RESEARCH ARTICLE

Impact of Heat Units on the Phenology and Yield of Baby Corn (*Zea mays* L.) in Western Agro Climate Zone of Tamil Nadu

SANKAR T*, RAMANATHAN SP, KOWSHIKA N, KOKILAVANI S AND ARUNKUMAR P

Agro Climate Research Centre, Tamil Nadu Agricultural University, Coimbatore-641003, Tamilnadu, India

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ABSTRACT

Field investigation was carried out during winter 2022 at Tamil Nadu Agricultural University, Coimbatore to study the phenological behaviour and yield of baby corn (Zea mays L.) as influenced by heat units. The split-plot design consisting of three dates of sowing viz., D_1 – 21st January, D_2 – 5th February and D_3 – 20th February as a main plot and three spacing viz., 60x45 cm (S_1), 60x30 cm (S_2) and 60x20 (S_3) as a sub plot was adopted and replicated thrice. Growing Degree Days, Helio Thermal Unit and Heat Use Efficiency were calculated for different phenological stages viz., plant emergence to 50% flowering (P_1), 50% flowering to cob emergence (P_2), cob emergence to harvest (P_3), plant emergence to cob emergence (P_4), 50% flowering to harvest (P_5) and plant emergence to harvest (P_6). The results revealed that sowing on 20th Feb. had completed the phenophases early, followed by 5th Feb and 21st Jan. GDD required for attaining physiological maturity was highest in 20th Feb. (1194.6 °C days)). Except morning relative humidity, wind speed and solar radiation, all other weather parameters had negative correlation with baby corn yield (R^2=0.921). The optimum temperature was obtained during D_1 (27.2 – 27.5 °C) along with short-day length (11.7 hours) resulting in higher corn yield (9333.3 kg/ha) as well as higher HUE (5.75).

Keywords: *Baby corn; sowing window; heat units; phenology; cob yield; HUE*

INTRODUCTION

Baby corn (*Zea mays* L.) known as mini corn or candle corn is an unfertilized young earhead, harvested when silks have turned pinkish colour just after emergence (Rani *et al.,* 2017). The crop is newly evolved as dual purpose (vegetable and fodder) crop that grown round the year in India (Kumar *et al.,* 2015). Baby corn is popular among domestic and foreign markets as it has both processing and export potential (Das *et al.,* 2008). Presently in Indian, Meghalaya, Uttar Pradesh, Haryana, Karnataka, Maharashtra and Andhra Pradesh (Rahan and Sow, 2021) are growing Baby corn. Being a very short duration crop, 3 to 4 crops of baby corn can be taken up in a single year, depending upon agro-climatic conditions. Besides, it produces higher green fodder per unit area (Nataraj *et al.,* 2011). The increase in production of baby corn is necessary to meet the demand of vegetables for the burgeoning population of both human and animals (Kumar *et al.,* 2013).

Growth and yield potential of baby corn crop is highly season bound, vary across the growing seasons (Moreira *et al.,* 2010). Baby corn is extremely sensitive to temperature and growth and yield is highly temperature dependent (Hatfield and Prueger, 2015). Successful growth of baby corn requires an optimum temperature of 22°C to 28°C and if daytime temperature exceeds 30°C, Baby corn may be injured and suffered with slow growth and yield reduction (Ben-Asher *et al*., 2008).

Optimum sowing window can not only improve maize yield but also fit corn in existing cropping pattern (Choudhury *et al.,* 2021). Several researches had confirmed that baby corn yield significantly decreases with increase in temperature. Usually, plants require a definite Growing Degree Day (GDD) to get change in phenophases, which is calculated based on daily average temperature from date of sowing (Dahmardeh, 2012). Due to the environmental variations over time and space, sowing window has a profound influence on both

*Corresponding author's e-mail: sankaracrc@gmail.com

growth and yield of crops (Iizumi and Ramankutty, 2015). For example, late sowing of sunflower experiences lower temperature, with decrease in GDD from 1731 to 1621 during the grain filling period resulting in low yield (Sur and Sharma, 1999). Soler *et al.*, 2007 reported that delayed sowing reduced the hybrid maize yield by about 55 per cent under rainfed condition, whereas yield reduction was only 21 per cent in irrigated condition.

Thermal environment during reproductive phase of baby corn contributed more towards yield formation process, as compared to during vegetative phases. Hence, the experiment was taken to study the phenological behaviour of baby corn (*Zea mays* L.) and thermal indices as influenced by sowing window and crop geometry in western region of Tamilnadu.

MATERIAL AND METHODS

Experimental location

Coimbatore district lies between 10º 13' 00" to 11º 23' 30" N latitude and 76º 39'00" to 77º 30' 00" E longitude and confined on northwest side by Nilgiris, northeast by Erode districts and to the southeast by Dindigul district and on the west and south by Kerala state. Soil of the experimental plot was clay loam in texture and calcareous in nature, which contains low organic carbon and available nitrogen (213 kg ha^{-1}), high in available phosphorus (31.0 kg ha^{-1}) and potassium status (640 kg ha^{-1}).

Experimental details

The variety F1 Sundar of baby corn (*Zea mays* L.) was used as test crop to conduct the field experiment during winter 2022. The split-plot design consisted of three dates of sowing viz., D_1 – 21st January, D_2 – 5th February and D_3 – 20th February as a main plot and three spacing *viz.*, 60x45 cm (S_1), 60x30 cm (S_2) and 60x20 (S_3) as a sub plot which was replicated thrice. Totally, 27 sub-plots with the plot size of 5x5 m^2 area used for the experiment. All other package of practices were followed as per the TNAU Crop Production Guide (CPG, 2020). Harvesting of baby corn was done when the silk turns milky white to pinkish colour.

Date of occurrences of baby corn phenophases like Plant Emergence (PE), 50 per cent flowering, cob emergence (CE) and harvesting were recorded when the 50 per cent baby corn plants reached respective stages. Accordingly, weather parameters pertaining to the different baby corn phenological stages viz., plant emergence to 50% flowering (P_1), 50% flowering to cob emergence (P_2), cob emergence to harvesting (P_3), plant emergence to cob emergence (P_4), 50% flowering to harvesting (P_5) and plant emergence to harvesting (P_6) were also studied. In addition, weather derivatives such as, Growing Degree Day (GDD) with a base temperature (Tb) of 6.6ºC, Photo Thermal Unit (PTU), Helio Thermal Unit (HTU), Relative Temperature Disparity (RTD) and Heat Use Efficiency (HUE) were also calculated as given in Table 1 to study the growth and development as well as yield. Correlation between the baby corn yield and all the heat units were worked out as suggested by Gomez and Gomez (1984).

Table 1 Formulae used for heat units calculation,

Parameter	Relationship	Reference
GDD	$GDD = \sum_{i=1}^{n}((\mathrm{Tmax} + \mathrm{Tmin}/2)) - Tb$	Iwata, 1984
HTU	$HTU = \sum_{i=1}^{n}(GDD * SSH)$	Rajput, 1980
HUE	$\mathrm{HUE} = \mathrm{Yield}/\mathrm{GDD}$	Haider *et al.,* 2003

The daily data of weather parameters viz., maximum and minimum temperature, wind speed, rainfall, bright sunshine hours and relative humidity during the crop season (winter 2022) were obtained from the Agro Climate Research Centre, TNAU, Coimbatore. The weather prevailed during the cropping season viz., maximum temperature (31.1 ºC to 35.4 ºC), minimum temperature (19.0 ºC to 24.7 ºC), total rainfall (49.4 mm), RH (52.9 % to 71.0%), wind speed (4.0 km/hr to 6.0 km/hr) and sunshine hours (3.0 hours to 8.6 hours) are depicted in the Fig. 1.

Data on the baby corn phenological stages and yield attributes were statistically analyzed by correlation coefficient and step wise regression techniques at 5% significance level and critical differences of the treatment were examined through using R software. The detailed results were discussed in this paper.

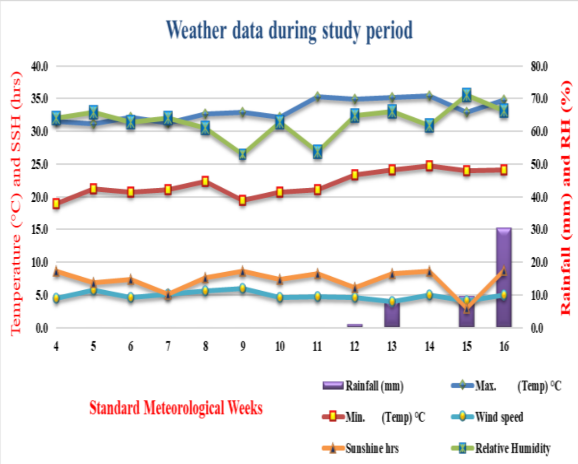

Fig 1. Standard meteorological data during the study period (winter 2022)

RESULTS AND DISCUSSION

The results of the present field experiment during the winter 2022 to study the impact of different sowing window and crop geometry on the phenology and yield of baby corn were statistically analyzed and presented in this paper.

Phenophases duration of baby corn

The duration of different phenophases across the different dates of sowing were summarized and presented in Table 2. The mean duration for emergence to 50% flowering (P_1), 50% flowering to emergence of cobs (P_2) and emergence of cobs to harvest (P_3) were 47.8, 3.0 and 3.2 days, respectively.

Among the different sowing window, the quick attainment of phenophases had noticed in D_3 (20th February), which was followed by D_2 (5th February) and D_1 (21st January). In crop geometry, wider spacing (60x45 cm – S_1) attained the phenological maturity earlier than other two crop geometries (60x30 cm – S_2 and 60x20 cm – S_3). Among the treatment combinations, D_1S_3 had taken longer duration between the first and final harvest (16.3 days), whereas lesser duration recorded in D_3S_1 treatment (7.3 days). The same trend of phenophases duration was obtained in the total duration of the crop, where the D_1S_3 had completed the life cycle in 81.7 days and the shortest duration was noticed in D_3S_1 treatment (62.0 days) (Table 2).

Results on the days to phenophases of the crop indicated that the crop duration had reduced with delayed planting due to the start facing of summer at its early stage itself. The amount of solar radiation and daily mean temperature received were higher in late sown crops than early and mid-sown, which accelerated the physio-chemical process and thereby enhanced the growth and development of baby corn.

Similar results were obtained by Thavaprakash *et al.,* 2007 that the crop attained phenophases very quickly during summer season and it was delayed during late *rabi* and early winter seasons. Borowiecki (1992) reported that May month sown crop had shortened period from emergence to spikelet differentiation of the tassel and effective heat sums was 1299-1450 °C days. Bairagi *et al.,* 2020 observed that early to mid-winter sown plants' cobs took longer days to attain maturity whereas late winter to early summer sown plants' cobs took lesser duration to mature.

The late winter sown (D_3- 20th February) cobs matured early due to higher ambient temperature which favoured the cob yield. Days taken to attain the flowering stage was lesser in late sown (D_3- 45.8 days) than early sown (D_1- 49.9 days). High temperature significantly reduced the days to 50% flowering and maturity in maize (Vanaja *et al.,* 2017). The main plot and subplot interactions showed that the treatments of February planting of baby corn took significantly lower number of days to 50% flowering than November planting (Bairagi *et al.,* 2015). Shrestha *et al.,* 2016 mentioned that days to attain different phenological stages were decreased with delayed sowing due to the mean ambient temperature during their research period was increasing with delayed sowing.

Coefficients of variabilities of various weather parameters

Growing Degree Days (GDD)

Growing Degree Days (GDD) required for attaining physiological maturity was highest in D_3 (1195 °C days) followed by D_2 (1174 °C days) and D_1 (1162 °C days). Delayed sowing during winter season increased the GDD by up to 32.6 °C days. Results revealed that CV (%) was lowest during P_1 stage (0.2%) than all other stages which clearly explained that early sowing (21st January) received increasingly stable weather condition during sowing to 50% flowering stage of Baby corn as compared to other phenophases. In contrast, the highest CV (%) was observed during the physiological harvest stage (26.8%) followed by P_2 stage (23.4%) (Table 3). It showed that physiological harvest stage and 50% flowering to cob emergence stage of Baby corn had experienced to maximum variability of weather and these variations at different phenophases were affected the yield components of baby corn at harvest. The same trend was obtained by Bairagi *et al.,* 2020. Shrestha *et al.,* 2016 mentioned that statistically similar GDD was recorded for different sowing dates and higher values were noticed with delay in planting.

Helio Thermal Unit (HTU)

The HTU observed among different phenophases was highest at P_6 stage (8759.0 °C day hour) than all other stages. Among the different sowing windows, D_1 achieved the highest HTU (11236.7 °C day hour), followed by D_2 and D_3 (10496 and 10486.5 °C day hour) respectively (Table 3). The higher accumulation of HTU was observed under early sowing because of the longer phenophasic duration of the baby corn. The days taken to complete each stage was minimum in summer and lower values of degree days which in turn reduced the HTU.

Heat units on baby corn yield

The yield was highest in S_3 crop geometry during all the sowing windows. Among the different sowing windows, D_1 achieved the highest yield than other sowing dates (Fig 2). The optimum temperature during D_1 (27.4°C), D_2 (28.2°C) and D_3 (28.5 °C) and mean day length of D_1 (11.7 hours), D_2 (11.9 hours) and D_3 (12 hours), combined helped to obtain the maximum yield under D_1 sowing window than others. The planting densities of baby corn were 37,037, 55,555 and 83,333 plants ha^{-1} at S_1 (60x45), S_2 (60x30) and S_3 (60x20) crop geometries, respectively. The result showed that the increase in planting density combined with proper agronomic management and micro-meteorological influences significantly improved the physiological traits, which consequently increased the crop yield. Result obtained by Thiem *et al.,* 2020 supported this research that highest planting density combined was effective in controlling weeds and increased the cob yield. Panda and Dutta (2019) also found similar results that closer spacing (45x20) of Baby corn achieved highest yield due to increasing in the plant population.

Statistical relationship

Detailed statistical relationship between baby corn yield and weather variables pertaining to a particular phenophases showed maximum degree of association and the results were presented in Fig. 3a-3d. The results revealed that all meteorological weather parameters had negative significant correlation with the Baby corn yield, except RH1, WS and SR which had positive correlation with respect to crop yield (Table 4). Similarly, the correlation analysis between various thermal indices and yield revealed that there was significant relationship among GDD, HTU and Baby corn yield (Fig 3c-3d). Using correlation analysis, the relationship between yield and average weather parameters was analysed and developed a regression model as given below,

$$Y= -20517.326+18.231 (GDD), R^2=0.921$$

The correlation relationship between cob yield and weather parameters indicates that comparatively lesser mean temperature during early winter sowing (27.4°C) was more conducive for higher cob yield than average temperature observed during late winter period (28.5°C). This relationship also corroborated by Hemalatha *et al.,* (2013) that higher accumulation of heat units with respect to long phenophasic duration of early sowing increased maize yield, while lower accumulation of heat units in late sowing resulted with low yield. Naveen *et al.,* 2020 found the same relationship in green gram study.

Heat Use Efficiency (HUE)

HUE values of baby corn during different sowing windows were calculated and presented in Fig 4. Among the different sowing windows, higher HUE was observed during D_1 (5.7) sowing window, which could be attributed to the higher baby corn yield. Due to high maximum temperature during D_3 sowing window, baby corn yield was reduced, as the crop is highly sensitive to increasing temperature. The optimum temperature for Baby corn is 22°C to 28°C which was obtained during the D_1 sowing, optimum mean temperature and short-day length during the D_1 sowing of winter 2022 season resulted in higher baby corn yield. Similar relationships were obtained by Rajput *et al.,* 1987, Paul and Sarkar (2000) and Haider *et al.,* (2003) in different sowing windows. Sahoo and Panda (1999) got the highest yield of Baby corn in both wet and winter season.

CONCLUSION

It is concluded that, among the different weather parameters, temperature played a vital role in plant growth and development, which had decided the change of different phenophases of the crop. Though the maximum temperature was beneficial for the quick attainment of phenophases in D_3 sowing window, the yield was reduced drastically. The optimum temperature obtained during D_1 (27.2 – 27.5 °C) along with short-day length (11.7 hours) supported the equitable day-night temperature condition and thereby resulted in higher corn yield.

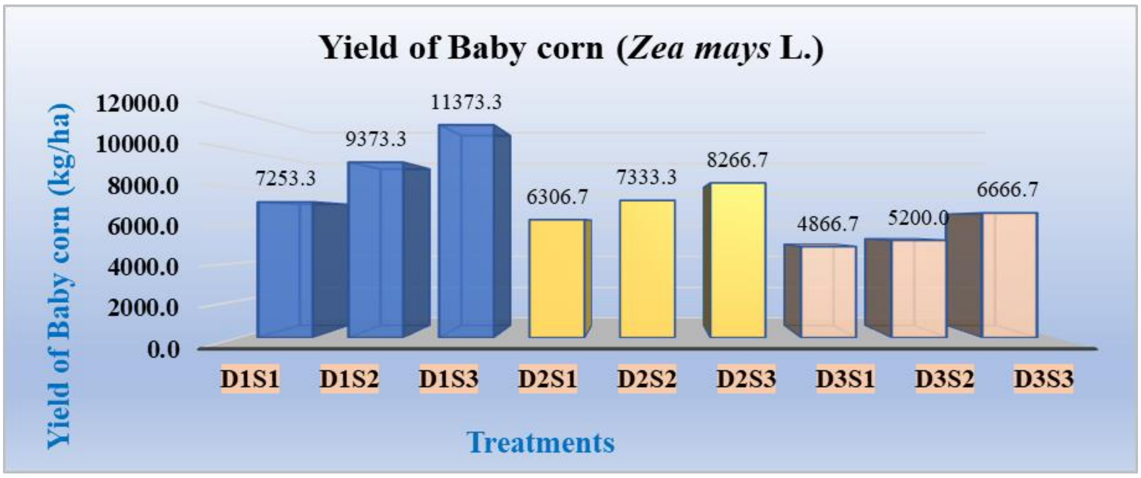

Fig 2. Yield of Baby corn (*Zea mays* L.) during different sowing window

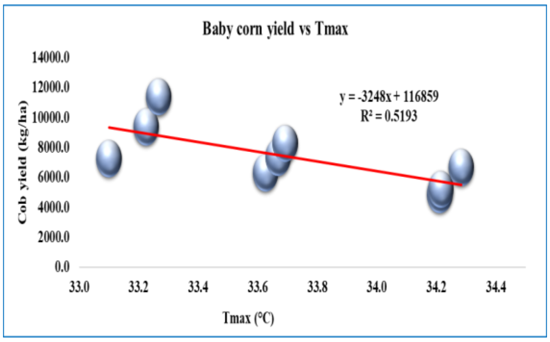

Fig 3a. Impact of Tmax (°C) on Baby corn yield

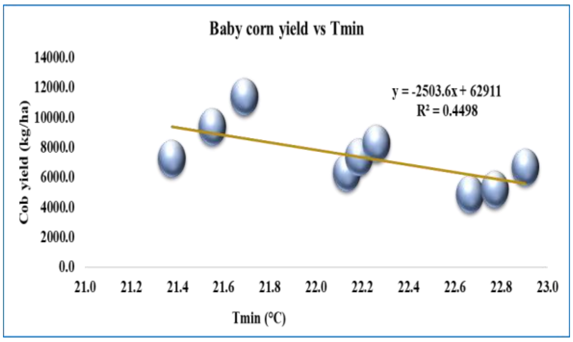

Fig 3b. Impact of Tmin (°C) on Baby corn yield

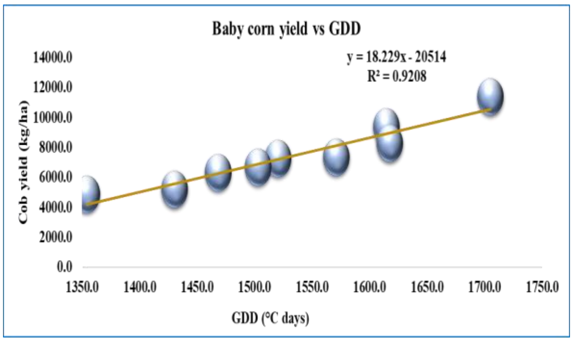

Fig 3c. Impact of GDD (°C days) on Baby corn yield

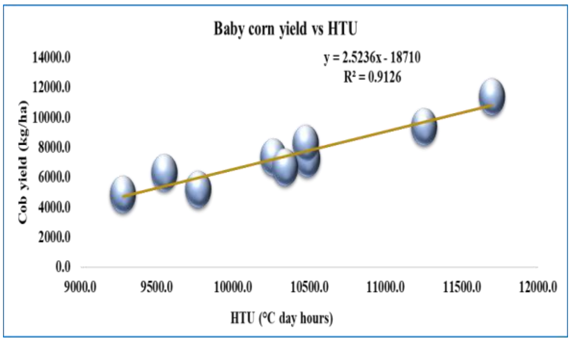

Fig 3d. Impact of HTU (°C day-hours) on Baby corn yield

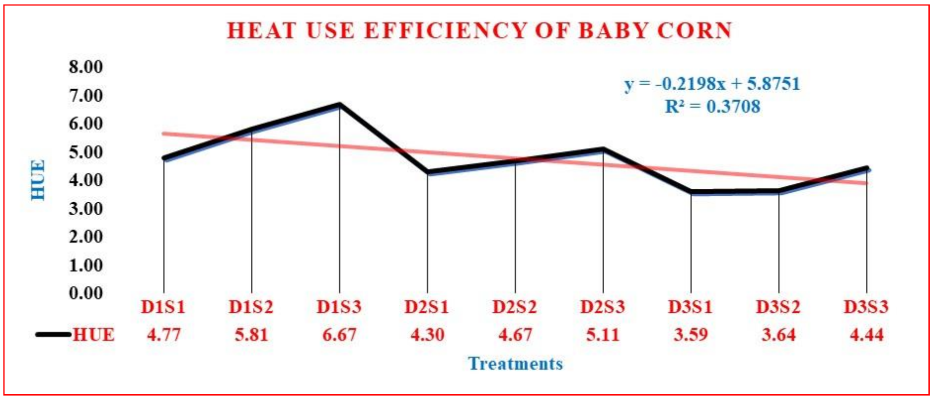

Fig 4. Heat Use Efficiency during different sowing window of winter season

Table 2. Duration of different phenophases of Baby corn as influenced by dates of sowing

Phenophases	D_1			D_2			D_3			Mean	SD	CV (%)
	S_1	S_2	S_3	S_1	S_2	S_3	S_1	S_2	S_3			
P_1	48.7	50.3	50.7	47.3	48.0	48.3	45.3	45.7	46.3	47.8	1.9	4.0
P_2	3.0	3.7	4.3	2.3	3.0	3.3	2.0	2.0	3.3	3.0	0.8	26.0
P_3	3.3	3.3	4.3	2.7	3.3	3.7	2.0	3.0	3.0	3.2	0.6	20.1
P_4	51.7	54.0	55.0	49.7	51.0	51.7	47.3	47.7	49.7	50.9	2.6	5.1
P_5	6.3	7.0	8.7	5.0	6.3	7.0	4.0	5.0	6.3	6.2	1.4	22.4
P_6	54.7	57.3	59.3	52.3	54.3	55.3	49.3	50.7	52.7	54.0	3.1	5.8
1st to final Harvest	14.0	15.0	16.3	10.7	13.3	13.7	7.3	9.0	9.7	12.1	3.0	25.1
Total duration	74.0	78.0	81.7	69.0	73.7	75.7	62.0	65.3	68.3	72.0	6.3	8.8

Table 3. Weather parameters pertaining to indices (GDD and HTU)

Phenophases	GDD						HTU					
	D_1	D_2	D_3	Mean	SD	CV (%)	D_1	D_2	D_3	Mean	SD	CV (%)
P_1	1001.4	1003.4	1005.1	1003.3	1.9	0.2	7536.6	7436.3	7745.3	7572.7	157.6	2.1
P_2	80.2	67.2	49.6	65.7	15.4	23.4	550.1	584.0	147.7	427.3	242.7	56.8
P_3	80.3	75.6	56.9	70.9	12.4	17.5	481.3	636.2	343.7	487.1	146.3	30.0
P_4	1081.6	1070.6	1053.3	1068.5	14.3	1.3	8086.7	8020.3	7905.6	8004.2	91.6	1.1
P_5	158.0	142.8	110.2	137.0	24.4	17.8	1013.6	1220.2	492.3	908.7	375.1	41.3
P_6	1162.0	1174.0	1194.6	1176.9	16.5	1.4	8568.0	8892.7	8816.3	8759.0	169.8	1.9
1st to final Harvest	348.6	283.1	200.3	277.3	74.3	26.8	2668.7	1603.3	1670.2	1980.7	596.7	30.1

Table 4. Correlation coefficient of weather parameters and pertaining indices with respect to Baby corn yield during Winter 2022

Correlations	yield	Tmax	Tmin	BSS	Daylength	RH-I	RH-II	RF	WS	Evp	SR	GDD	HTU	PTU	RTD	HUE
yield	1															
Tmax	-.700*	1														
Tmin	-.669*	.994**	1													
BSS	-.352	.351	.292	1												
Daylength	-.665	.965**	.971**	.120	1											
RH-I	.713*	-.576	-.547	.000	-.614	1										
RH-II	-.468	.905**	.927**	.072	.934**	-.331	1									
RF	-.576	.869**	.886**	.099	.860**	-.440	.917**	1								
WS	.546	-.745*	-.694*	-.811**	-.582	.273	-.567	-.600	1							
Evp	-.821**	.765*	.769*	.000	.841**	-.822**	.628	.616	-.325	1						
SR	.726*	-.995**	-.994**	-.291	-.980**	.599	-.913**	-.878**	.701*	-.815**	1					
GDD	.960**	-.652	-.602	-.445	-.603	.779*	-.346	-.431	.582	-.788*	.666	1				
HTU	.955**	-.650	-.629	-.096	-.684*	.818**	-.454	-.540	.353	-.902**	.692*	.922**	1			
PTU	.822**	-.361	-.300	-.440	-.303	.744*	.009	-.108	.410	-.623	.374	.929**	.799**	1		
RTD	.944**	-.874**	-.846**	-.394	-.840**	.763*	-.649	-.682*	.669*	-.880**	.886**	.934**	.908**	.747*	1	
HUE	.998**	-.722*	-.695*	-.329	-.695*	.707*	-.511	-.617	.552	-.835**	.751*	.945**	.955**	.791*	.946**	1

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Ethics statement

No specific permits were required for the described field studies because no human or animal subjects were involved in this research.

Consent for publication

All the authors agreed to publish the content.

Competing interests

There were no conflict of interest in the publication of this content

Data availability

All the data of this manuscript are included in the MS. No separate external data source is required. If anything is required from the MS, certainly, this will be extended by communicating with the corresponding author through corresponding official mail; sankaracrc@gmail.com

Author contributions

Author contributions: Research idea conceptualization - ST, SPR, SK, Experiments Conducted - ST, Guidance – SPR, SK, NK, PA, Writing original draft – ST, Writing, reviewing and editing of manuscript - ST, SPR.

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