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Studying the cumulative vigor response index of morpho-physiological, quality, and yield-related traits of wheat cultivars using planting dates

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ABSTRACT

Wheat (*Triticum aestivum* L) is one of the major staple food crops consumed globally. Nonetheless, the cultivation of wheat is influenced by various environmental factors, with the planting date being significantly impacted by the effects of climate change. Addressing these changes could involve evaluating wheat genotypes to identify appropriate planting dates. A phenotypic screening experiment was conducted in the field crop station of Agriculture College of Tikrit University to determine the suitable planting time for wheat cultivars under local environmental conditions during 2022-23. Several morpho-physiological, quality, and yield traits were measured. Factorial experiment using spilt plot through randomized completely block design (RCBD). was used with three replications. The five planting dates (5-10, 25-10, 15-11, 5-12, and 25-12) were considered as the main plot, and the eight wheat cultivars (Ipaa99, Al-Rasheed, Al-Baraka, Sham6, Tammuz2, Al-Hashimiya, Al-Noor, and Al-Adnanieh) as sub-main plot. Data were used to calculate the Individual, Cumulative, and Total Vigor Response Indices (IRI, CRI & TRI). Cultivars were classified into different categories using total cumulative early or late planting date vigor response index values (TRI-e) or (TRI-l) and standard deviation (SD). The (TRI-e) values ranged from 36.07 (sensitive) for the cultivar Al-Baraka to 39.13 (tolerant) for the cultivar Al-Hashimiya. However, the (TRI-l) values ranged from 36.59 (sensitive) for the cultivar Al-Noor to 39.52 (tolerant) for the cultivar Al-Hashimiya. The correlation coefficient (r^2) between the (TRI-e) and cumulative very early/early planting date vigor response index was positively correlated (r^2 = 0.70 for very early planting date (5-Oct) and r^2 = 0.60 for early planting date (25-Oct). Furthermore, 76% of the total variation in the (TRI-l) was explained by the cumulative very late planting date vigor response index (CRI-vl) while just 49% of the total variation was explained by the cumulative late planting date vigor response index (CRI-l). Based on those results, wheat producers could select either tolerant cultivars for early planting or tolerant cultivars for late planting to maximize wheat production in their specific growing environments including planting dates.

دراسة مؤشر الاستجابة التراكمي للصفات المظهرية والفسيولوجية والنوعية والحاصل ومكوناته لأصناف من الحنطة باستخدام مواعيد الزراعة

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الخلاصة

يعتبر القمح (*Triticum aestivum* L.) واحدًا من اهم المحاصيل الغذائية الأساسية المستهلكة عالميًا. ومع ذلك، فإن زراعته تتأثر بعوامل بيئية مختلفة، منها مواعيد الزراعة التي تتأثر بشكل كبير بآثار تغير المناخ. قد تتضمن معالجة هذه التغييرات المناخية تقييم التراكيب الوراثية للحنطة لتحديد مواعيد الزراعة المناسبة. وعليه فقد أجريت تجربة حقلية في محطة أبحاث قسم المحاصيل الحقلية التابعة لكلية الزراعة جامعة تكريت لتحديد الموعد المناسب لزراعة بعض أصناف الحنطة في ظل الظروف البيئية المحلية خلال الموسم الزراعي 2022–2023. تم قياس العديد من الصفات المورفولوجية والفسيولوجية والنوعية وصفات الحاصل ومكوناته. أجريت تجربة عاملية باستخدام الالواح المنشقة ضمن تصميم القطاعات العشوائية الكاملة (RCBD) وبثلاثة مكررات. وضعت مواعيد الزراعة (5–10، 25–10، 15–11، 5–12، و25–12) في القطع الرئيسية، بينما وضعت اصناف الحنطة (اباء99 والرشيد والبركة وشام6 وتموز2 والهاشمية والنور والعدنانية) في الالواح الثانوية. تم استخدام البيانات لقياس مؤشرات الاستجابة الفردية والتراكمية والكلية (IRI, CRI & TRI). تم تقسيم الأصناف إلى فئات مختلفة باستخدام مؤشر الاستجابة الكلي للزراعة المبكرة أو المتأخرة (TRI–e) أو (TRI–l) والانحراف المعياري (SD). وتراوحت قيم (TRI–e) بين 36.07 (حساس للزراعة المبكرة) الصنف البركة إلى 39.13 (متحمل للزراعة المبكرة) الصنف الهاشمية. أما قيم (TRI–l) فقد تراوحت بين 36.59 (حساس للزراعة المتأخرة) الصنف النور إلى 39.52 (متحمل للزراعة المتأخرة) الصنف الهاشمية. كان معامل الارتباط (r2) بين (TRI–e) من جهة ومؤشر الاستجابة التراكمية للزراعة المبكرة جدا (CRI–ve) /المبكرة (CRI–e) من جهة اخرى مرتبطًا بشكل إيجابي (r^2 = 0.70) للزراعة المبكر جدًا (5 تشرين الاول) و0.602r = للزراعة المبكرة (25 تشرين الاول). علاوة على ذلك، 76% من إجمالي التباين في (TRI–l) تم تفسيره من خلال مؤشر الاستجابة التراكمية للزراعة المتأخرة جدًا (CRI–vl) (25 كانون الاول) بينما تم تفسير 49% فقط من إجمالي التباين من خلال التراكمي مؤشر الاستجابة للزراعة المتأخرة (CRI–l) (5 كانون الاول). نأمل ان تمكن هذه النتائج منتجي ومربي محصول الحنطة من اختيار إما أصناف تكون متحملة او مقاومة للزراعة المبكرة أو أصناف متحملة او مقاومة للزراعة المتأخرة لغرض زيادة إنتاج الحنطة إلى أقصى حد ممكن في بيئات النمو المختلفة وبما في ذلك مواعيد الزراعة.

الكلمات الافتتاحية: الحنطة، مواعيد الزراعة، مؤشر الاستجابة التراكمي

INTROUCTION

Wheat (*Triticum aestivum* L) is considered one of the most productive grain crops in the world. The total global wheat grain production reached around 778.6 million tons in 2021-2022, compared to 697.0 million tons in 2011-2012, and 756.5 million tons in 2016-2017, which led to an annual increase of 1.24% in the last ten years and 0.83% in the last five years. Those results show a decline in the annual growth rate against the desired rate of 1.5-2% to meet the growing demand of the world population (Moshawih et al., 2023). The importance of wheat comes from the dependence of two-thirds of the world's population on it, and it provides human food with more than 25% of calories and proteins, containing quantities of fats, some mineral salts, vitamins thiamine B1, and riboflavin B2 (FAO, 2008).

The main problem facing increasing production and achieving self-sufficiency in wheat is low productivity per unit area, so work must be done to raise its production efficiency via the use of resistant and highly productive genotypes of wheat. Cultivars vary in the nature of their growth due to their different genetic compositions, so the growth of the crop and its arrival at the vegetative growth stage and the yield differ depending on the cultivar, which is reflected in its growth and productivity. The total crop yield is affected by multiple genetic and environmental factors, most notably planting dates, and developing genotypes that are compatible with early and late planting is considered one of the best solutions to obtain a resistant cultivar (Jardón et al., 2023). The planting dates are considered one of the basic inputs for field crops, and the optimal sowing date is affected by climate change, therefore, it is assumed that the best planting date is determined to obtain the best plant yield. The characteristics of crop production are directly related to the temperature and relative humidity of the atmosphere during a growing season, so it is necessary to provide the thermal requirements of the cultivars. The late planting influences each growth stage and each characteristic of the plant like the number of grains spike^{-1}, grain yield, and 1000-grain weight (Coventry et al., 2011; Anwar et al., 2011; and Sattar et al., 2015). Meanwhile, Gul et al., (2012) have mentioned that the delay in a day from optimum planting time has decreased by 1% grain yield. In contrast, the higher grain yields are related to the optimal planting date, and each day delay in sowing from 15-20th November decreases grain yield at 39 $kg \cdot ha^{-1}$ per day (Singh and Ultam, 1999). Hence, to become customary to crop systems to the changing climate and to match the growing population, it is vital to know how climate change influences agricultural production and water productivity (Rockström et al., 2009).

Producing quantitative values and identifying important traits to screen and classify wheat cultivars for early-late vigor would be valuable to select current cultivars and develop new genotypes better appropriate for the production system. Using of the total cumulative vigor response index (TCVRI) to examine the relationship among crop characteristics is an additional tool for breeders and producers to understand physiological changes during variety development and could be a useful basis for selection in plant breeding. Vigor indices of each trait provide information about the growth rate and uniform development of genotypes under varied environmental conditions including planting dates (Powell and Matthews, 2005), which is crucial for the growth and development of the crop when competing for limited resources. Plants with high vigor usually compete successfully under limited environmental resources, influencing stand establishment and, ultimately, grain yield (Jumaa et al., 2020).

There are some studies that have dealt with the cumulative vigor response index as Wijewardana et al., 2015, Singh et al., 2017, Lone et al., 2019, Jumaa et al., 2019, and Kakar et al., 2019, which studied the effect of cold tolerant on maize hybrids, the effect of soil moisture on rice cultivars, the effect of drought on genotypes (*Indica*), the effect of high-low temperature on rice cultivars, and the effect of salinity on rice genotypes (*Japonica*), respectively. Hence, due to the limited availability of research examining the cumulative response index concerning wheat yields based on planting dates, the experiment was undertaken as the inaugural study to assess the wheat cultivars across both early and late planting dates. The objective was to categorize cultivars into distinct groups, identifying their sensitivity or tolerance to either early or late planning.

MATERIAL AND METHODS

Experimental condition:

The experiment was carried out during the winter season of 2022-2023 at the research station of the Field Crops Department, College of Agriculture, Tikrit University (34˚ 35’ E, 34˚ 27’ N). A randomized complete block design (R.C.B.D.) was used according to the split-plot arrangement with three replicates. Each replicate has 40 experimental units coming from five main plots including planting dates (5/10, 25/10, 15/11, 5/12, and 25/12), which were divided into eight sub-main plots having wheat cultivars Ipaa99, Al-Rasheed, Al-Baraka, Sham6, Tammuz2, Al-Hashimiya, Al-Noor, and Al-Adnanieh. The experimental unit area (plot) was (2 x 1m) including five lines with 10 cm among lines and 10 cm among seeds. The soil of the experiment was plowed with disc harrows then it was leveled and amended, and fertilized by DAP as a source of phosphorus at a rate of 100 kg ha^{-1}, and nitrogen fertilizer (urea) 46% N at a rate of 200 kg ha^{-1}, which added in the vegetative stage and at the reproductive stage (Iqbal et al., 2012). The well water was used for irrigation, and weeds were removed manually whenever necessary.

Total Cumulative Planting Date Response Index (TCPDRI):

Initially, individual very early planting date response indices (IRI-ve) and individual early planting date response indices (IRI-e) were calculated by dividing the value of parameter (Pve) at very early planting date (5-10) or the value of parameter (Pe) at early planting date response index (25-10) for a given cultivar by the value of the same parameter (Po) at optimum planting date (15-11) [Eq. 1 and 2] (Wijewardana et al., 2015). Also, the individual late planting date response indices (IRI-l) and individual very late planting date response indices (IRI-vl) were calculated by dividing the value of parameter (Pl) at late planting date (5-12) or the value of parameter (Pvl) at very late planting date response index (25-12) for a given cultivar by the value of the same parameter (Po) at optimum planting date (15-11) [Eq. 3 and 4]. Then, the cumulative very early planting date vigor response index (CRI-ve) and cumulative early planting date vigor response index (CRI-ve) were calculated as the sum of 20 IRI-ve or 20 IRI-e for each cultivar that includes Flowering date (Fl), Leaf area (LA), Plant height (PH), SPAD, Spike $plant^{-1}$ (SP), Spike length (SL), Maturity date (MT), Tiller number (TN), Weight seed (WG), Yield of protein (YP), Seeds of spikelet (SS), Biological yield (BY), Harvest index (HI), Yield of seeds (YS), Ashes (PR), sedimentation (RM), Wet gluten (GW), Dry Gluten (GD), Humidity (RR), and Yield $plant^{-1}$ (WW) [Eq. 5 and 6]. Similarly, cumulative late and very late planting date response index (CRI-l) and (CRI-vl) were calculated as the sum of 20 IRI-l or 20 IRI-vl for each cultivar [Eq. 7 and 8]. Finally, the total early planting date vigor response index TRI-e was estimated by summing CRI-ve and CRI-ve for each cultivar [Eq. 9]. Also, the total late planting date vigor response index TRI-l was generated by summing CRI-l and CRI-vl for each cultivar [Eq. 10].

$IRI\text{-}ve = Pve/Po$ {Equ. 1}

$IRI\text{-}e = Pe/Po$ {Equ. 2}

$IRI\text{-}l = P_L/Po$ {Equ. 3}

$IRI\text{-}vl = P_{VL}/Po$ {Equ. 4}

$$CRI\text{-}ve = (P_{FLve}/P_{Flo}) + P_{LAve}/P_{LAo} + P_{PHve}/P_{PHo} + P_{SPADve}/P_{SPADo} + P_{SPve}/P_{SPo} + P_{SLve}/P_{SLo} + P_{MTve}/P_{MTo} + P_{TNve}/P_{TNo} + P_{WGve}/P_{WGo} + P_{YPve}/P_{YPo} + P_{SSve}/P_{SSo} + P_{BYve}/P_{BYo} + P_{HIve}/P_{HIo} + P_{YSve}/P_{YSo} + P_{PRve}/P_{PRo} + P_{RMve}/P_{RMo} + P_{GWve}/P_{GWo} + P_{GDve}/P_{GDo} + P_{RRve}/P_{RRo} + P_{WWve}/P_{WWo}$$
{Equ. 5}

$$CRI\text{-}l = (P_{FLe}/P_{Flo}) + P_{LAe}/P_{LAo} + P_{PHe}/P_{PHo} + P_{SPADe}/P_{SPADo} + P_{SPe}/P_{SPo} + P_{SLe}/P_{SLo} + P_{MTe}/P_{MTo} + P_{TNe}/P_{TNo} + P_{WGe}/P_{WGo} + P_{YPe}/P_{YPo} + P_{SSe}/P_{SSo} + P_{BYe}/P_{BYo} + P_{HIe}/P_{HIo} + P_{YSe}/P_{YSo} + P_{PRe}/P_{PRo} + P_{RMe}/P_{RMo} + P_{GWe}/P_{GWo} + P_{GDe}/P_{GDo} + P_{RRe}/P_{RRo} + P_{WWe}/P_{WWo}$$
{Equ. 6}

$$CRI\text{-}l = (P_{FLl}/P_{Flo}) + P_{LAl}/P_{LAo} + P_{PHl}/P_{PHo} + P_{SPADl}/P_{SPADo} + P_{SPl}/P_{SPo} + P_{SLl}/P_{SLo} + P_{MTl}/P_{MTo} + P_{TNl}/P_{TNo} + P_{WGl}/P_{WGo} + P_{YPl}/P_{YPo} + P_{SSl}/P_{SSo} + P_{BYl}/P_{BYo} + P_{HIl}/P_{HIo} + P_{YSl}/P_{YSo} + P_{PRl}/P_{PRo} + P_{RMl}/P_{RMo} + P_{GWl}/P_{GWo} + P_{GDl}/P_{GDo} + P_{RRl}/P_{RRo} + P_{WWl}/P_{WWo}$$
{Equ. 7}

$$CRI\text{-}vl = (P_{FLvl}/P_{Flo}) + P_{LAvl}/P_{LAo} + P_{PHvl}/P_{PHo} + P_{SPADvl}/P_{SPADo} + P_{SPvl}/P_{SPo} + P_{SLvl}/P_{SLo} + P_{MTvl}/P_{MTo} + P_{TNvl}/P_{TNo} + P_{WGvl}/P_{WGo} + P_{YPvl}/P_{YPo} + P_{SSvl}/P_{SSo} + P_{BYvl}/P_{BYo} + P_{HIvl}/P_{HIo} + P_{YSvl}/P_{YSo} + P_{PRvl}/P_{PRo} + P_{RMvl}/P_{RMo} + P_{GWvl}/P_{GWo} + P_{GDvl}/P_{GDo} + P_{RRvl}/P_{RRo} + P_{WWvl}/P_{WWo}$$
{Equ. 8}

$TRI\text{-}e = CRI\text{-}ve + CRI\text{-}e$ {Equ. 9}

$TRI\text{-}l = CRI\text{-}l + CRI\text{-}vl$ {Equ. 10}

Cultivars were classified into various groups as the early or late tolerance or sensitivity of each cultivar according to the results from the classification vigor indices using standard deviation.

Data Analysis:

The data of morpho-physiological and yield-related measurements were recorded and compiled in Microsoft Excel 2016. Descriptive analysis including means, standard deviations (SD), coefficients of variation (CV), and analysis of variance (ANOVA), was calculated for the traits under optimum and planting dates treatments using the SAS program (SAS] (v 9.4, SAS Institute, Inc., Cary, NC, USA, 2011) using wheat cultivars and planting date as a source of variance via spilt-plot within randomized completely block design. Data were analyzed using a one-way ANOVA via PROC GLM in SAS to determine the effect of planting dates on the morpho-physiological and yield-related traits. The Fisher's protected least significant difference test at p = 0.05 was employed to test the differences among the treatments for the measured characteristics. The standard errors of the mean were calculated using Sigma Plot 14.0 (Systat Software, Inc., San Jose, CA, USA, 2017) and presented in the figures as error bars.

RESULTS AND DISSCUSION

Using five planting dates in combination with morpho-physiological and yield-related traits, this study effectively developed a scoring system for early/late planting date tolerance in wheat, and the results indicated that by using two indices (TRI-e and TRI-l). The (TRI-e) and (TRI-l) values of the cultivars and their standard deviations were further used to classify wheat cultivars into three response groups of (TRI-e) and four groups of (TRI-l). Furthermore, wheat cultivars were classified into different groups viz sensitive, moderate, and tolerant for (TRI-e) and sensitive, sensitive-moderately, tolerant-moderately, and tolerant for (TRI-l) to planting dates based on their cumulative response for all morpho-physiological and yield-related traits. The (TRI-e) values ranged from 36.07 (sensitive) for the cultivar Al-Baraka to 39.13 (tolerant) for the cultivar Al-Hashimiya (Table 1). Four cultivars were classified as moderately sensitive or tolerant to early planting dates Sham6 (37.19), Al-Adnanieh (37.39), Al-Rasheed (37.50), and Al-Noor (38.08) (Table 1). The (TRI-l) values ranged from 36.59 (sensitive) for the cultivar Al-Noor to 39.52 (tolerant) for the cultivar Al-Hashimiya (Table 2). Four cultivars were classified as sensitive moderately to late planting dates Al-Baraka (37.95), Ipaa99 (38.07), Tammuz2 (38.35), and Al-Adnanieh (38.41). However, one cultivar was classified as tolerant moderately to late planting dates Al-Rasheed (38.58) (Table 2).

Table 1. Classification of eight wheat cultivars into three planting date response groups based on total cumulative early planting date vigor response index (TRI-e) for all parameters, along with individual scores in parentheses.

Sensitive	**Moderate**	**Tolerant**
(36.07 – 37.10)	**(37.11 – 38.12)**	**(38.13 – 39.14)**
Al-Baraka (36.07)	Sham6 (37.19)	Al-Hashimiya (39.13)
Tammuz2 (36.40)	Al-Adnanieh (37.39)	
Ipaa99 (36.50)	Al- Rasheed (37.50)	
	Al- Noor (38.08)	

Table 2. Classification of eight wheat cultivars into four planting date response groups based on total cumulative late planting date vigor response index (TRI-l) for all parameters, along with individual scores in parentheses.

Sensitive	**Sensitive - moderately**	**Tolerant - moderately**	**Tolerant**
(36.59 – 37.52)	**(37.53 – 38.45)**	**(38.36 – 39.38)**	**(39.39 – 40.31)**
Al-Noor (36.59)	Al-Baraka (37.95)	Al-Rasheed (38.58)	Al-Hashimiya (39.52)
Sham6 (36.94)	Ipaa99 (38.07)		
	Tammuz2 (38.35)		
	Al-Adnanieh (38.41)		

The correlation coefficient (r^2) between the total cumulative early planting date vigor response index and cumulative very early/early planting date vigor response index using (TRI-e) for early planting dates was positively correlated (r^2 = 0.70 for very early planting date (5-Oct) and r^2 = 0.60 for early planting date (25-Oct). This implies the light importance of very early parameters than early parameters in identifying planting dates tolerant wheat cultivars using these indices. The plot of the very early planting date vigor response index relative to the early planting date vigor response index revealed a very weak positive correlation coefficient (r^2 = 0.09). This result means both very early or early shares separately to explain the variations in total cumulative early planting date vigor response index and the selection for very early or early planting dates of these wheat cultivars are the same. Figures (1 and 2). Correlations between morpho-physiological, quality, and yield-related traits with total cumulative early planting date vigor response index are shown in Fig. 3, with the coefficient of determination (r^2) values, which give the percentage of total differences response index described by each independent variable. An overall high linear positive correlation was observed between the quality traits (r^2 = 0.74) and the TRI-e. On another hand, moderate correlations were observed between TRI-e and yield-related traits (r^2 = 0.65), and weak correlations were observed between TRI-e and morphophysiological traits (r^2 = 0.46) for the selected wheat cultivars (Figure. 3).

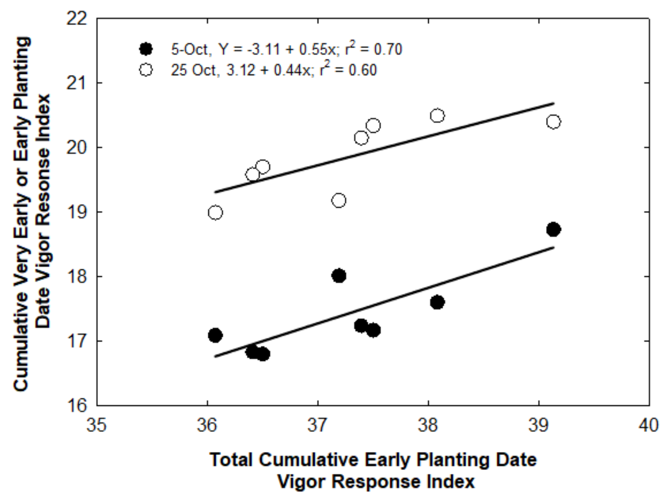

Figure 1. The relationship between total cumulative early planting date vigor response index and very early or early planting date vigor response indices of eight wheat cultivars.

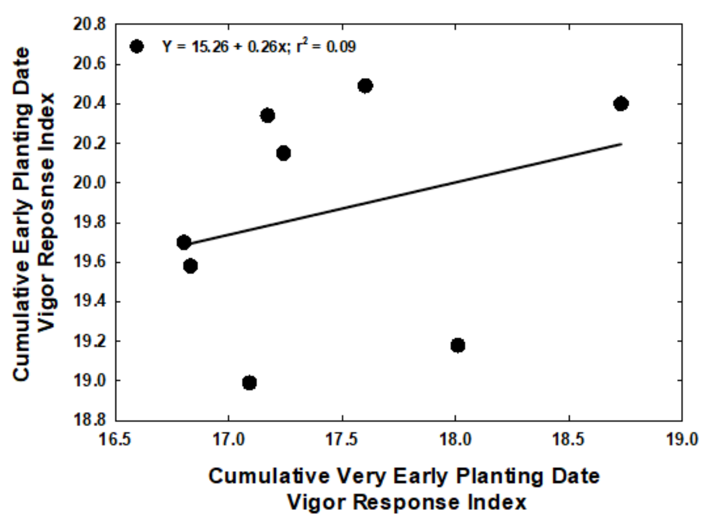

Figure 2. The relationship between cumulative very early planting date vigor response index and cumulative early planting date vigor response index of eight wheat cultivars.

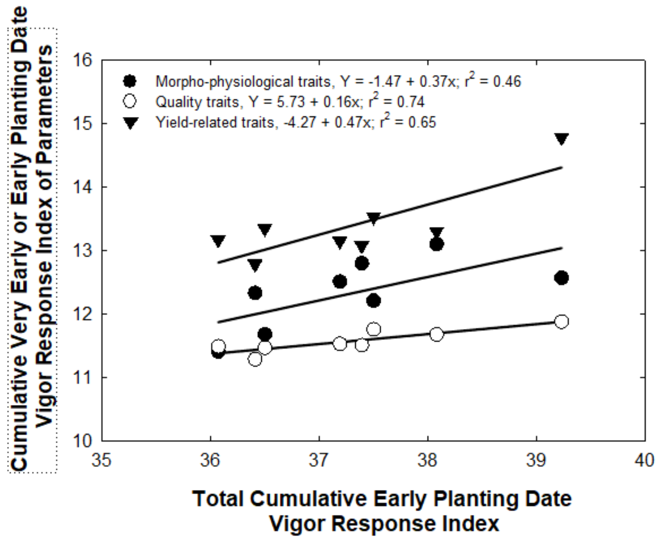

Figure 3. The relationship between total cumulative early planting date vigor response index and morpho-physiological (*closed circle*), quality (*open circle*), and yield-related (*triangle*) individual response index of eight wheat cultivars.

According to Figure 4, 76% of the total variation in the cumulative late planting date vigor response index (TRI-l) was explained by the cumulative very late planting date vigor response index while just 49% of the total variation in the cumulative late planting date vigor response index (TRI-l) was explained by the cumulative late planting date vigor response index. There is no relationship between the cumulative late planting date vigor response index and the cumulative very late planting date vigor response index (r^2 = 0.07) Figure 5. An overall very high linear positive correlation was observed between the yield-related traits (r^2 = 0.86) and the TRI-l. In contrast, very weak correlations were observed between TRI-l and morpho-physiological traits (r^2 = 0.02) and quality traits (r^2 = 0.19) for the selected wheat cultivars (Figure 6).

A similar response index has been used as selection criteria for phenotyping cereals and legume crops for abiotic stress tolerance, such as cold tolerance (Wijewardana et al., 2015), drought tolerance (Singh et al., 2017; Lone et al., 2019), salt tolerance (Kakar et al., 2019), and low or high-temperature tolerance (Jumaa et al., 2020; Reddy et al., 2021).

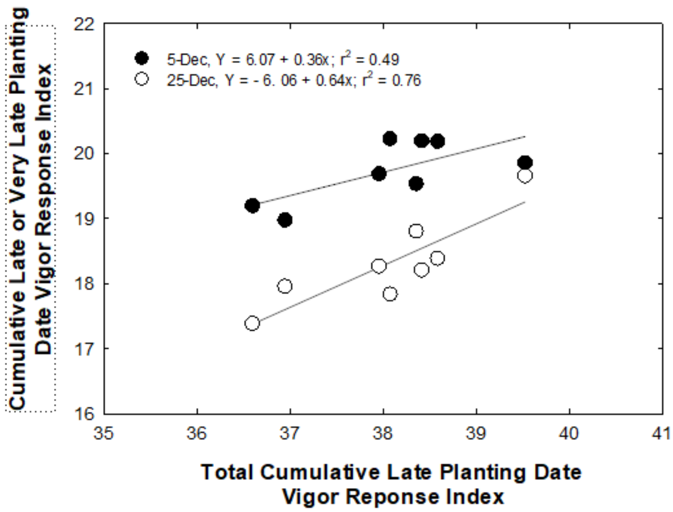

Figure 4. The relationship between total cumulative late planting date vigor response index and late or very late planting date vigor response indices of eight wheat cultivars.

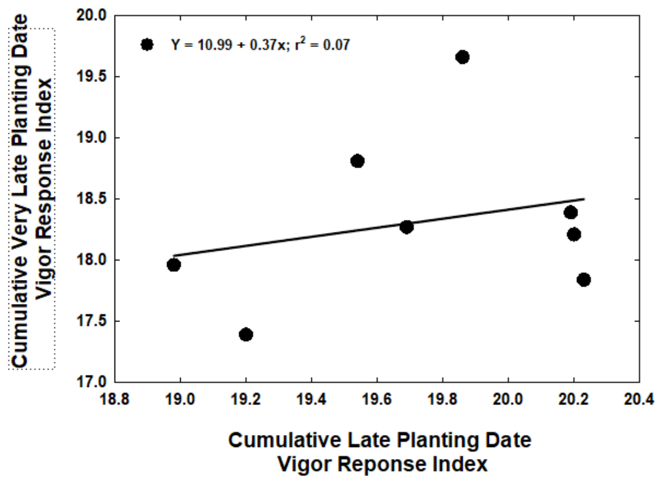

Figure 5. The relationship between cumulative late planting date vigor response index and cumulative very late planting date vigor response index of eight wheat cultivars.

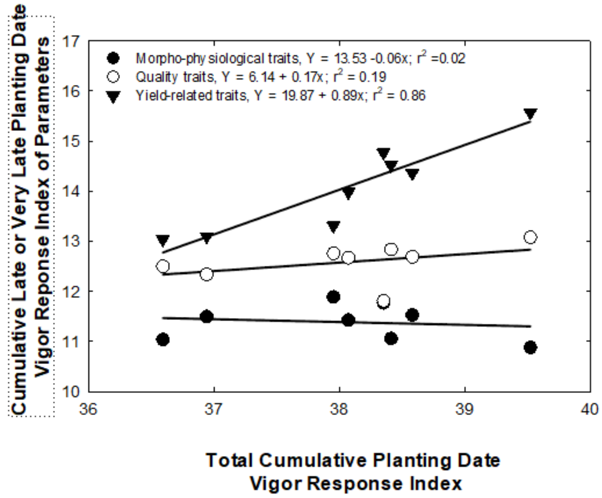

Figure 6. The relationship between total cumulative late planting date vigor response index and morpho-physiological (*closed circle*), quality (*open circle*), and yield-related (*triangle*) individual response index of eight wheat cultivars

CONCLUSION

Selected wheat cultivars were evaluated for planting date responses. The very early and very late planting date treated plants showed significantly lower morpho-physiological, qualitative traits, and yield-related parameters. Al-Hashimiya cultivar was shown to be the most tolerant to early or late planting dates among wheat cultivars. The moderate coefficient of determination between total cumulative early planting date vigor response index (TRI-e) and cumulative very early planting date vigor response index (CRI-ve) or cumulative early planting date vigor response index (CRI-e) ($r2 = 0.70$ and $r2 = 0.60$) respectively, for the studied eight wheat cultivars. This result indicates that very early and early planting date tolerance mechanisms are different and selection must be made independently in developing tolerance to very early and early planting dates. However, a strong, positive, and linear coefficient of determination between the total cumulative late planting date vigor response index (TRI-l) and total late yield-related response index ($r2 = 0.86$, $n = 8$; $p = 0.01$. This may imply that yield-related traits are vital for selecting late planting dates more than morpho-physiological and quality traits.

CONFLICT OF INTEREST

The authors declare no conflicts of interest associated with this manuscript.

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