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IS PHOTOTHERMAL QUOTIENT DETERMINANT FACTOR FOR SPRING WHEAT YIELD?

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Abstract

Photothermal Quotient as combined effect of temperature and solar radiation were studied as determinant factor for spring wheat grain yield. The data obtained at anthesis and maturity for grain m^{-2}, grain weight and grain yield were examined in experiments involving three wheat genotypes under five different environmental conditions (E) provided in the form of planting windows (PW's) during 2008-09 & 2009-10 at National Agricultural Research Center (NARC), Islamabad. The mean temperature at anthesis (T1) and maturity (T2) was calculated by averaging all temperature from germination till anthesis and maturity, respectively. Similarly, solar radiation at anthesis (SR1) and maturity (SR2) was calculated- with the Angstrom formula while Photothermal quotient (PTQ) was calculated at anthesis (PTQ1) and maturity (PTQ2). The data obtained was subjected to STATISTICA 8 software and scatter plot regression model was developed- at 95% confidence interval with crop data and climate variables (T1, T2, SR1, SR2, PTQ1 and PTQ2). The b (regression coefficient) recorded were 623.73 (GM vs T1), 0.0037 (GW vs T1), -5.97 (Y vs T1), -0.028 (GW vs T2), -1356.28 (GM vs T2), -57.86 (Y vs T2), 29.53 (GM vs SR1), 0.0005 (GW vs SR1), 3.95 (Y vs SR1), 19.90 (GM vs SR2), 0.0003 (GW vs SR2), 2.57 (Y vs SR2) 314.20 (GM vs PTQ1), 0.0049 (GW vs PTQ1), 49.88 (Y vs PTQ1), 0.0037 (GW vs PTQ2), 31.87 (Y vs PTQ2), 237.40 (GM vs PTQ2) while, b for E and PW with yield was -872.51 and -309.75, respectively. Direct relationship between PTQ and yield parameters confirmed that it determined crop yield and its management for variable environmental conditions need to be opted by adopting suitable sowing time.

Introduction

Climatic factors like temperature, solar radiation and rainfall impact on crop yield all over the world. Changes in climatic factors like rise in temperature and decline in rainfall were reported in the report of the Intergovernmental Panel on Climate Change (IPCC, 2007a, b). Low temperature in the growing season may reduce germination, retard vegetative growth by inducing metabolic unbalances and can delay or prevent reproductive devolvement (Mohsen & Yamada, 1991). You *et al*., (2009) observed significant reduction in yield due to rise in temperature and it was concluded that with 1.8°C rise in temperature caused 3-10 % reduction in wheat yields. The impact of climatic variables can be assessed by studying climatic parameters like temperature, solar ration and Photothermal Quotient (PTQ) during crop life-cycle and by developing a quantitative relationship among climatic variables and crop yield. Li *et al*., (2010) observed significant change in yield of wheat due to variation in temperature and solar radiation. Similarly, 0.6 to 8.9% reduction in wheat yield per 1°C rise in temperature has been recorded by Lobell & Field, (2007). Ormerod *et al.,* (2003) reported that agricultural production is more complex because of the need to balance global food security, optimum production, technological innovation, preservation of environmental functions and protection of biodiversity. The ecological knowledge achieved in the present study enables considerable compliance with most of those objectives.

Development of genotypes resistance to extreme climatic events needs to be considered as potential option for wide range of conditions with agronomic managements like sowing dates (Bedo *et al*., 2005). Limited availability of climatic resources has generated marginal environments where wheat production drops to 70% of optimum yield (Rajaram, 2005).

Photothermal quotient (PTQ) can be defined as the ratio of total solar radiation in MJ $m^{-2}day^{-1}$ to the mean daily temperature minus a base temperature (4.5°C for Spring Wheat). Nalley *et al*., (2009) identified, PTQ to improve the explanatory power of statistical regression models on grains per meter square (GM), grain weight (GW) and yield under climate change scenario. Similarly, Khichar & Niwas (2007) concluded direct relationship with PTQ and growth of wheat under different planting systems. However, Loomis & Amthor (1996) documented that crop growth and yield were derived from photosynthesis, therefore dependent on receipt and capture of solar radiation. Hence studies are needed to understand and quantify the crop response and its relationship with varied combination of temperature and solar radiation to workout suitable planting windows for wheat. This is only possible if the canopies are tested under varying circumstances of temperature and radiation. The practical way to record such reading is to alter the sowing time of the crop within recommended growing season. The objectives of this study were to evaluate the effect of mean temperature, total solar radiation and PTQ at anthesis and maturity stage of wheat crop during different environments (2008-09 & 2009-10) and thereafter to develop a regression model for climatic variables with grain weight, grains per meter square and yield of wheat crop for wide range of conditions.

Materials and Methods

Experimental site and field conditions: Five different planting windows (PW's) were used to provide variable climatic conditions at anthesis and maturity of wheat for two environments i.e. 2008-09 & 2009-10. The planting windows were; PW1 (Sowing on 20-10-2008 & 23-10-2009), PW2 (Sowing on 28-10-2008 & 05-11-2009), PW3 (Sowing on 05-11-2008 & 19-11-2009), PW4 (Sowing on 19-11-2008 & 27-11-2009) and PW5 (Sowing on 05-12-2008 & 10-12-2009). The study was conducted at National Agriculture Research Center (NARC), Islamabad, Pakistan, located at latitude of 33° 42/ N and longitude of 73° 10/ E. The soil series of study site was Rajar, with great groups Ustorthents and soil order Entisol. The experiments were laid out using randomized complete block design (RCBD), replicated four times in 4.5 x 10 m plot with row spacing of 25 cm. Wheat genotypes Chakwal-50, Wafaq-2001 and GA-2002 were used in the study. Sowing was done by hand drill using seed rate of 50 kg $acre^{-1}$. Prior to sowing particular field remained fallow during summer which was ploughed once with soil inverting implement and thereafter thrice with tractor mounted cultivator. Recommended doses of fertilizer Nitrogen and Phosphorus at the rate of 100 kg ha^{-1} was added with last cultivation in the form of Urea and DAP.

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Environmental characterization: Data regarding weather prevailed during the study period was collected from the weather station located at NARC. The mean temperature at anthesis (T1) and maturity (T2) was calculated by averaging all temperature from germination till anthesis and maturity, respectively. Similarly, solar radiation at anthesis (SR1) and maturity (SR2) was calculated with the Angstrom formula, which relates solar radiation to extraterrestrial radiation and relative sunshine duration:

$$R_s = \left(a_s + b_s \frac{n}{N} \right) R_a$$

where R_s = solar or shortwave radiation [MJ m^{-2} day^{-1}], n = actual duration of sunshine [hour], N= maximum possible duration of sunshine or daylight hours [hour], n/N = relative sunshine duration [-], R_a = extraterrestrial radiation [MJ m^{-2} day^{-1}], a_s = regression constant, $a_s + b_s$ = fraction of extraterrestrial radiation reaching the earth on clear days (n = N). The default values for a_s and b_s were 0.25 and 0.50. The photothermal quotient was calculated on daily basis with following formula: If T > 10, PTQ day^{-1} = Solar Radiation / (T - 4.5), If T < 4.5, PTQ day^{-1} = 0; and, If 4.5 < T < 10, PTQ day^{-1} = Solar Radiation x [(T – 4.5) / 5.5] /5.5. Where, T is the daily mean temperature [(max + min) / 2] and PTQ is expressed as MJ m^{-2} day^{-1} $^oC^{-1}$ (Monasterio *et al*., 1994). The following PTQs were generated for individual genotypes by adding the daily PTQ: PTQ1 at anthesis by adding daily PTQs from germination to anthesis; PTQ2 at maturity by adding daily PTQs from germination to anthesis + anthesis to maturity. All genotypes at maturity were harvested and grain number per meter square (GM), grain weight (GW) and grain yield (kg ha^{-1}) were calculated.

Statistical analysis and procedures: The data obtained was subjected to STATISTICA 8 (Statsoft, Inc. 2007) software to develop a regression models among T1, T2, SR1, SR2, PTQ1 and PTQ2 with GM, GW and grain yield (kg ha^{-1}). Two-dimensional scatterplots obtained visualized a relation between two variables X and Y (e.g. T1 and GM). The regression analysis performed was with confidence interval of 95%.

Results

Relationships between grain number m^{-2} (GM), grain weight (GW) and grain yield (kg ha^{-1}) with T1 (mean temperature at Anthesis) and T2 (mean temperature at maturity): The results of scatter plot of GM against T1 (Fig. 1a) showed significant and positive relationship between anthesis temperature and grain numbers. The maximum number of GM was recorded between temperatures of 18-20°C with R^2 (0.89). The regression equation obtained was GM = 5308.99 + 623.73 (T1) with 0.95 confidence interval. The result clearly indicated a strong relationship of anthesis temperature with grain number which may be further correlated with grain yield. Thus, at anthesis if available temperature to crop is optimum it leads to good seed setting. Similarly, response of grain weight with T1 showed the maximum grain weight obtained at 17°C with regression equation (GW = 0.34 + 0.0037 (T1). The relationship between anthesis mean temperature and grain weight depicted a positive association with R^2 of 0.78 but up to optimum level (Fig. 1b). Further increase in temperature after optimum level may lead to shriveled grains and produce lesser grain weight. However, yield association with temperature at anthesis showed yield reduction with increase in temperature (Fig. 1c). Similarly temperature rise may have caused yield stagnation. The regression equation obtained for yield in relation with T1 was Y = 3284.7553-5.9702 (T1). The relationship of mean temperature from germination till maturity (T2) with GM, GW and grain yield revealed decline in GM, GW and yield with increase in temperature (Fig. 1d-f). The adverse effect of high temperature on yields could partially be modified by avoidance strategy including earlier sowing. The biological clock acceleration because of the increased temperature brought forward developmental stages and reduced the growing period between emergence and maturity. The regression equations obtained at 95% confidence interval for GM, GW and grain yield was GM = 47367.06-1356.28 (T2), GW = 1.05-0.02 (T2) and Y = 4542.37-57.86 (T2), respectively. The regression model showed a negative trend with unit increase in temperature from emergence to maturity.

Relationships between grain number per square meter (GM), Grain weight (GW) and Grain yield (kg ha^{-1}) with SR1 (total solar radiation at Anthesis) and SR2 (total solar radiation at maturity): Solar radiation might affect crop growth through a variety of direct and indirect mechanisms. Similarly, solar radiation activates the photosystem by which light reaction of photosynthesis started and electrons generated by photolysis of water moves to produce energy carriers (e.g. NADPH & ATP). The scatterplot regression model showed a positive relationship between GM, GW and grain yield with SR1 and SR2 (Fig. 2). The regression model obtained for GM, GW and yield with SR1 was GM = -19542.51 + 29.53 (SR1), GW = -0.15+0.0005 (SR1), Y = -1516.47+3.9549 (SR1), respectively. The result showed that SR1 linked positively with yield which may be because of good source-sink activity. Likewise, the responses of crop yield parameters (GM, GW and yield) with SR2 were associated positively. The result indicated that with increase in solar radiation from emergence till maturity brought a significant yield impact. The regression model equation showed a direct relationship with SR2 and GM, GW and yield (GM = -21272.63 + 19.90(SR2), GW = -0.1551+0.0003(SR2) and Y = -1575.8369+2.57 (SR2)).

Relationships between grain number per square meter (GM), grain weight (GW) and grain yield (kg ha^{-1}) with PTQ1 (Photothermal quotient at anthesis) and PTQ2 (Photothermal quotient at maturity): Photothermal Quotient portrayed the combined effect of solar radiation and temperature on crop yield components. Grain numbers per meter square (GM), grain weight (GW) and grain yield (kg ha^{-1}) were positively related to PTQ1 with R^2 of 0.88, 0.66 and 0.59. The regression equation indicated that with unit change in PTQ1, GM increased at the rate of 314.20 while GW showed increase of 0.0049. Similarly, grain yield associated directly with the impact of 49.88 per unit of PTQ1. The regression model obtained between PTQ1 and yield components clearly indicated that PTQ1 determined the GM, GW and yield positively if all other resources remained available at optima. The regression model obtained was GM = -28518.88 + 314.20 (PTQ1), KW = -0.287 + 0.0049 (PTQ1) and Y = -3814.91 + 49.88 (PTQ1) at 0.95 confidence interval (Fig. 3a-c). Similarly, PTQ from emergence to maturity determined the overall impact of climate variables on crop growth. Therefore, PTQ available to crop for late planting windows was recorded minimum. Hence, yield GM, GW and yield recorded for late planting windows remained significantly lower. The scatterplot obtained for PTQ2 with grain numbers per meter square (GM), grain weight (GW) and grain yield (kg ha^{-1}) indicated a positive association (Fig. 3d-f). The regression models obtained between PTQ2 and GM, GW and yield depicted that PTQ is key determinant factor which affected yield significantly (GM = -27382.86 + 237.40 (PTQ2), GW = -0.27 + 0.0037 (PTQ2) and Y = -2582.43 + 31.87 (PTQ2)).

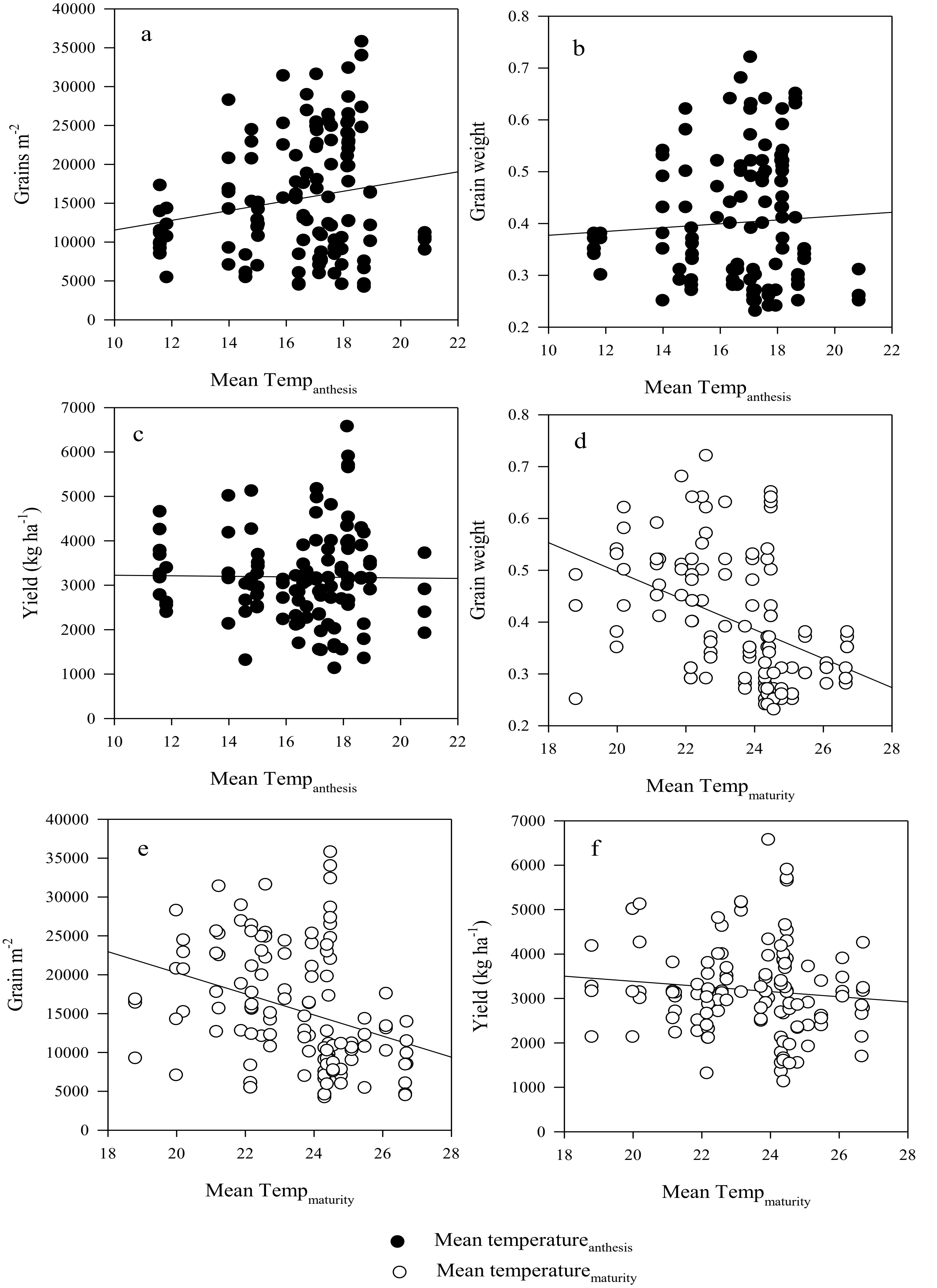

Fig. 1. Scatter plot of (a & e) Grains per meter square (GM), (b & d) Grain weight (GW) & (c &f) Yield (kg ha^{-1}) against mean temperature (°C) at anthesis (T1) & at maturity (T2).

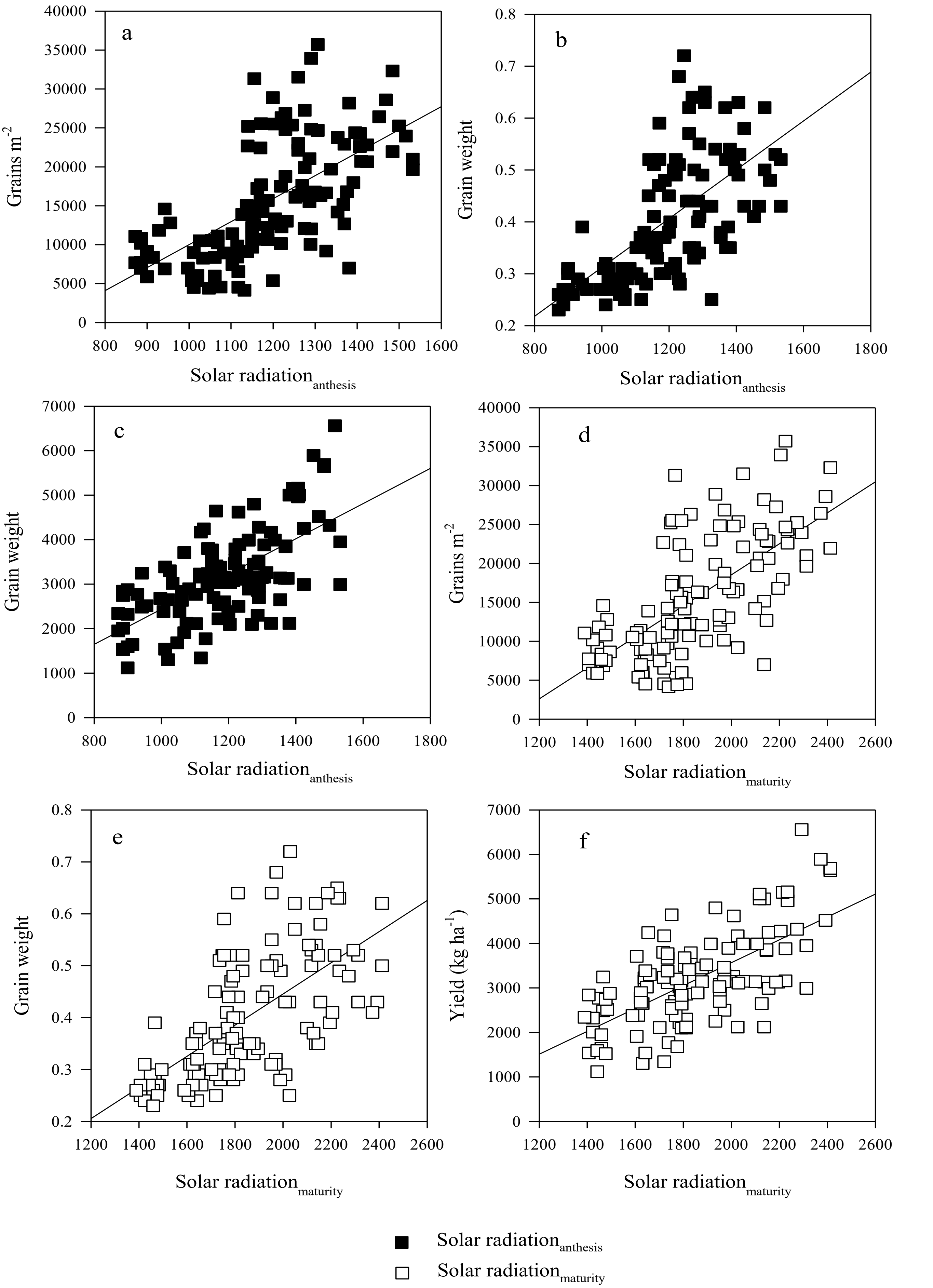

Fig. 2. Scatter plot of (a & d) Grains per meter square (GM), (b & e) Grain weight (GW) & (c & f) Yield (kg ha^{-1}) against total solar radiation (MJ m^{-2}) at anthesis (SR1) & at maturity (SR2).

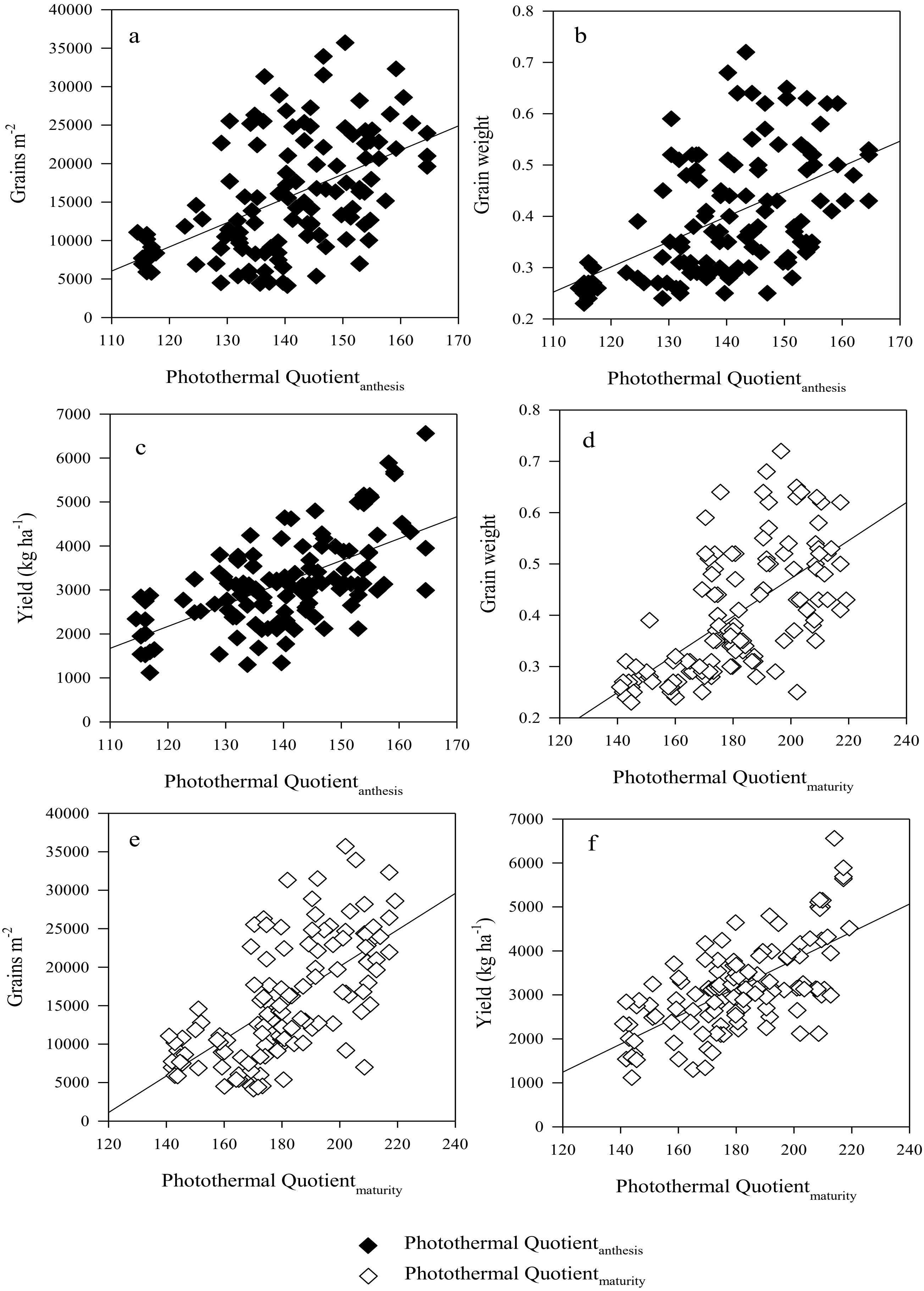

Fig. 3. Scatter plot of (a & e) Grains per meter square (GM), (b & d) Grain weight (GW) & (c &f) Yield (kg ha^{-1}) against Photothermal Quotient (MJ m^{-2} day^{-1} $^{o}C^{-1}$) at anthesis (PTQ1) & at maturity (PTQ2).

Discussion

The significant negative trend of GM and GW with increased temperature revealed that crop growth and development was affected adversely with rise in temperature. Gate, (2007) concluded that maximum temperatures above 25ºC significantly reduced grain weight while Kalra *et al*., (2008) confirmed that wheat yields have fallen by 0.2–0.5 t ha^{-1} per degree Celsius rise in temperature. Similarly, decrease in grain m^{-2} may be due to high temperature near heading. This phenomenon is similar to findings of Dawson & Wardlow (1989). They reported that high temperature during the pre-heading stage might have minimized pollen viability, resulting in less number of kernels per spike. The reduction in grain weight due to rise in temperature may be because of inefficient activity of sink (Fig. 1). Lin *et al*., (1997) concluded that floral sterility may limit sink due to increased temperature. In present study yield obtained was maximum at optimum and decreased due to rise in temperature. The temperature rise during crop growth cycle might result in seed abortion and reduced grain yield (IPCC, 2001a). Increased temperature from germination to maturity may affect grain developmental period of wheat crop. The rising temperature would shorten the period of grain filling in wheat (Wheeler *et al*., 1996).

Solar radiation is an important environmental factor of crop growth which brings positive changes in the crop growth by altering leaf architecture and light partioning. The result showed that with increase in solar radiation GM, GW and yield increased significantly. Richards, (2006) found a significant similar effect of seasonal variations of solar radiation on yield. This significant responsive trend of crop toward solar radiation may be due to modification in duration of photosynthesis. Sowing time may be used to bring variability in solar radiation which ultimately effects on the duration of crop growth due to differential partioning of light. Since if crop is exposed to favorable environmental conditions for longer period of time it may bring good seed setting and yield. However, growth and development would become negative because of weaker solar radiation due to cloud cover. Therefore, result clearly indicated that variations in environmental factors may lead to change in crop yield, thus conclusion of present investigation is in line with Rodriguez & Sadras (2007).

GM was the determinant factor for variation in grain yield (Slafer *et al*., 1994; Egli, 1998) which was significantly affected due to Photothermal Quotient at anthesis and maturity (Fig. 3). Hence, results of present study are similar to above conclusion. Significant positive association was recorded between grain m^{-2} with PTQ1 and PTQ2 (R^2 = 0.97 and R^2 = 0.90). The maximum value of PTQ (217.66) recorded for early sowing may be due to favorable environmental conditions throughout crop life cycle. Thus, these results correspond with the results of Monasterio *et al*., (1994). Similarly, kernal weight (KW) and photothermal quotient accounted a linear positive trend. The highest kernal weight was recorded when maximum PTQ avialble from emergence to maturity. Similar findings were reported by Khichar & Niwas (2007) who concluded that photothermal quotient effects on kernel weight decisively provided all other resources were available at optimum level. Yield was strongly linked with PTQ1 and PTQ2 (Fig. 3). The highest yield was obtained with maximum Photothermal quotient which dropped significantly due to decrease in PTQ. This declining trend may be because of unavailability of optimum environmental conditions. Similar findings were reported by Abbate *et al*., (1997). The association of Photothermal quotient at maturity with GW and grain yield followed a positive trend. As explained by Giulioni *et al*., (1997), high temperature has been suggested a factor that accelerates the ending of crop cycle. The outcomes generated in this study clearly indicated a strong association between Photothermal Quotient and GM, GW and yield (Dumoulin *et al*., 1994). However, work like association of Photothermal quotient models with grain developments and yield components needs to be documented in order to build a comprehensive model between Photothermal quotient and crop growth and development. Since, PTQ elaborated the combined effect of temperature and solar radiation on crop yield it may be considered as limiting factor which may control overall crop growth.

Conclusion

Experimental results clearly indicated that yield is directly proportional to the PTQ provided rests of all the resources are available optimally. Since, PTQ fulfilled the crop light, temperature and solar radiation requirement so it is the main limiting factor which determined the crop adaptation under specific environments. Management such as Planting Windows option may be a tactical measure for the adjustment of PTQ's according to varying climate of experimental site. Adaptability of Wheat genotype based upon its relationship with PTQ knowledge for a particular climate zone can be recommended to minimize losses in the yield due to extreme climatic events.

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