sowing influenced the performance of the crop through better utilization of heat units. However, location-specific technologies are needed to achieve higher yield potential for Baby corn.

ACKNOWLEDGEMENTS

The authors acknowledge the support provided by Agro Climate Research Centre, Tamil Nadu Agricultural University, Coimbatore-641003.

Conflict of interest

The authors declare that they have no conflict of interest.

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