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**Research Paper**

# Utilization of thermal indices for production of nutri-cereals in non-traditional areas of Bihar

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## ABSTRACT

An experiment was conducted during summer seasons of 2017 and 2018 on clay-loam soil of the ICAR-Research Complex for Eastern Region, Patna, Bihar, to study the performance of different nutri-cereals and their heat-unit requirements to complete their phenological cycles. Significantly higher grain yield, i.e. 1.92, 1.76 and 1.53 t/ha, was achieved in barnyard millet (*Echinochloa esculenta* (A. Braun) H. Scholz) followed by sorghum [*Sorghum bicolor* (L.) Moench] and pearl millet [*Pennisetum glaucum* (L.) R. Br.], respectively. Whereas the higher straw and biological yields were observed in sorghum (8.91 and 10.8 t/ha), pearl millet (7.14 and 8.67 t/ha) and little millet (*Panicum sumatrense* Roth ex Roem. & Schult.) (5.50 and 6.67 t/ha). Barnyard millet also showed the maximum crop productivity (24 kg/ha/day). Remarkably higher biomass productivity was noted in sorghum (114.7 kg/ha/day), followed by pearl millet and little millet (96.3 and 85.5 kg/ha/day). Pearl millet (702.9°C-day) accumulated the minimum growing degree-days (GDD) to attain 50% flowering. Further, pearl millet (4,111. 4°C day-hr) being at par with proso-millet (*Panicum miliaceum* L.) (4,280.3°C day-hr) and little millet (4,295.7°C day hr) attained significantly lower heliothermal units (HTU) to reach 50% flowering. Barnyard millet (1.25 kg/ha °C-day), followed by sorghum and pearl millet (1.01 and 0.91 kg/ha °C-day) acquired considerably higher HUE for grain production. Sorghum (6.11 kg/ha °C-day) followed by pearl millet (5.17 kg/ha °C-day) and little millet (4.48 kg/ha °C-day) captured significantly maximum HUE for biomass production. Our results indicated that, cultivation of nutri-cereals such as barnyard millet, sorghum, pearl millet and little millet is a viable option to utilize the fallow period (summer season) for achieving the nutritional security and realizing the livelihood improvement in this region.

***Key words***: Agro-meteorological indices, Crop productivity, Heat-use efficiency, Nutri-cereal

Millets/nutri-cereals are major staple food of rainfed agricultural production system. These are highly nutritious in terms of protein, essential fatty acids, dietary fibre, B-vitamins, minerals, i.e. Ca, Fe, Zn, K and Mg. These nutri-cereals can help in rendering various health benefits, viz. reduction in blood sugar level, blood pressure regulation, thyroid, cardiovascular, celiac and many more neonatal diseases. It scores relatively high in nutritional values compared to other cereal grains like wheat and rice (Kumar *et al.,* 2018). Major cereals, which are grown with heavy fertilization, irrigation, and pesticides, have now reached yield plateau (Kumar *et al.,* 2021a, b). Further, climate uncertainties and vulnerability also aggravate the problems for food-production systems. Therefore, over the last few decades, cultivation of nutri-cereals has gained importance. Shorter growing period, resistance to drought, tolerance to several insect-pests and diseases are certain unique characteristics of these crops which make possible their survivability in less-fertile soil with lower water requirement. Being $C_4$ crops, millets possess higher water-use efficiency and help sustain climatic uncertainties, decrease atmospheric $CO_2$ and play a role in mitigating the adverse effects of climate change.

Presently, in eastern regions of the country, there exist a large time gap (~70–90 days) between harvesting of winter (*rabi*) crops and transplanting of rice. Thus, major portion of this part of the country remains fallow during this period, which otherwise can be used for cultivation of short-duration nutri-cereals (Kumar *et al.,* 2020). In coastal areas of Odisha, large area remains fallow after rainy (*kharif*) paddy due to non-availability of adequate water for growing succeeding crop (Kumar *et al.,* 2017). In such areas, millets as a climate-change compliant crops have a

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potential to contribute to food and nutritional security, besides improving the livelihood standards of a common man (Mishra *et al.,* 2017). Hence, the phenology and yield of millets in response to atmospheric temperature needs to be studied under field conditions through accumulated heat-unit system. Rate of their plant growth and development is highly dependent on fluctuations in micro-climatic temperatures as each species has a specificity for cardinal temperatures, represented by a minimum, maximum and optimum range and values of which has already been summarized by Hatfield *et al.* (2011). Meteorological indices, viz. growing degree-days (GDD) and heliothermal unit (HTU)-based on air temperature can also be quite useful in predicting growth behaviour and crop yield (Prakash *et al.,* 2017, 2018; Prasad *et al.,* 2017). Presently, the information available on agro-meteorological indices of nutri-cereals to forecast changes in their growth pattern and crop yield are scanty in the eastern region of our country. Therefore, the present study was undertaken with an objective to establish the heat-unit requirements for various millets to complete their phenology in the alluvial soils of Bihar.

## MATERIALS AND METHODS

This study was carried out at ICAR-Research Complex for Eastern Region, Patna (25°30'N, 85°15'E, 52 m above mean sea-level) during the 2 summer seasons of 2017 and 2018. Initial status of soil (0–15 cm depth) of experimental field was clay loam (23.37% sand, 39.63% silt and 38% clay) in nature, low in organic carbon (0.48%) and nitrogen (212 kg N/ha), medium in available phosphorus (19.8 kg $P_2O_5$/ha), high in available potassium (335 kg $K_2O$/ha) and neutral in soil reaction (*p*H 7.46). Meteorological phenomenon occurred during study period (March–July of 2017 and 2018) are presented in Fig. 1. The performance of 9 nutri-cereals including 2 major millets, viz. sorghum [*Sorghum bicolor* (L.) Moench] cv. 'CSV 17' and pearl millet [*Pennisetum glaucum* (L.) R. Br.] cv. 'HHB 67'; and 7 minor millets, viz. finger millet [*Eleusine coracana* (L.) Gaertn.] cv. 'DHFM 78-3', barnyard millet [*Echinochloa frumentacea* (L.)] cv. 'DHBM 93-2', brown top millet [*Brachiaria ramose* (L.) Stapf] cv. 'BP 1', foxtail millet [*Setaria italica* (L.) P. Beauv.] cv. 'DHFM 109-3', kodo millet [*Paspalum scrobiculatum* (L.)] cv. 'JK 41', little millet [*Panicum flexuosum* Retz.; syn. *P. sumatrense* Roth] cv. 'DHLM 36-3' and proso-millet [*Panicum miliaceum* (L.)] cv. 'DHPM 2769', were evaluated in a randomized block design with 3 replications. Recommended dose of nutrients, i.e. 80 kg N + 40 kg $P_2O_5$ + 40 kg $K_2O$ kg/ha, was applied to major millets (sorghum and pearl millet) whereas minor millets were fertilized with a common nutrient dose of 60 kg N/ha + 30 kg $P_2O_5$/ha + 30 kg $K_2O$/ha. Diammonium phosphate (DAP) and muriate of potash (MoP) fertilizers were used to supply basal P and K, respectively, whereas N was applied through urea in 2 equal splits-50% basal and remaining at 35 days after sowing (DAS) after subtracting the amount of N supplied by basal DAP.

Net plot size of experimental plot was 5.0 m × 4.0 m. Sorghum and pearl millet planted manually at a spacing of 45 cm × 15 cm, while all the minor millets were planted at a spacing of 30 cm × 15 cm. To control the initial weed flushes, atrazine @ 0.50 kg/ha was applied as

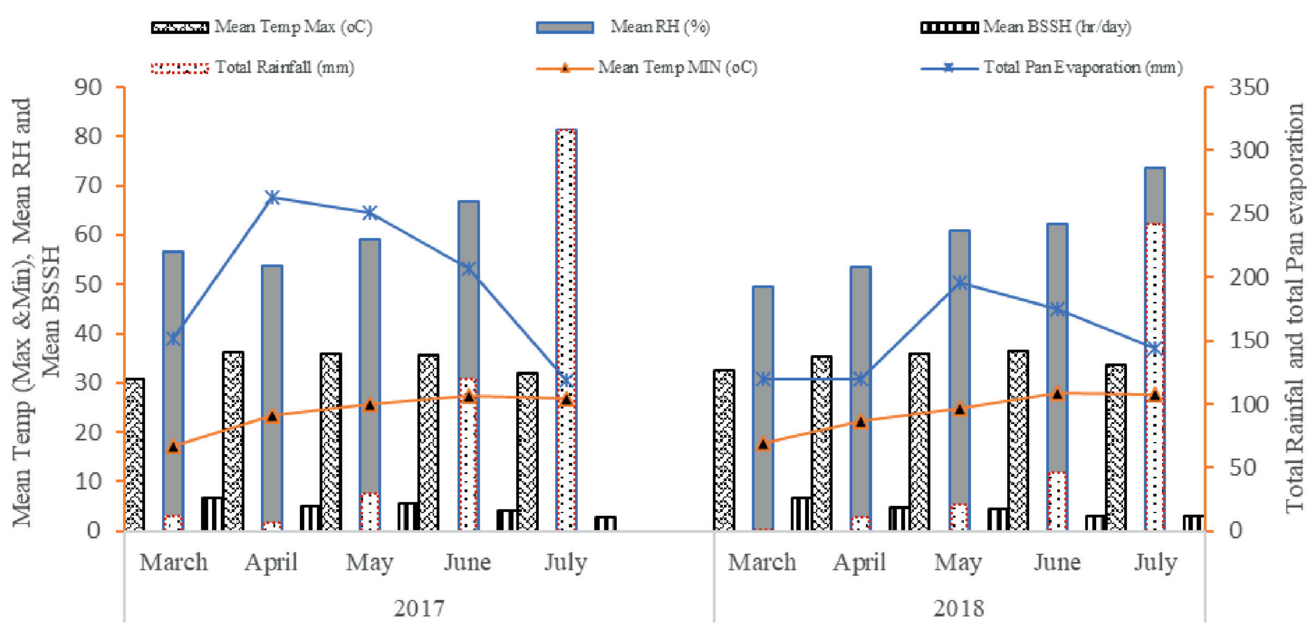


**Fig. 1.** Mean month-wise meteorological observations during period of active growth of different nutri-cereals

pre-emergence using 500 litres water/ha with the help of knap-sack sprayer, fitted with flat-fan nozzle. Hand-hoeing was also done at 25 DAS and the intra-row weeds were removed by hand-weeding simultaneously. To supplement the total rainfall, 3 irrigations were given during cropping period at critical stages like flowering and grain filling. The occurrence of phenological events were recorded from each plot and their average dates were calculated and used for analysis. Base temperature of 10°C was used for computation of growing degree-days (GDD) on daily basis (Leong and Ong, 1983). Agro-meteorological indices were computed for 2 phenophases of crop (50% flowering and physiological maturity) by adopting the procedure suggested by Rajput (1980). All recorded data were analyzed with help of analysis of variance (ANOVA) technique using Indian NARS Statistical Computing Portal. The least significant difference test (LSD) was used for comparison of treatment means at 5% level of significance ($P$=0.05). Correlation analysis was performed using the Pearson coefficient procedure (SPSSv19.) to determine the association between the parameters.

## RESULTS AND DISCUSSION

### *Phenological attributes*

Results revealed that, the nutri-cereals differed significantly among themselves to attain 50% flowering and physiological maturity (Table 1). Finger millet took significantly maximum number of days for attaining 50% flowering (95 days), whereas pearl millet (43), being at par with proso and little millet (45 and 47 days respectively) took the shortest time to reach 50% flowering. Kodo millet (117), being at par with finger millet (115), took more number of days to attain physiological maturity. However, foxtail millet (76), little millet (78), proso millet (79), and barnyard millet (80) were statistically similar and took considerably lower time to attain physiological maturity. Inherent variations due to genetic behaviour of nutri-millets has led to these differences in specific phenological attributes (Mishra *et al.,* 2017; Prakash *et al.,* 2017).

### *Crop productivity*

Significant variation in productivity levels among different nutri-cereals were recorded (Table 1). Higher grain yield was obtained with barnyard millet (1.92 t/ha), followed by sorghum (1.76 t/ha) and pearl millet (1.53 t/ha). Foxtail millet (0.98 t/ha), which remained at par with brown top millet (1.02 t/ha) witnessed noticeably lower grain yield. Markedly higher straw and biological yields were obtained in sorghum (8.91 and 10.7 t/ha), followed by pearl millet (7.14 and 8.67 t/ha) and little millet (5.5 and 6.67 t/ha). The trend for harvest index by various millets followed the pattern as barnyard millet > finger millet > kodo millet > foxtail millet > proso millet > brown top millet > pearl millet > little millet > sorghum. The harvest index (HI) of barnyard millet was significantly higher than all the other millets and the significantly lowest HI was exhibited by sorghum. It was also observed that, harvest indexes of 2 major millets-sorghum and pearl millet-were almost half of barnyard and finger millet, indicating the better efficiency of the latter 2 in producing grains per unit of straw produced. The grain productivity recorded in barnyard millet (24 kg/ha/day) was also significantly the highest compared with the other millets and was followed by sorghum (18.9 kg/ha/day) and pearl millet (17 kg/ha/day). The biomass productivity recorded in sorghum (114.7 kg/ha/day) was the highest and it was significantly higher than pearl millet (96.3 kg/ha/day) which was again significantly higher than little millet (85.51 kg/ha/day) which in turn was significantly better than barnyard millet (64.9 kg/ha/day). The biomass productivity of 4 minor millets, namely

**Table 1.** Crop phenology and yield attributes of different nutri-cereals in irrigated ecosystem of non-traditional growing area of Bihar (mean data of 2 years)

| Millet crops | Days to 50% flowering | Days to physiological maturity | Grain yield (t/ha) | Straw yield (t/ha) | Biological yield (t/ha) | Harvest index (%) | Grain productivity (kg/ha/day) | Biomass productivity (kg/ha/day) |
|---|---|---|---|---|---|---|---|---|
| Sorghum | $65^{C}$ | $93^{B}$ | $1.76^{B}$ | $8.91^{A}$ | $10.67^{A}$ | $16.49^{I}$ | $18.92^{B}$ | $114.7^{A}$ |
| Pearl millet | $43^{E}$ | $90^{B}$ | $1.53^{C}$ | $7.14^{B}$ | $8.67^{B}$ | $17.65^{G}$ | $17^{C}$ | $96.3^{B}$ |
| Finger millet | $95^{A}$ | $115^{A}$ | $1.13^{DE}$ | $2.20^{G}$ | $3.33^{F}$ | $33.93^{B}$ | $9.83^{F}$ | $28.9^{F}$ |
| Barnyard millet | $55^{D}$ | $80^{C}$ | $1.92^{A}$ | $3.27^{D}$ | $5.19^{D}$ | $36.99^{A}$ | $24^{A}$ | $64.9^{D}$ |
| Brown top millet | $65^{C}$ | $116^{A}$ | $1.02^{EF}$ | $2.87^{DE}$ | $3.89^{E}$ | $26.22^{F}$ | $8.79^{F}$ | $33.5^{F}$ |
| Foxtail millet | $56^{D}$ | $76^{C}$ | $0.98^{F}$ | $2.35^{FG}$ | $3.33^{F}$ | $29.43^{D}$ | $12.89^{E}$ | $43.8^{E}$ |
| Kodo millet | $79^{B}$ | $117^{A}$ | $1.20^{D}$ | $2.56^{EFG}$ | $3.76^{EF}$ | $31.91^{C}$ | $10.26^{F}$ | $32.1^{F}$ |
| Little millet | $47^{E}$ | $78^{C}$ | $1.17^{D}$ | $5.50^{C}$ | $6.67^{C}$ | $17.54^{H}$ | $15^{D}$ | $85.5^{C}$ |
| Proso millet | $45^{E}$ | $79^{C}$ | $1.14^{DE}$ | $2.75^{EF}$ | $3.89^{E}$ | $29.31^{E}$ | $14.43^{DE}$ | $49.2^{E}$ |
| CD (P=0.05) | 4.7 | 7.5 | 0.13 | 0.41 | 0.53 | 0.00 | 1.54 | 6.2 |

Data followed by different capital letters differ significantly ($P$=0.05) using least significant difference test for separation of mean of a particular parameter finger, brown top, foxtail and kodo millets, were even less than half of 2 major millets (sorghum and pearl millet). Variations in temperature and light intensity during different growth and reproductive phases of millets, affected initiation and duration of these phenophases. Prolonged reproductive period due to early attainment of flowering ensured proper development of grain and consequently higher yield in respective millets (Singh *et al.,* 2016).

### *Agro-meteorological indices*

Data related to different agro-meteorological indices for attaining days to 50% flowering and physiological maturity stages of millets are presented in the Table 2. Results elucidated that, finger millet (1,780.2°C day and 9,713.1°C day/hr), followed by kodo millet (1,515.4°C day and 8,656.1°C day-hr) accumulated higher growing degree-days (GDD) and helio thermal units (HTU) compared to other millets to attain 50% flowering. Whereas pearl millet (702.9°C Day) accumulated the minimum GDD to reach this stage. Pearl millet (4,111.4°C day-hr), being at par with proso millet (4,280.3°C day-hr) and little millet (4,295.7°C day-hr), significantly lower HTU to reach 50% flowering. Kodo millet (2,314.3°C day and 12,039°C day-hr), finger millet (2,210. 6°C day and 1,1748°C day-hr) and brown top millet (2,295.4°C day and 11,999.2°C day-hr) were found to be statistically similar and accumulated significantly higher GDD and HTU, respectively, to attain the physiological maturity compared to other tested nutri-cereals. Various researchers also reported similar results for different nutri-cereals (Maurya *et al.,* 2015; Bhuva and Detroja, 2018).

### *Heat-use efficiency*

Among the nutri-cereals, barnyard millet (1.25 kg/ha °C day) followed by sorghum and pearl millet (1.01 and 0.91 kg/ha °C day), showed considerably higher heat-use efficiency (HUE) for grain production (Fig. 2). However, brown top millet, finger millet and kodo-millet (0.44, 0.51

**Table 2.** Growing degree-days (GDD) and heliothermal units (HTU) accumulated by different nutri-cereals to attain 50% flowering and physiological maturity in irrigated ecosystem of non-traditional growing area of Bihar (mean data of 2 years)

| Millet crops | 50% flowering | | Physiological maturity | |
|---|---|---|---|---|
| | GDD (°C day) | HTU (°C day-hr) | GDD (°C day) | HTU (°C day-hr) |
| Sorghum | 1,150.8 C | 6,584.5 C | 1,745.5 B | 9,713.1 B |
| Pearl millet | 702.9 F | 4,111.4 E | 1,675.8 BC | 9,372.7 BC |
| Finger millet | 1,780.2 A | 9,713.1 A | 2,210.6 A | 11,748 A |
| Barnyard millet | 1,002.6 D | 5,572.6 D | 1,536.1 CD | 8,764.5 CD |
| Brown top millet | 1,203 C | 6,729.1 C | 2,295.4 A | 11,999.2 A |
| Foxtail millet | 1,021.5 D | 5,756.4 D | 1,443.8 D | 8,263.9 D |
| Kodo millet | 1,515.4 B | 8,656.1 B | 2,314.3 A | 12,039 A |
| Little millet | 837.7 E | 4,295.7 E | 1,490.1 D | 8,540 D |
| Proso millet | 801.8 E | 4,280.3 E | 1,515.4 D | 8,656.1 CD |
| CD (P=0.05) | 85.8 | 472.2 | 144.4 | 798.6 |

Data followed by different capital letters differ significantly (*P*=0.05) using least significant difference test for separation of mean of a particular parameter

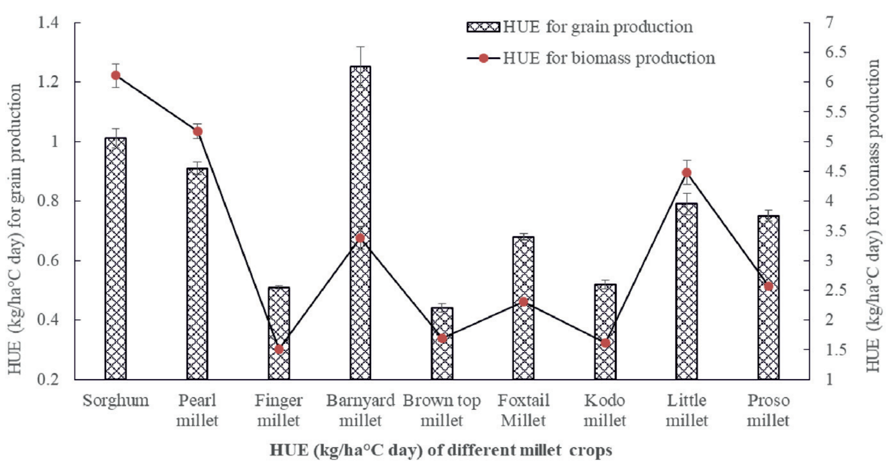


**Fig. 2.** Mean heat-use efficiency (HUE) of different nutri-cereals for grain and total biomass production

and 0.52 kg/ha °C day) showed markedly lower HUE for grain production. Significantly maximum HUE for biomass production was recorded in sorghum (6.11 kg/ha °C day), followed by pearl millet (5.17 kg/ha °C day). However, finger millet, kodo millet and brown top millet (1.51, 1.62 and 1.69 kg/ha °C day) were found at par with each other and showed remarkably lower HUE for biomass production compared to rest of the nutri-cereals. The HUE is conversion of heat energy into dry matter and depends on several factors including crop type and genetics of crops. Higher HUE for grain and biomass indicates the efficient dry-matter portioning to these respective plant parts of a particular nutri-cereals (Nandini and Sridhara, 2017).

Pearson's correlation coefficients showed significant variations in association among the studied parameters (Table 3). Grain yield (GY) exhibited significant positive correlation with grain productivity (G-P) (r = 0.896**), HUE-GY (r = 0.893**), HUE- biological yield (BY) (r = 0.659**) and with biomass productivity (B-P) (r = 0.662**). A significant positive correlation was found between GY and BY (r = 0.664**), whereas a non-significant negative correlation between GY and phenological attributes [days to 50% flowering (DFF) and physiological maturity (DPM)] and agro-meteorological indices (GDD, HTU). Biological yield had significant positive correlation with HUE-BY (r = 0.967**), B-P (0.966**), HUE-GY (0.601**) and G-P (0.574**), whereas significant negative correlation with GDD-FF (r = -0.382*). A strong significant positive correlation existed between G-P and HUE-GY (r = 0.999**), G-P and B-P (r = 0.685**), and between G-P and HUE-BY (r = 0.682**). While G-P showed the highest negative correlation with GDD-PM (r = -0.605**), followed by DPM (r = -0.582**). Biomass productivity (B-P) had highest negative correlation with GDD-FF (r = -0.547**), followed by HTU-FF (r = -0.526**), whereas B-P showed positive correlation with HUE-GY (r = 0.711**). Phenological attributes (DFF and DPM) and agro-meteorological indices i.e., GDD-FF, GDD-PM, HTU-FF and HTU-PM showed significant positive correlation. The highest positive correlation existed between DPM and HTU-PM (r = 0.997**); DFF and GDD-FF (r = 0.997**) followed by the correlation between DFF and HTU-FF (r = 0.993**). The HUE-GY as well as HUE-BY too exhibited negative correlation with phenological attributes (DFF and DPM) and agro-meteorological indices (GDD and HTU).

From the above study, it may be concluded that cultivation of different nutri-cereals, viz. barnyard millet, sorghum, pearl millet and little millet, proved significantly better in terms of crop productivity as well as agro-meteorological indices. Thus, these nutri-cereals might be cultivated for nutritional security particularly in eastern region of India.

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**Table 3.** Pearson's correlation matrix of different nutri-cereals in irrigated ecosystem of non-traditional growing area of Bihar (mean data of 2 years)

| Parameters | GY | BY | G-P | B-P | DFF | DPM | GDD-FF | GDD-PM | HTU-FF | HTU-PM | HUE-GY |
|---|---|---|---|---|---|---|---|---|---|---|---|
| BY | 0.664** | | | | | | | | | | |
| G-P | 0.896** | 0.574** | | | | | | | | | |
| B-P | 0.662** | 0.966** | 0.685** | | | | | | | | |
| DFF | -0.150NS | -0.324NS | -0.468* | -0.495** | | | | | | | |
| DPM | -0.188NS | -0.209NS | -0.582** | -0.436* | 0.803** | | | | | | |
| GDD-FF | -0.186NS | -0.382* | -0.491** | -0.547** | 0.997** | 0.798** | | | | | |
| GDD-PM | -0.224NS | -0.266NS | -0.605** | -0.487** | 0.793** | 0.996** | 0.795** | | | | |
| HTU-FF | -0.151NS | -0.348NS | -0.476* | -0.526** | 0.993** | 0.817** | 0.995** | 0.812** | | | |
| HTU-PM | -0.191NS | -0.239NS | -0.574** | -0.459* | 0.797** | 0.997** | 0.796** | 0.998** | 0.812** | | |
| HUE-GY | 0.893** | 0.601** | 0.999** | 0.711** | -0.476* | -0.593** | -0.502** | -0.619** | -0.486* | -0.587** | |
| HUE-BY | 0.659** | 0.967** | 0.682** | 1.000** | -0.494** | -0.437* | -0.547** | -0.489** | -0.524** | -0.461* | 0.708** |

**P*=0.05; **P*=0.01; NS-Non-significant (*P*<0.05); GY, grain yield; BY, biological yield; G-P, grain productivity; B-P, biomass productivity; DFF, days to 50% flowering; DPM, days to physiological maturity; GDD-FF and GDD-PM, accumulated growing degree-days' requirements to attain 50% flowering and physiological maturity respectively; HTU-FF and HTU-PM, heliothermal units requirements to attain 50% flowering and physiological maturity respectively; HUE-GY, heat-use efficiency for grain yield/production; HUE-BY, heat-use efficiency for biomass yield/biomass production

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