Indian J. Genet., **56** (3): 292–298 (1996)

HEAT AND PHOTOTHERMAL INDICES AND THEIR RELATIONS TO PHENOLOGY IN WHEAT

IQBAL SINGH* AND PHOOL SINGH

Department of Plant Breeding, CCS Haryana Agricultural University
Hisar 125004

(Received: September 26, 1994; accepted: June 11, 1995)

ABSTRACT

Thirty wheat varieties (10 varieties each of early, medium and late maturing groups) were sown on November 10, 1988; November 30, 1989 and December 20, 1990 with three replications in randomized block design. Observations on 10 randomly selected plants in each plot were recorded for phenophases, growing degree-days summations, and photothermal units. The duration from commencement of crop emergence to flowering can best be explained by photothermal units for different genotypes except cultivars WH 157 and HD 2122. On the contrary, the duration from flowering to physiological maturity is best explained by the number of degree- days in all the genotypes irrespective of their maturity groups. The varieties WH 157 and HD 2122 may be recommended through out the globe provided the temperature is not the limiting factor.

Key words: Wheat, photoperiod, temperature, phenophases, growing degree-days, photothermal units.

Although many climatic factors influence the growth and development of plants but photoperiod and temperature are the most important factors. In recent years, interest has increased in preparing crop simulation models for estimation of different phenophases. The most of the models are based on heat units.

The heat unit system has been widely used as a guide for planting schedules for an orderly harvest of crops and as an index in making crop zonation maps. Furthermore, it has been adopted to manipulate flowering time of parent varieties in cross-pollinated crops for synchronizing the flowering time for breeding and seed production. The use of photothermal summation was reported to be more efficient in prediction of flowering in peas [1] and barley [2]. Rawson [3] has shown with the assumption that rate of development increases linearly with increased temperature, as intrinsic in the heat sum concept, is not

*Address for correspondence: 10/70, New Campus, CCS Haryana Agricultural University, Hisar 125004.

correct at higher temperatures. As proposed by Angus et al. [4], Rawson [3] also supported the use of curvilinear models to estimate development time. The information regarding photoperiod and temperature makes it easier for planning the shuttle breeding programme [5] with the aims to break the undesirable association like active seed filling period and total duration of genotype [6] and the drought tolerance and the nonresponsiveness of genotypes of crop species [5]. Thus, it is clear that such knowledge is to be used in breeding though one has no control on these natural factors. Little information is available about the relationship between phenological events and weather elements at varietal level in India. The present paper is, therefore, an attempt to give an account for heat and photothermal indices needed for different phenological events of wheat varieties.

MATERIALS AND METHODS

Thirty (Raj 821, Sonalika, WH 291, HD 2285, P 1200-5, HD 2270, VW 120, Raj 2184, HD 1925 and HD 2122; WH 283, WG 377, Red Poll, HD 1981, UP 262, CPAN 1676, CPAN 1907, CPAN 1830, Raj 1579, and HD 2236; WH 147, HD 2009, Kharchia-65, Chat, NP 846, C 306, WL 711, HW 517, WH 157 and Kalyan Sona of early, medium and late maturing groups, respectively) wheat (*Triticum aestivum* L. em. Thell) varieties were sown on November 10, 1988; November 30, 1989; and December 20, 1990 with recommended package of practices (120 kg N, 60 kg P_2O_5, 30 kg K_2O and 25 kg zinc sulphate per hectare) under irrigated condition (irrigations 22, 45, 65, 85, 105 and 120 days after sowing) in a randomized block design with three replications. The occurrence of different phenological events were closely observed from the ten randomly selected plants in each plot. The degree-days during a day were calculated by subtracting the base temperature from the daily mean temperature [7]. The summation of degree-days for the days required for a phenophase is the product of days and average temperature [8]. The daily effective photoperiod for photoperiodic responses was estimated as per procedure given by Keisling [9]. The photothermal units were calculated as a multiple of the average length of day and the summation of degree-days [10]. The value of base temperature was taken as zero [11]. The coefficient of variability for heat units and thermal units is applied to the standard deviation when it is expressed in percentage of the mean of the sample [12].

RESULTS

EMERGENCE TO FLOWERING

A multiple of the average length of day and the summation of degree-days referred to as photothermal unit, provides a less variable unit of measurement of the interval between emergence and flowering than the use of degree-days summations alone irrespective of different maturity groups of wheat varieties as shown in Tables 1 and 2. Nuttonson [10] reported that a multiple of the average length of day and the summation of degree-days (photothermal units) provided a less variable unit of measurement of the interval between phenological events than the use of degree-days summations alone. Similarly, Reath and Wittwer [1] in pea found the photothermal summations for flowering less variable expression than the degree-days summation. Iwata [7] found that substituting night length for day length of photothermal units could be applicable for measuring development of the short day plants. Rawson [3] examined some advantages and problems associated with the use of thermal time or heat units to estimate heading time in wheat grown under high temperature during the vegetative phase. Nonlinearity at higher temperatures is a particular evidence when development is delayed either by short photoperiod or by unsatisfied vernalization response, may be partially associated with carbon limitation and slowing or cessation of primordia production on the growing apex.

We found that amongst early maturing genotypes, cv. HD 2122 is a photoinsensitive genotype (Table 1) for flowering events, while all other genotypes except cv. WH 157 (Table 1) are photosensitive for this event. Nuttonson [2] observed that photoinsensitive variety Trebi of barley did not improve the consistency of the photothermal units compared with degree-days summations for any of the growth period. On the other hand, photosensitive cv. Olli of barley

Table 1. Comparison of coefficients of variation for growing degree-days and photothermal units from emergence to flowering and flowering to physiological maturity in wheat varieties of different maturity groups

Variety	Emergence to flowering		Flowering to physiological maturity	
	growing degree-days	photothermal units	growing degree-days	photothermal units
Early maturing:				
Raj 821	1.6	1.6	1.9	5.6
Sonalika	3.4	1.5	1.6	4.6
WH 291	2.1	0.6	3.1	6.8
HD 2270	1.8	0.2	2.7	6.2
HD 2285	4.2	2.2	1.2	4.6
P 1200-5	2.7	0.7	2.2	5.6
VW 120	9.6	7.9	2.4	5.5
Raj 2184	1.4	0.4	4.7	7.9
HD 1925	8.6	7.4	3.4	6.1
HD 2122	1.1	1.6	3.6	6.9
	3.7 ± 0.9	2.4 ± 0.8	2.7 ± 0.3	6.0 ± 0.3
Medium maturing:				
WH 283	3.3	1.4	1.8	4.9
WG 377	3.7	2.1	0.6	2.6
Red Poll	3.4	1.4	0.1	5.6
HD 1981	5.4	3.7	0.8	2.6
UP 262	5.2	3.6	1.0	3.6
CPAN 1676	5.5	3.5	1.0	3.5
CPAN 1907	5.2	4.3	1.3	3.0
CPAN 1830	4.1	3.2	1.1	3.6
Raj 1579	7.3	5.7	0.9	3.0
HD 2236	3.9	2.5	0.9	3.8
	4.7 ± 0.4	3.2 ± 0.4	0.9 ± 0.1	3.6 ± 0.3
Late maturing:				
WH 147	4.2	2.9	2.8	5.4
HD 2009	4.9	3.5	4.4	6.9
Kharchia 65	4.5	3.8	4.8	7.5
Chat	4.5	2.8	3.8	9.8
NP 846	3.6	1.6	4.0	6.5
C 306	1.9	0.6	4.9	7.4
WL 711	4.6	3.0	4.1	6.6
HW 517	3.1	1.1	3.9	6.5
WH 157	0.7	1.2	5.4	7.9
Kalyan Sona	2.5	0.6	3.3	6.0
	3.5 ± 0.4	2.1 ± 0.4	4.2 ± 0.2	7.0 ± 0.4

provided more consistency of the photothermal units than degree-days summations. Thus, the effectiveness of an application of the photothermal unit or degree-days summation systems for plants depends upon their sensitivity to photoperiod and vernalization requirement. We found that cv. WH 157, a late maturing genotype has low coefficient of variability for growing degree-days than for photothermal unit reflecting its photoinsensitivity and thermosensitivity. All the varieties, irrespective of maturity groups except cv. HD 2122 (early maturing) and cv. WH 157 (late maturing), are photosensitive for flowering. Singh and Singh [13] reported that cv. WH 157 is a photoinsensitive and thermosensitive (low temperature) variety. We found that amongst early maturing genotypes, varietal variations in coefficients of variability for photothermal units from emergence to flowering for early maturing group were greater than it exists amongst medium and late maturing genotypes (Table 2). Amongst early maturing genotypes, it varied from 1.1 (cv. HD 2122) to 9.6 (cv. VW 120) (Table 1). Late maturing genotypes are most sensitive to photoperiod for flowering than other groups (Table 2). Similar results were reported by Major et al. [14]. Medium maturity group was the least sensitive to photoperiod (Table 2), which might be a wider adaptable group for flowering events.

The photothermal units required to complete the duration from emergence to flowering for early, medium and late maturing genotypes were 9864.4 ± 87.4; 10655.6 ± 72.2; and 12070.8 ± 30.4, respectively (Table 2).

FLOWERING TO PHYSIOLOGICAL MATURITY

A summation of degree-days provides a less variable units of measurements for flowering to physiological maturity than photothermal units irrespective of different maturity groups of wheat varieties as shown in Table 1. Our results are not in agreement

Table 2. Growing degree-days and photothermal units and comparisons of their coefficients of variation in different phases in wheat varieties of different maturity groups

Group	Growing degree-days (flowering to physiological maturity)	Photothermal units (emergence to flowering)	Coefficients of variation			
			emergence to flowering		flowering to physiological maturity	
			growing degree-days	photothermal units	growing degree-days	photothermal units
Early maturing	1467.4 ± 8.9	9864.4 ± 87.4	3.7 ± 0.9	2.4 ± 0.8	2.7 ± 0.3	6.0 ± 0.3
Mid maturing	1573.4 ± 8.2	10655.6 ± 72.2	4.7 ± 0.4	3.2 ± 0.4	0.9 ± 0.1	3.6 ± 0.3
Late maturing	1776.9 ± 13.9	12070.8 ± 30.4	3.5 ± 0.4	2.1 ± 0.4	4.2 ± 0.2	7.0 ± 0.4

with the results obtained by Nuttonson [2, 10] in wheat and barley. He worked on temperature climate where the air temperature and photoperiod start decreasing with flowering onward, whereas under our conditions reverse is true.

For duration from flowering to physiological maturity, medium maturity group was most thermosensitive based on the coefficients of variability followed by early and late maturing groups (Table 2). Amongst early maturing genotypes for duration from flowering to physiological maturity, the maximum variation in coefficients of variability exists for growing degree-days (thermosensitivity). It varied from 4.7 in cv. Raj 2184 to 1.2 in cv. HD 2285 (Table 1). This group may be used for breeding studies for developing high temperature tolerant genotypes during grain filling period.

Growing degree-days required to complete the duration from flowering to physiological maturity for early, medium and late maturity groups were 1467.4 $\pm$ 8.9, 1573.4 $\pm$ 8.2 and 1776.9 $\pm$ 13.9, respectively (Table 2).

DISCUSSION

Temperature summation alone has proved to be an adequate method for predicting development of field crops such as corn [15] which are not greatly affected by day length. However, development of other crops, for example soybean [14], wheat [3, 10, 13], barley [2, 16], pea [1], is affected by interaction of photoperiod and temperature. In our studies we found that in wheat the flowering in most of the varieties is influenced by the interaction of day lengths and growing degree-days, whereas temperature summation alone has proved itself to be an adequate method for cvs. WH 157 and HD 2122 based on smaller coefficients of variability. The thermal time concept in its simplest linear version does not apply to wheat grown under higher temperatures during the vegetative phase.

Late maturing genotypes are more photosensitive based on the average values of coefficient of variability for flowering than the genotypes of early and medium maturity groups (Table 2). It seems that in late maturing genotypes, having longer crop duration, the growth of the growing point from maximum primordia stage to boot stage is controlled more by photoperiod [16] as compared to the growth of this phase in early and medium maturity groups. There are certain exceptions in this statement. The cv. WH 157 is a late maturing genotype but it is controlled by growing degree-days more than by photoperiod. This is because of the fact that the floral inductions in cv. WH 157 is controlled by vernalization genes [13] and the growth of the growing point from maximum primordia stage to boot stage is not controlled by photoperiod. In this variety, vernalization response is balanced by photoinsensitivity during maximum primordia to boot stage under normal sown conditions. Amongst early maturing genotypes, there are certain genotypes like cvs. VW 120 and HD 1925, which gave higher coefficients of variability for photothermal units for flowering as compared to other genotypes in this maturity group (Table 1). These two genotypes, i.e. VW 120 and HD 1925 may be relatively less photosensitive than the remaining genotypes of this group.

The commencement of phase from emergence to flowering can best be explained by photothermal units for different genotypes except cvs. WH 157 and HD 2122. On the contrary, the duration from flowering to physiological maturity is best explained by growing degree-days in all the genotypes irrespective of their maturity groups. The cvs. WH 157 and HD 2122 may be recommended throughout the globe provided the temperature is not the limiting factor.

It must be concluded, therefore, that because of the complex interactions among development, temperature, photoperiod, radiation and vernalization response, the successful use of thermal time in a linear form to predict flowering under tropical conditions would be at best a lucky situation. The serial sowing approach is less expensive as compared to the controlled environments but this should be supported with the day length extension using electric light at several sites differing in latitude as suggested by Rawson [3].

REFERENCES

1. A. H. Reath and S. H. Wittwer. 1952. The effect of temperature and photoperiod on the development of pea varieties. Proc. Am. Soc. Hort. Soc., **60**: 301–310.

2. M. Y. Nuttonson. 1957. Barley–Climate Relationships and the Use of Phenology and Ascertaining the Thermal and Photothermal Requirement of Barley. Am. Inst. Crop. Ecol., Washington D.C.

3. H. M. Rawson. 1993. Prediction of heading time in wheat grown under high temperature. Effect of temperature, vernalization and photoperiod. Indian J. Plant Physiol., **36(4)**: 239–245.

4. J. F. Angus, D. H. Mackenzie, R. Morton and C. A. Schafer. 1981. Phasic development in field crops. II. Thermal photoperiodic responses of spring wheat. Field Crops Res., **4**: 269–283.

5. M. Osmanzai, S. Rajaram and E. B. Knapp. 1987. Breeding for moisture-stressed areas. *In:* Drought Tolerance in Winter Cereals (eds. J. P. Srivastava, E. Proceddu, E. Acevedo and S. Verma). John Wiley and Sons Ltd.: 151–161.

6. S. Rodriguez de Cianzio, D. E. Green, C. S. Chang and R. M. Shibles. 1991. Developmental periods in soybean: photoperiod sensitive x insensitive crosses evaluated at diverse latitudes. Crop. Sci., **31**: 8–13.

7. F. Iwata. 1975. Heat unit concept of crop maturity. *In*: Physiological Aspects of Dryland Farming (ed. U. S. Gupta). Oxford and IBH Publishing Co., New Delhi, 351–370.

8. W. H. van Dobben. 1979. Aaropassingen bij het millieu. *In*: De Groene Narde (ed. Th. Alberda). Aula-bock 250. Het spectrum. Utracht/Antwerpen, 313–396.

9. T. C. Keisling. 1982. Calculation of the length of day. Agron. J., **74**: 758–759.

10. M. Y. Nuttonson. 1955. Wheat–Climate Relationships and the Use of Phenology in Ascertaining the Thermal and Photothermal Requirement of Wheat. Am. Inst. Crop Ecol., Washington D.C.

11. A. van Keulen. 1986. Simulation of water use and herbage growth in arid regions. Simulation Monographs. Pudoc, Wageningen: 176.

12. C. H. Goulden. 1962. Methods of Statistical Analysis. Asia Publishing House, London, New York, Bombay.

13. K. P. Singh and Iqbal Singh. 1990. Genetic variability for photothermal responses and their impact on correlations in wheat. Bhartiya Krishi Anusandhan Patrika, **5**(3): 159–168.

14. D. J. Major, D. R. Johnson, J. W. Tanner and I. C. Anderson. 1975. Effect of day lengths and temperature on soybean development. Crop Sci., **15**: 174–179.

15. H. Z. Cross and M. S. Zuber. 1972. Prediction of flowering dates in maize based on different methods of estimating thermal units. Agron. J., **64**: 351–355.

16. E. J. van Oosterom and E. Acevedo. 1992. Adaptation of barley to harsh environments. Euphytica, **62**: 29–38.