INTERACTION OF WHEAT LINES WITH REDUCED IRRIGATION UNDER HEAT STRESSED ENVIRONMENTS

By

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THE THESIS

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DEDICATION

To my parents, brothers, sisters and friends.

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Firstly thanks to ALLAH who owed me with health, courage and patience to accomplish this work.

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ABSTRACT

Drought, heat, and heat plus drought are the main abiotic stresses affecting wheat yields in the Sudan. The purpose of this investigation are to identify potential selection physiological traits related to stress tolerance in diverse genetic backgrounds and examining genotype by environment (G x E) interaction under different stressed environments.

This study was conducted at the International Center for Maize and Wheat Improvement (CIMMYT), at their experimental station, Obregon, Mexico, during the crop season 2001/02, using thirty bread wheat genotypes and three stressed environments based on sowing date and irrigation (drought stress, heat stress and heat reduced irrigation). It was arranged in a square lattice design. Trials were managed for optimal crop growth. The data collected in the three environments were the phenology, physiological traits, water status, and yield and yield components.

Results showed that the relative performance of the genotypes were greatly influenced by environmental variation. The G x E interaction sum of squares for grain yield, though relatively large and very highly significant, was smaller than that for genotypes as well as that of environments.

Mean grain yield of genotypes under drought stress was larger than under heat stress or heat reduced irrigation environments by 113% and 45%, respectively. High temperature significantly decreased grain yield by decreasing kernel weight and reduced the rate of grainfilling after anthesis. Under the three environments, increased grain/m^2, rapid grainfilling rate, increased biomass, high canopy temperature depression (CTD) during grainfilling or prior to heading, high light interception, increased plant height and lower accumulation of carbohydrates during maturity stage were good indicators of high grain yield.

Correlation analysis indicated that under the three environments grain yield was significantly and positively correlated with grain number/m^2, grainfilling rate and canopy temperature depression (CTD) but negatively significantly correlated with stem carbohydrate during maturity stage. Under heat stress grain yield was positively and significantly associated with 1000-kernel weight, relative time of grainfilling, stomatal conductance, chlorophyll content, light interception, plant height and normalized difference vegetation index (NDVI). Under heat reduced irrigation positive and significant correlation coefficients between grain yield and percentage graifilling, peduncle, stem dry weight, and stem carbohydrate after anthesis were observed. Grain number/m^2, grainfilling rate, CTD and light interception can be used as selection criteria for grain yield under stress conditions.

تفاعل طرز وراثية من القمح مع الإجهاد المائي

تحت ظروف البيئات الحارة

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الخلاصة

الجفاف، الحرارة والحرارة المصحوبة بالإجهاد المائي من أهم المؤثرات البيئية على إنتاج القمح في السودان. هدفت الدراسة إلى معرفة الصفات الفسيولوجية المتعلقة بكل بيئة في الطرز الوراثية المختلفة لأستخدامها كصفات إنتخابية. وكذلك تقييم تفاعل الطرز الوراثية في البيئات المناخية المختلفة. أجريت التجربة في المركز الدولي لتطوير الذرة الشامية والقمح "سميت" بالمكسيك في الموسم الزراعي 2001-2002م وإستعملت ثلاثون طرز وراثية من القمح الطري تم زراعتها في ثلاثة بيئات مناخية مختلفة (بيئة جافة، بيئة حارة وبيئة حارة مصحوبة بإجهاد مائي) بنيت على أساس تاريخ الزراعة والري وفق نظام التصاميم الشبكية المربعة (A Square Lattice Design) وطبقت كل الحزم التقنية الموصى بها والبيانات التي جمعت هي الصفات التطورية، الصفات الفسيولوجية، الحالات المائية وإنتاج الغلة ومكوناتها.

أوضحت النتائج أن البيئات المختلفة كان لها أثر كبير في أداء الطرز الوراثية وكان أثر تفاعل الطرز الوراثية مع البيئة أثراً معنوياً واضحاً في إنتاجية الغلة مقارنة بالناتج من الطرز الوراثية لوحدها أو من البيئة لوحدها. لقد أعطت البيئة الجافة أعلى متوسط إنتاجية مقارنة مع البيئة الحارة والبيئة الحارة المصحوبة بإجهاد مائي 113% و45% على التوالي. لقد كان لدرجة الحرارة أثر معنوي على تدني إنتاجية الغلة بتدني وزن الألف حبة وكذلك إبطاء معدل إمتلاء الحبوب بعد الإزهار.

تحت الظروف البيئية الثلاثة، زيادة عدد الحبوب/ المتر المربع، سرعة معد ل إمتلاء الحبوب، زيادة الكتلة الحيوية، الإنخفاض العالي لدرجة حرارة النبات أثناء مرحلة إمتلاء الحبوب أو فترة ظهور السنابل، إرتفاع كمية الأشعة الضوئية المستقبلة بالنبات، زيادة طول النبات وإنخفاض تراكم الكاربوهيدرات أثناء مرحلة النضج، يعتبر مؤشر جيد للإنتاجية العالية من الغلة.

أظهرت دراسة إرتباط الصفات تحت الظروف البيئية الثلاثة أن إنتاجية الغلة ترتبط إرتباطاً معنوياً وموجباً مع عدد الحبوب/ متر المربع، معدل إمتلاء الحبوب وإنخفاض درجة حرارة النبات. وإرتباطاً معنوياً وسالباً مع تراكم الكاربوهيدرات في الساق أثناء مرحلة النضج. تحت ظروف البيئة الحارة، إنتاجية الغلة ترتبط إرتباطاً معنوياً وموجباً مع وزن الألف حبة، نسبة فترة إمتلاء الحبوب، معدل النتح عبر فتحات الثغور، محتوى الكلورفيل، كمية الضوء المستقبل بالنبات، طول النبات ومعامل النمو الخضري الطبيعي (Normalized difference vegetation index).

تحت ظروف البيئة الحارة المصحوبة بإجهاد مائي لوحظ أن الإرتباط المعنوي الموجب بين إنتاجية الغلة ونسبة فترة أمتلاء الحبوب، عنق السنبلة، الوزن الجاف للساق وكمية الكاربوهيدرات المخزونة في الساق بعد الإزهار.

عدد الحبوب/ المتر المربع، معدل إمتلاء الحبوب، إنخفاض درجة حرارة النبات وكمية الضوء المستقبلة بالنبات يمكن الإستفادة منها كوسيلة لإنتخاب إنتاحية الغلة تحت ظروف الإجهاد.

LIST OF CONTENTS

Title **Page**

Title **Page**

LIST OF TABLES

Number of table	**Title**	**Page**

LIST OF FIGURES

LIST OF APPENDICES

INTRODUCTION

Wheat (*Triticum aestivum L.*) is an important food crop worldwide. In several developing countries, consumption has been rising with the population growth. Rising incomes have contributed to this increased demand (Guillermo, 1996). Demand for wheat has been projected to increase by 1.3% per year on worldwide basis and 1.8% in developing countries for the period up to 2018 (Morris *et al*., 1991). Substantial improvements in crop cultivars and management methods will be needed if the increases in yield of wheat are to even approach these projected demands (Hall, 2001).

Availability of irrigation water is the primary limiting factor in increasing wheat production on global basis. In particular in developing countries, with the increase in population growth and consequently the demand for water increase, the water available for agriculture faces new pressure for reallocation and effective utilization. Drought tolerance is becoming increasingly important in both irrigated and low rainfall areas (Elahmadi *et al*., 1994).

Traditionally, wheat has been grown at low latitudes only in high-altitude (>1000 m) environments (e.g., Central Mexico, Ecuador, Kenya). But during the last several years it gained importance as an irrigated winter crop in tropical environments of lower altitudes (Ortiz Ferrara *et al*., 1993). In Sudan, wheat is grown during the short, dry and comparatively cooler winter season from November to February, under irrigation. It is then frequently exposed to moisture stress, due to the long irrigation intervals caused by the inadequate water delivery by the canals and temperature stress. These are considered to be the major abiotic constraints to wheat production in the tropics and have become of paramount importance in recent years (Ali and Salih,1995). Physiologists and breeders are now interested in the possibility of identifying appropriate phenological, morphological and physiological traits that are related to grain yield rather than selecting for grain yield alone under such stresses.

Production of wheat is constrained by drought in many regions of the world (Schmidt, 1983, Rajaram *et al*., 1996). According to Morris, *et al*. (1991) drought stress reduces wheat yields by 50-90% of their irrigated potential in 60 million hectares of the developing world. Richards *et al*. (2001) mentioned that low rainfall is usually perceived to be the most important factor resulting in low yields in dry environments. They mentioned that drought could also be a problem in favorable environments. Therefore the physiological means of minimizing drought stress or improving water use efficiency may also influence yield in high yielding, rain fed environments.

Yield and drought resistances are controlled at separate genetic loci, improved drought tolerance involves the identification and transfer of physiological traits responsible for drought resistance to high-yielding and agronomically acceptable cultivars (Chimenti *et al*., 2002). According to Richards *et al*. (2001) the challenge lies in trait validation, given that a character may be important in one year but not in the next year, whereas important traits will be effective from one season to the next. Richards *et al*. (2001) indicated that the physiological approach has substantial potential to improve yields and yield stability over and above that attainable through empirical breeding alone. Firstly it may identify key traits that currently limit yield in dry environments and therefore identify parental germplasm with traits that would not normally be found in a breeding program. Secondly it has the potential to more effectively cull large populations so that only the most elite lines are yield tested. Often this can be done out of season, making it possible to advance more than one generation per year. Lastly if correlations with yield are found it may be more effective to select for the trait itself rather than for yield in early generations.

Heat stress affects approximately 7 million hectares of wheat grown in over 50 countries, while terminal heat stress is a problem in 40% of temperate environments, which cover 36 million ha. Continual heat stress is defined by a mean daily temperature of over 17.5 ^{0}C in the coolest month (Fisher and Byerlec, 1991). The productivity of wheat decreases as mean daily temperatures rise above approximately 15^{0}C in part because accelerated crop development rate reduces crop duration (Midmore *et al.*, 1982). Common wheat cultivars differ in performance under warm conditions (Midmore *et al.*, 1982). Heat stress reduces yield potential by accelerating the development process thereby impeding the plant's ability to assimilate an adequate amount of growth resources as it speeds through its life cycle (Warrington *et al.*, 1977).

Drought and Heat stresses are notorious both for their unpredictable variability from location to location and their ability to limit the yield of crop plants in many agricultural regions of the world (Lewis and Christiansen, 1981; Martiniello, 1984). In cereals most of the progress in breeding for drought tolerance has been achieved by using empirical methods. In practice a drought tolerant cultivar is defined as a cultivar with the greatest yield under limited soil moisture, however better progress could be made if the physiological responses of plant to drought were known and could be used in selection programs. Breeders and physiologists are looking for ways to measure and analyze the underlying physiological mechanisms of tolerance. The chain of physiological events between gene and phenotype is not known but if a key step in the chain were known to be correlated with stress tolerance, the breeder could select directly for traits rather than selecting for the final phenotype (Sullivan and Eastin, 1974; Larsson, 1982; Martiniello and Lorenzoni, 1985).

The objectives of this study are to:

I/ Identify potential selection physiological traits related to stress tolerance in diverse genetic backgrounds.

II/ Evaluate genotype x environment (GxE) under different stressed environments.

LITERATURE REVIEW

Effects of water and heat stresses on different developmental phases

Water stress is probably the most common type of plant stress and is often associated with deficiency of soil moisture or transient stress, or both, during periods of high radiation on hot days. However, increasing wheat productivity under abiotic stressed environments (drought and heat) has become of paramount importance. The sensitivity of various growth stages to water stress is variable, depending on soil conditions, weather factors, and variety maturity period.

Simane *et al.* (1993) found that yield reduction of durum wheat was largest under mid-season drought stress (85%), followed by terminal stress (30%), and early stress (22%). They also reported that grain yield was highly associated with kernels spike^{-1} under early stress and grainfilling period (GFP) and kernels spike^{-1} under terminal stress. The development of drought tolerant cultivars is hindered by poor understanding of the mechanisms of drought tolerance and by inadequate selection techniques (Bruckner and Fohberg, 1987; Richards, 1996).

There are numerous reviews in the literature about how temperature affects different wheat characters and how the effects differ from one phenological stage to another (Geisler, *et al*., 1982; Fisher, 1985). The understanding of physiology of heat stress and resistance is still limited. However it is known that in excessive heat, plants lose their transpiration cooling and when surface temperatures reach 48-50^{0}C, a process of cumulative destruction begins, first killing cells, then tissues, and organs, and finally the whole plant (Levitt, 1972). Plant organs may reduce their temperature either by heat exchanges with the atmosphere or by shading under the canopy (Blum, 1988). According to Rawson (1988), the effects of temperature on growth are not due to temperature *per se*, but due to the increased requirement for growth resources (radiations, nutrients, and water) per unit of calendar time as temperature increase.

Review of physiological screening traits in drought and heat stress

Understanding the biological factors limiting the performance of genotypes across target environments is essential for improving breeding programs through physiological research (Jackson, 2001).

To incorporate physiological criteria in a breeding program, previously published work on traits and methodologies can be consulted (Reynolds *et al*., 2001). Reynolds *et al*. (1999) mentioned a conceptual model for drought tolerance with a good capacity for stem reserve accumulation and remobilization, early ground cover, high pre-anthesis biomass, spike photosynthesis, stomatal conductance, osmotic adjustment and accumulation of abscisic acid (ABA) and leaf anatomical traits (rolling etc). He stated that not all traits would be useful in all environments.

Water use efficiency (WUE)

Is defined here as the ratio of shoot biomass production (root biomass is rarely measured) to the total amount of water transpired (Ludlow and Muchow, 1990).WUE is generally used to express the ratio of total dry matter to evapotranspiration. An increase in transpiration efficiency (TE, dry matter/ transpiration) and/ or a reduction in soil evaporation will increase WUE (Richards *et al*., 2001).

Relative water content

It has been reported that low lethal water status refers to more negative leaf water potential. Punjabrao (1980) found that favorable temperatures during the growing period increased water use efficiency (WUE) of wheat.

Plant water status, measured as leaf water potential, leaf rolling or relative water content (RLWC), can differ significantly among cultivars exposed to the same period of water stress (O’toole and Moya, 1978). In rice, these differences are related to variation in stomatal control of transpiration (Dingkuhn *et al*., 1989).

Lafitte, (2002) mentioned that leaf water status appears to be related to yield and spikelet sterility in rice in some cases, but the relatively weak correlations indicate that other characteristics of the lines are also important in determining the integrated response of the reproductive stage to drought stress. Relative leaf water content could be used as a secondary selection target for improved grain yield under reproductive stage water deficit. Chimenti *et al*. (1996) reported that on a study of leaf relative water content (LRWC) and Osmotic adjustment (OA) in maize, a high LRWC indicates a high degree of osmotic adjustment. All genotypes showed some degree of OA. The range of LRWC obtained varied with genotype from 87% to 58%, and significant differences ($p < 0.05$). Penuelas *et al*. (1997) reported that a correlation coefficient of around 0.55 between water index and LRWC.

Osmotic Potential (OP) and osmotic adjustment (OA)

Osmotic adjustment results from the accumulation of solutes within cells, which lowers the osmotic potential and helps maintain turgor of both shoots and roots as plants experience water stress (Ludow and Muchow, 1990). (Morgan and Condon, 1986; McCree and Richardson, 1987; Ludlow *et al.*, 1990) It has been mentioned that OA has no effect on water use efficiency but it contributes to grain yield in water-limited conditions by increasing the amount of water transpired and by minimizing the reduction in harvest index. OA reduces the rate of leaf senescence (sometimes called stay green character in grain crops) (Wright and Simth 1983; Hsiao *et al.*, 1984;).

Chimenti *et al.* (2002) conducted a study on a set of 25 inbred lines reputed to differ for drought tolerance and OA expression in sunflower. He crossed lines with high and low OA; and selected individuals from the F_2 population and derived F_3 families by self-pollination of these individuals. These plants were grown under rain-out shelters and subjected to a 30-day drought before anthesis. He found that high OA families expressed greater OA (OA at full turgid, estimated as the difference in OP between drought and control treatments) than low OA families at the end of the drought period.

Crops of High OA families extracted more water from the profile during the stress period, had greater shoot biomass and harvest index at physiological maturity, and greater grain yield (Ca 30%). No effect of OA on these variables in the irrigated controls, and yield components were most affected by levels of OA. Yield maintenance under drought conditions was attributable to variations in the post-drought shoot biomass increases and harvest index which could be used as markers for developing the OA trait.

Morgan and Condon (1986) found that some maintenance of stomatal permeability under stress and the maintenance of turgor, given levels of drought stress, by either OA or elevated leaf water potential. It has been found that OA will help maintaining transpiration, leaf metabolism and root growth (Morgan and Condon, 1986). Chimenti *et al*. (1996) suggested that OA estimates could be used to identify drought tolerant genotypes.

Stem reserve accumulation and remobilization

Stem reserves from pre-anthesis plant assimilation are being increasingly recognized as an important source of carbon for grain filling when photosynthesis is inhibited by drought or heat stress during this stage (Blum, 1998). Genotypic and environmental factors affecting reserve accumulation and utilization during grain filling have been studied and practical guidelines for selection work are available (Blum, 1998). Stem reserve accumulation and storage capacity in the stem strongly depends on growing conditions before anthesis as total stem weight at anthesis was shown to vary from 50-350gk^{-1}dry mass between different experimental conditions (Kiniry, 1993). Potential stem storage is determined by stem length or stem weight density. Stem weight density is equal to the stem dry weight per unit stem length. Storage and remobilization may vary along the stem (Blum, 1998).

Stem reserve mobilization or the percentage of stem reserves in total grain mass, is affected by sink size (Blum, 1998). When detraining reduced sink size more reserves were stored in the stem compared with intact ears (Kuhbauch and Thome, 1989). Taller cultivars have a greater capacity for storage in stems, which appears to be a genetically controlled constitutive trait (Blum *et al*., 1994). Traits such as dehydration avoidance and tolerance have been found to be positively associated with yield under stress across genotypes of wheat and barley (Acevedo *et al*., 1991). Acevedo and Fereres (1996) reported that dehydration avoidance is interpreted as the ability of genotypes to maintain a higher leaf water potential when grown under soil water deficits. The same authors mentioned that an important form of drought stress tolerance is the tolerance to post-anthesis stress. In wheat, as in other cereals, grainfilling depends partly on carbohydrates stored during pre-anthesis, which is translocated from vegetative plant parts. Grain growth rate was correlated with yield (Sayre *et al.*, 1997). He and Rajaram (1994) found that grain-filling rate is more temperature sensitive than days to anthesis and duration of grainfilling.

Peduncle length and extension

In winter barley, the basal internodes were found to contribute the most to storage of reserves (Bonnett and Incoll, 1992). Other studies with barley showed that the peduncle and penultimate internodes (and leaf sheath) contained the most storage (Daniels and Alcock, 1982). Similarly in wheat the peduncle and the penultimate internodes contained the most storage (Wardlaw and Willenbrink, 1994).

Canopy temperature depression (CTD)

Reynolds *et al.* (2001) reported that experimental data has shown a clear association between CTD and yield in both warm and temperate environments. CTD has a high genetic correlation with yield and a high response to direct selection indicating that the trait is heritable and therefore amenable to early generation selection (Reynolds *et al.*, 1997). Amani *et al.* (1996) found a highly significant correlation between CTD, grain yield and stomata conductance. The strongest correlation with yield occurred with CTD measurements taken between noon and 4 p.m. CTD is affected by many physiological factors, which makes it a powerful trait. Since an integrated CTD value can be measured almost instantaneously on scores of plants in a small breeding plots, work has been conducted to evaluate its potential as indirect selection criterion for genetic gains in yield (Reynolds *et al*., 2001).

Stomatal conductance

Leaves maintain their stomata open to permit the uptake of CO_2, and differences in the rate of CO_2 fixation may lead to differences in leaf conductance that can be measured using a porometer. Barma (1995) reported that stomatal conductance correlates with yield and other traits such as days to anthesis, maturity, leaf chlorophyll content and is inversely related to canopy temperature. In wheat at pre-anthesis and post-anthesis stages, a positive significant correlation between stomatal conductance and yield was found (Fisher *et al*., 1998, Reynolds *et al*., 2000).

Chlorophyll content

Reynolds *et al*. (2000) reported that chlorophyll content; photosynthetic rate, stomatal conductance and dark respiration rate were measured in 16 wheat cultivars. There were clear differences between the cultivars at three growth stages for these physiological traits. The grain filling period was also found to be strongly associated with chlorophyll loss. Chlorophyll concentration at anthesis and post-anthesis of wheat-advanced lines grown under heat stress vary significantly and are positively associated with grain yield. Physiological evidence indicates that loss of chlorophyll during grainfilling is associated with reduced yield in the field (Reynolds *et al*., 1999).

Light interception or ground cover and biomass at anthesis

Thinner, wider leaves (i.e. with a relatively low specific leaf weight) and a more prostrate growth habit help to increase ground cover, thus conserving soil moisture and potentially increasing radiation use efficiency (Richards, 1996). This trait is considered to be more important in the Mediterranean type of drought environment where rain may occur during the early part of the growth cycle (Reynolds *et al.*, 2001).

Calderini *et al.* (1997) examined the effect of wheat breeding on crop biomass and its physiological determinants, i.e. radiation and radiation use efficiency. He found that biomass at anthesis tended to be less in the most recently released cultivars compared to the older materials and accumulated intercepted radiation at similar developmental stages differed between cultivars. These differences, as well as the trend of biomass at anthesis, were caused by differences in the length of developmental phases between cultivars rather than by changes in the architecture of the canopies. Early ground cover seems to be important in an agronomic context (Rawson, 1988).

Ground level measurement of vegetative index has been used successfully as a tool for assessing early biomass and vigor of different wheat genotypes (Elliott and Regan, 1993; Bellairs *et al.*, 1996). Bellairs *et al.* (1996) reported that young wheat canopies where leaf area index was less than 1.5, had a coefficient of determination (r^2) of 0.90-0.95 between biomass and normalized difference vegetation index.

Spectral reflectance

Another promising technology can be used to estimate a range of physiological characteristics including plant water status, leaf area index, chlorophyll content, and absorbed through the photosynthetically active radiation (Araus *et al.*, 1999). The pattern of light reflection on leaves at different wavelengths through the photosynthetically active radiation (PAR, 400-700 nm) and near infrard radiation (NIR, 700-1200 nm) regions of the electromagnetic spectrum is very different from that of soil and other materials (Araus *et al*., 2001). This author mentioned that leaf pigments absorb light strongly in the PAR region but not in the NIR, thus reducing the reflection of PAR but not NIR.

The measurement of spectra reflected by vegetation that can be used to estimate a large scope of parameters, some of them are related to the green biomass of the canopy, its photosynthetic size (i.e. total area of leaves and other photosynthetic organs), the amount of PAR absorbed by the canopy, its photosynthetic potential. The physiological parameters that can be estimated by spectral reflectance techniques include chlorophyll and carotenoid concentrations photosynthetic radiation use efficiency and water content.

Chapelle *et al*. (1992), developed the ratio analysis of reflectance spectra (RARS) indices, RARSa, RARSb, and RARSc, which optimized the estimation of chl a, chl b, and Cars, respectively, in soybean. Penuelas *et al*. (1997) showed that normalized difference vegetation index (NDVI) was a useful tool for measuring agronomic responses of barley to salinity. Leaf area index, green area index, etc., can be estimated through their positive correlation with vegetation indices (Wiegand and Richardson, 1990; Baret and Guyot, 1991 ; Price and Bausch, 1995).

The most promising methods allow for quick screening of "integrative" physiological traits; so called because the integrate physiological processes either in time (i.e., during the plant cycle) or at the organization level. (e.g. whole plant, canopy).

Genetic diversity and physiological traits

The genetics of wheat and its wild relatives has already been exploited through wide crossing to introduce disease resistance (e.g. Villarreal *et al*., 1995). The genetic resources available to plant physiologists and breeders are found in several *triticeae* genepools recognized by Von Botmer *et al.* (1992). Once the value of a physiological trait has been established it may be useful to determine its genetic basis, such as the number and location of genes involved in its expression (Reynolds *et al.*, 2001). Physiological traits are often identified as having contributed to improving yield potential, but usually in retrospective, after the germplasm has been developed (Skovmand *et al.*, 2001). The investment of fingerprinting for stress tolerance, on fixed lines in any breeding program worldwide, would allow strategic crossing programs to improve drought tolerance.

Genotype by environment interactions and the factors that can affect the expression of trait (i.e. macro-environment, micro-environment and physiological factors) may show an interaction with genotype, for what is collectively called genotype by environment interaction (G x E). Some traits demonstrate little (G x E), i.e. genotypes ranked based on these traits will largely maintain this rank across different environments, regardless of the absolute expression of trait. These traits are highly heritable, as the environment has little influence on their expression. Therefore selection for these traits will be effective across locations and years.

G x E is differential genotypic expression across environments, it reduces association between phenotypic and genotypic values, and may cause selections from one environment to perform poorly in another, forcing plant breeders to examine genotypic adaptation (Romagossa and Fox , 1993).

Quarrie *et al.* (1981). Reported that genetic variation in drought induced abscisic acid accumulation (ABA) among wheat cultivars. Using an excised leaf test and an analyzing of the progeny from a cross between two cultivars, he found difference in their capacity to accumulate ABA. The technique was used to study the heritability of ABA accumulation and to develop lines different in their capacity to accumulate ABA.

Genetic variation in photosynthetic rate, stomatal conductance, leaf chlorophyll content, and dark respiration was studied in 16 wheat genotypes grown under heat stress, and all measured on flag leaves showed a strong interaction between photosynthetic rate with genotype, and a clear association among the parameters and correlated significantly with grain yield (Delgado *et al*., 1994). Genetic variation exists within cereal crop species in the ability to sustain kernel growth by remobilization of reserves (Austin *et al*., 1980). Acevedo *et al.* (1991) identified some useful traits for bread wheat grown in stressed Mediterranean environments.

Acevedo and Fereres (1993) found that genetic variation has been observed in wheat for a number of adaptive traits related to resistance to environmental stress. They included maintenance of relatively higher leaf potential under soil water deficits, osmotic adjustment, tolerance to stress in plant or organ growth rate, plant recovery upon dehydration, tolerance in the photosynthetic system or its components, tolerance in enzyme activities, root growth. Ludlow and Muchow (1990) reported that genotypes of wheat with high OA produce more root biomass and greater root length density and extract more soil water than do genotypes with low OA. (Wright *et al*., 1983; Morgan and Condon, 1986). Genetic variability in OA has been found in wheat (Morgan *et al*., 1986).

Genetic diversity for heat tolerance in cultivated wheat is well established (Midmore *et al*., 1982; Rawson, 1986; Al-Khatib and Paulsen, 1990). Barma *et al.* (1995) reported significant variation among the F_5 generation in stomatal resistance. These results pointed at the possibility of exploiting this variability in selecting genotypes for heat tolerance on the basis of stomatal resistance. Reynolds *et al.* (2001) mentioned in some case CTD was associated with over 50% of yield variability of some lines at sites in Sudan, Brazil, and Egypt. This encouraged the author to start work, using CTD as a tool for selection in early generations by crossing lines contrasting in CTD to generate homozygous sister lines.

Physiologists and breeders have been continuously confronted with the need to develop screening tests to identify stress-resistance traits as an aid to selections (Acevedo and Fereres, 1993). Thus the authors mentioned that if screening tests are sought, the traits to be selected for must satisfy the following criteria:

1. There should be genetic variation within the germplasm pool for the trait under consideration.
2. The traits should have greater heritabilities than yield itself.
3. They should be correlated with yield under stress or with a yield-based stress resistance index.
4. Prefer ably, they should be causally related to yield.
5. They should be economically, easy and rapid to assess.

MATERIALS AND METHODS

Field conditions

This investigation was conducted at the International Center for Maize and Wheat Improvement (CIMMYT), at their experimental station in the Yaqui Valley, Cd Obregon Sonora, in northwestern Mexico (27^0 $29^/$ N, 109^0 $55^/$ W and 40 meters above sea level). The soil was a coarse, sandy, clay montmorillonite (Typic calciorthid) with less than 0.05% organic matter and a pH 7.7. Thirty genotypes were sown in three environments based on sowing date and irrigation. All environments received an application of one irrigation before seeding. The environments were

I) Planting on 22 November 2001 and one irrigation after seeding (Drought stress environment).

II) Seeding on 15 February 2002 and applying irrigation at a reduced rate of a month interval (Heat stress reduced irrigation environments).

III) Seeding on 15 February 2002 but with full irrigation(Heat stress environment)

The average temperature during the first growing date was 19.4^0C, with a maximum of 38.2^0C and a minimum of 1.4^0C, (October 2001 until 31 march 2002), while the later sowing date was characterized by relatively higher temperature. Fig 1. showed the maximum and minimum temperature at Obregon (Mexico) during the crop season 2001/02.

Experimental design

The field plot design was a square lattice design with two replications for three environments.

Crop management

Planting

Non-irrigated environmental condition was sown on the 22 November 2001 (normal Obregon sowing date). The second sowing date, which included full and reduced irrigation under heat stress conditions, was sown on the 15 February 2002 (late sowing date). The first sowing date included 25 genotypes. Plots consisted of two beds, each 6m long and 0.8m wide with 3 rows. The seed rate was 120 g per plot in the drought trial. The late sown date (heat stress trial) included 30 genotypes. Plots consisted of two beds, each 4m long and 0.8 m wide with 3 rows. The seed rate was 75 g per plot. Both trials were managed for optimal crop growth which included treatment with foliaur to control rust diseases and velasistox to control insects (aphids), topick to control grass weeds and brominal (1 ml/ha) with estarane (700 ml/ha) to control broad-leaf weeds.

Fertilization

The experiment was fertilized with nitrogen and phosphorus. The nitrogen full dose was 300 kg urea/ha applied in to two doses, 200 kg/ha of urea was applied before seeding and 100 kg/ha of urea was applied with the first irrigation. Phosphorus was applied at the rate of 50 kg superphosphorus/ha before seeding.

Plant material

The material used consisted of 30 genotypes selected from diffused advance trials, heat tolerance wheat yield trials (HTWYT) and drought stress trials. Each genotype was noted for its high expression of particular physiological traits. Table-1 presents the origins of the material and the physiological traits they express.

Collection of data

Days to heading was estimated as the number of days from emergence until 50% of the spikes emerged from boot.

Days to Flowering was estimated as the number of days from the date of 50% emergence until the date when visually 50% of the spikes were flowering in each plot.

Days to maturity was recorded, as the numbers of days from the date of 50% emergence to the date when visually 50% of the spikes had reached maturity.

Light interception (%)

Light interception was measured using a Ceptometer (sunfleck ceptometer, decagon devices Inc, 1989 made in USA). Measurements were taken approximately between 11:00 am and 1:00pm at grain filling stage on sunny, clear days. The measurements were taken of the available light above the canopy and of the light reflectance from the canopy. Light interception of the canopy was measured in 3 areas per bed. Light interception of the canopy was calculated using the following formula:

= (1-(((B1+B2)/2)/LA))*(1-(LR/LA))*100

Where:

B1-Bed 1.
B2-Bed 2.
LA-Light above plot.
LR-Light reflectance from the canopy.

Canopy temperature measurement

Canopy temperature depression (CTD) was measured remotely using a hand-held infrared thermometer (IRT) (model AG-42, Telatemp crop, Fullerton, CA made in USA). Measurements were taken from the vegetative stage once when full canopy cover was reached. Two measurements were taken per plot, with the IRT held one meter away from the edge of the plot and approximately 50cm above the plot. Readings were taken over four days, at two times during the day between 9:30 to 11:00am, and 1:00 to 4:00pm.

Air temperature and relative humidity were measured simultaneously with CTD using an aspirated psychrometer.

Stomatal conductance

Stomatal conductance (SC) was measured using a thermoline porometer. This porometer measures the leaf resistance to airflow. In order to calculate SC, the leaf resistance to airflow is converted to conductance using the following formula: Conductance = (1/ (Resistance/6)100. Measurements were made between 10:30am to 3:00pm on flag leaves at flowering stage in both treatments on the second sowing date (mean of 10 samples per plot). Wet and dry bulb temperatures were measured simultaneously using an aspirated psychrometer.

Chlorophyll content

Chlorophyll content was estimated using a SPAD-502 Minolta chlorophyll meter. Measurements were made on flag leaves at vegetative and grain filling stages (mean of 6 samples per bed).

Biomass at flowering stage

This measurement was taken 6-8 days after flowering. A sample of 0.5m long of row and 0.8m wide was cut, and from this the fresh weight of 50 tillers was measured. Twelve stems were removed from the sample and oven dried at 70^0C for 48 hours, and the dry weight of each was recorded. The twelve stems were then analyzed for water soluble carbohydrates (CHO) content.

Leaf rolling

A scale of 1-10 was used to visually estimate leaf rolling, where 1 represents no leaf rolling.

Peduncle thickness (mm)

Peduncle thickness was measured using a micrometer Mitutoyo (made in USA, INT-mm) at maturity near the base of the spike (mean of 6 samples per plot).

Peduncle length (cm)

Peduncle length was taken at maturity from the first node in primary tillers up to the base of the spike (mean of 6 samples per plot).

Peduncle extrusion (cm)

This measure was taken at maturity from flag leaf up to the base of the spike (mean of 6 samples per plot).

Plant height

At maturity plant height was measured from the soil surface to the top of the spike (excluding the awns).

Yield and yield components

Biomass at maturity was estimated from a random sample of 100 tillers from each plot. The fresh weights of the samples were taken then the samples were dried in an oven at 70^0 for 48 hours and the dry weight for each sample was recorded. The samples were then threshed for grain and weighed. To obtain grain yield an area of 3 x 1.6m of each plot was harvested with a small plot combine. Thousand-kernel weight was recorded in grams by weighing a random sample of 200 kernels, then multiplying by 5. All other yield components were measured (spikes/m^2, harvest index and grain/m^2).

Spectral reflectance

Spectral reflectance, can be used to estimate a range of physiological characteristics including plant water status, chlorophyll content, absorbed PAR, a number of crop characteristics, and the normalized difference vegetation index (NDVI), etc. Spectral reflectance was measured using a FieldSpec^R (analytical spectral devices, inc, made in USA). Measurements were taken during the grain filling stage on sunny clear days between (12:00 to 1:00pm), (mean of 4 readings per plot).

Water status

Osmotic potential (mmol/kg)

Leaf samples were taken between 7.30 and 8.30am at booting and heading stages, in both the first and second sowing dates. Leaf samples were collected under different irrigation regimes and at different growth stages. Each plot sample consisted of mid-leaf sections of three flag leaves which were placed in 10.0 ml tubes. The leaves were hydrated by filling the tubes with distilled water and then refrigerated for three hours. After this time the leaves were dried with absorbent paper and placed in 1.5 ml tubes and then stored in a freezer until all samples were collected in first sowing date. Once all the samples had been collected osmotic potential was measured using a Vapor Pressure Osmometer (model 5500).

Osmotic adjustment

This was calculated using the following formula:

Osmotic adjustment= Osmotic potential drought (reduced)-Osmotic potential irrigation.

Leaf Relative water content (LRWC) %

Leaf samples were taken between 2 and 3pm at booting and heading stages in both the first and second sowing dates. Leaf samples were collected under different irrigation regimes and at different growth stages. Each entry sample consisted of the mid-leaf sections of four flag leaves cut with scissors. Each sample was placed in pre-weighed airtight tubes and returned to the laboratory as soon as possible and weighed to obtain the leaf fresh weight (FW). After which leaf samples were immediately hydrated to full turgidity overnight in the refrigerator. Then the samples were taken out of the refrigerator and dried well to remove any surface moisture with absorbent paper, then immediately weighed to obtain the fully hydrated weight (HW). Samples were then oven dried at 70^0C for 24 h and weighed to determine dry weight (DW). The LRWC is calculated:

$$RWC (\%) = [(FW-DW) / (HW-DW)] \times 100$$

where:

FW-sample fresh weight, HW-sample hydrated weight, DW-sample dry weight.

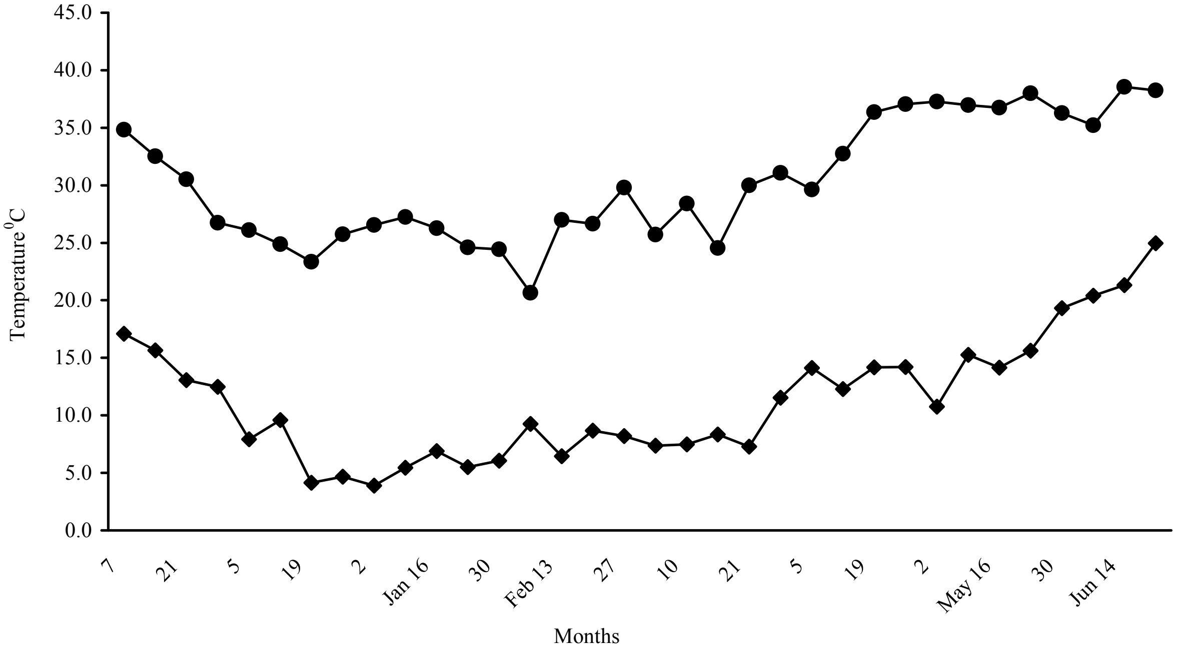

Fig. 1 Maximum and minimum temperature at Obregon (Mexico) during the crop season 2001/2002

Table 1. The physiological traits, origin and cross of the wheat genotypes used in the study.

Entry	Cross	Physiological traits and origin
1	W15.92	Osmotic potential (Advance line- drought trial)
2	CROC-1/AE.SQUARROSA (224)//OPATA	Biomass at anthesis (Synthetic line)
3	PUB94.15.1.12	Land race (Mexican land race)
4	MEX94.27.1.20	Land race (Mexican land race)
5	PRINIA	Stems carbohydrates (CHO) (Advance line-drought trial)
6	SW89.5193	Stems carbohydrates (CHO) (Advance line-drought trial)
7	JUN/GEN	Deep roots (Advance line-drought trial)
8	SYN/OPATA	Stems carbohydrates (CHO) (Advance line-drought trial)
9	BABAX	Biomass at anthesis(Advance line-drought trial)
10	WEEVIL-1	CTD-grainfilling (Advance line-drought trial)
11	FIRETAIL	Stems carbohydrates (CHO) (Advance line-drought trial)
12	OR791432/VEE#3.2	Deep roots (Advance lines)

13	PFAU/VEE#9//URES	CTD- grain filling (Advance lines)
14	GIM/LIRA	Osmotic adjustment (Advance lines)
15	MEX94.15.34	Heat tolerance (Mexican land race)
16	OAX93.24.35	Heat tolerance (Mexican land race)

Table 1. Cont.

Entry	Cross	physiological traits and origin
17	MEX94.2.18	Heat tolerance (Mexican land race)
18	MEX94.2.19	Heat tolerance (Mexican land race)
19	PASTOR/3/ALTAR84/AEGILOPS SQUARROSA (TAUS)//OPATA	Good emergence (Advance line-drought yield trial)
20	WEEBILL4	Good emergence (Advance line-drought yield trial)
21	PASTOR//HXL7573/2*BAU	Good emergence (Advance line-drought yield trial)
22	OAX93.24.35	Drought and heat tolerance (Mexican land race)
23	PUB94.15.	Drought tolerance (Mexican land race)
24	MEX94.12.	Drought tolerance (Mexican land race)
25	ATTILA	Check, heat tolerance (Attila release in Sudan)
26	IWA 8608663	Heat tolerance (Iranian landraces)
27	URES/JUN/KAUZ	Heat tolerance/ CTD (Advance lines)
28	KAUZ*2/TRAP//KAUZ	Heat tolerance/ CTD (Advance lines)
29	IWA 8606251	Heat tolerance/ Diversity genes (Iranian land races)

30	SYN/OPATA	Diversity genes(Iranian land races)

Statistical analysis

Analysis of variance was calculated for each environment separately. Means were compared using Duncan's Multiple Range test. Simple linear correlation coefficients were calculated using the means for each traits against itself across the three environments; correlation coefficient analysis was used to measure the association between yield and other related traits under the three environments. Coefficient of determination (R^2) from simple regression analysis was calculated.

RESULTS AND DISCUSSION

The combined analysis of variance revealed very high significant differences ($P < 0.001$) among genotypes for all the studied traits except osmotic potential which is just significant ($P<0.05$) (Table 2). The effects of environment on the yield and its components were mostly highly significant ($P < 0.01$).

Genotype x environment (G x E) interactions were very highly significant ($P< 0.001$) for most traits measured, indicating that the relative performances of the genotypes were greatly influenced by environmental variation. The G x E interaction sum of squares for grain yield, though relatively large and very highly significant, was smaller than that for genotypes as well as that of environments.

The current results are in agreement with the findings that differences in yield existed among wheat genotypes in their response to changes in environments and that of genetic variation in yield is masked by large genotype x year and/or genotype x location interactions (Ortiz and Assad, 1989; Ishag and Ageeb, 1991; Guillerm 1996; Tahir *et al*., 1999 and Richards *et al.*, 2001).

Mean grain yield of genotypes in each environment ranged from 1.06-2.96 t/ha, 0.24-2.94 t/ha and 0.21-2.38 t/ha for drought stress, heat stress and heat reduced irrigation environments, respectively (Table 3). It is quite clear that grain yield under drought stress conditions was larger than under heat stress or heat reduced irrigation environments by 113% and 45%, respectively (Fig 2). This could be attributed to the fact that under drought environment, the grainfilling period coincided with a cold spell (Fig.1). Ishag and Ageeb (1991) reported high grain yield could be attained when anthesis coincides with the coolest period. Yield is relatively higher under heat stress environment than under heat reduced irrigation condition. This may be due to the effect of water stress which maximizing the heat stress. Hanson and Hitz. (1982) reported that most metabolic processes in plants are either directly or indirectly affected by water stress. It is found that yield differences between cultivars are minimal under favorable conditions (Farah *et al.*, 1993). This fact should be very useful for scheme managers to allocate tolerant wheat cultivars in areas where irrigation water is scarce or difficult to manage.

Some genotypes showed grain yield stability across environments, e.g. genotype PASTOR/3/ALTAR84/AEGILOPS SQUAEEOSA (TAUS)//OPATA or no. 19 gave the highest grain yield in the three environments (2.96 t/ha) while genotype GIM/LIRA or no. 14 almost gave the lowest grain yield (0.21 t/ha) in these environments (Tables 3 and 4). The grain yield of genotype 19 was almost 10 times that of genotype 14.

Genotype 19 ranked number one in grain number/m^2 and grainfilling rate, have intermediate ranking values for 1000- grain weight, plant height, light interception, accumulation of carbohydrate and leaf rolling as well as high canopy temperature depression. It was early in anthesis and maturity, i.e. ranked as 25 and 24 in the two traits, respectively. Across environments, it flowered in two months and matured in 3 months time.

On other hand, genotype 14 showed almost the lowest ranking values for grain number/m^2, grainfilling rate, 1000-grain weight, light interception and plant height. It is similar to genotype 19 in anthesis and maturity.

Genotype 18 ranked second to genotype 19 in grain yield, in the three environments (Table 3). It was characterized by high grain number/m^2 and grainfilling rate and was intermediate in maturity and plant height.

Grains no. /m^2, grainfilling rate, days to anthesis, physiological maturity, plant height, light interception and CTD were suggested as simple selection criteria for high grain yield under stress conditions (Elahmedi, 1994; Richards and Reynolds *et al*., 2001). Cultivars with the ability to fill grain quickly should have an advantage in dry environments with short, hot, grain filling conditions (When *et al*., 1989).

Yield components

Comparison between drought stress, heat stress and heat reduced irrigation environments for yield components are given in Table 5. It was clear that there was significant variation among environments for all the studied traits, except number of grain/m^2 and days to heading (Table 5). Heavy kernel weights were attained under drought stress compared with the two other environments. Interestingly, while days to anthesis and maturity showed considerable variation among environments, the relative proportion of time for grain filling, did not vary significantly between drought stress and heat reduced irrigation environment (Table 5).

From the above results it can be concluded that high temperature significantly decreased grain yield by decreasing kernel weight, caused by reducing the rate of grain filling after anthesis. Many investigators found that high temperatures (>31^{0}C) after anthesis decrease the rate of grainfilling in wheat (Slafer and

Rawson 1994; Wheeler *et al.*, 1996). Acevedo *et al.* (1991), reported that, kernel weight is another important yield component. It depends on rate and duration of grainfilling; temperature shortens the duration of grainfilling and that decreased duration would reduce final grain yield.

Physiological and morphological traits

Canopy temperature depression (CTD)

Canopy temperature depression is the difference between temperatures at canopies minus air temperature. CTD showed considerable variation among environments and time of measurement (Table 6). The present results showed high CTD values at morning, during the vegetative stage and under drought stress environment. Generally, the CTD was high at the morning than at the afternoon, during both vegetative and grainfilling stages in the drought stress environment.

In the heat stress environment, the CTD was high during vegetative period in the afternoon. It is almost similar under drought and heat reduced irrigation environments.

During grainfilling the CTD was low under heat plus reduced irrigation environment in the whole day compared with the two other environments. However, under heat reduced irrigation environment, the CTD was high during the vegetative stage in the morning.

Thus, it is important that, in using CTD to develop germplasm for a biotic stresses, stage of growth and time of the measurement are to be taken in consideration.

Light interception

Light interception showed significant differences among environments. It was higher under drought stress (Table 6). This revealed the influence of heat stress on the ground cover. On the other hand light interception under heat stress full irrigation was higher by 4% when compared to heat stress reduced irrigation.

This indicated that the effect of heat stress on the total above ground biomass was larger than that from water stress. Similar results were reported by Acevedo *et al.*, 1991 and Richards *et al.*, 2001.

Chlorophyll content

The chlorophyll content of the plants in the heat reduced irrigation environment was higher than those under both drought and heat stress environments (Table 6). It is quite similar under drought and heat stress environments.

Stomata conductance

Data in Table (6) showed significant differences in stomata conductance between heat stress and heat reduced irrigation environment. It was reduced with increase of moisture stress and became difficult to measure; so care should be taken to avoid the effects of soil heterogeneity that may affect water availability.

Leaf rolling

There were significant variations among environments in leaf rolling (Table 6). The lowest rolling were observed in leaves of genotypes grown under heat stress followed by genotypes grown under drought stress. Thus with reduced irrigation under heat stress there is an increase the value of leaf rolling.

Relative leaf water content (RLWC)

There were significant variations in relative leaf water content among environments (Table 6); the lowest RLWC were noted in leaves of genotypes grown under drought stress environment during booting and grainfilling stages. However, non-significant differences in RLWC were observed under heat stress and heat reduced irrigation during grainfilling.

Osmotic potential and adjustment

Genotypes are usually characterized for osmotic adjustment by measuring responses of osmotic potential and relative water content to change in water potential in leaves of field grown plants (Morgan, 1999). There were significant differences in osmotic potential and adjustment under the different environments (Table 6). The highest osmotic potential and consequently adjustment were observed in the tissues of genotypes grown under drought stress environment followed by heat reduced irrigation.

Oleinlkova (1969) noted that the drought resistant wheat varieties showed greater water retaining ability than the drought susceptible. Drought resistance was associated with osmotic adjustment (Blum *et al.*, 1986).

Peduncle

Data in Table (6) showed great variation between heat stress and heat reduced irrigation environments for peduncle length, and extrusion. The longest peduncle length and consequently extrusion were noted in the genotypes grown under heat reduced irrigation than under heat stress environment.

Plant height

Plants became significantly taller under heat reduced irrigation than under the other two environments (Table 6).

Stem carbohydrate

There were highly significant differences in stem carbohydrate under the different environments (Table 6). The highest carbohydrate accumulation was observed under heat reduced irrigation followed by heat stressed environment. Thus genotypic and environmental factors affect carbohydrate reserve accumulation and utilization for grainfilling.

The present results indicated that the highest peduncle length and extrusions and plant height, caused more accumulation of carbohydrate in the stem under heat reduced irrigation compared to those under heat and drought stress, respectively (Table 6). The present results reinforced the importance of these characters under heat reduced irrigation as reported by Wardlaw and Willenbrink (1994) and Blum (1998).

Spectral reflectance

Spectral reflectance is sun light reflected from the surface of breeding plots. Leaf spectral reflectances were measured to determine whether leaf reflectance responses to plant stress may differ according to the agent of stress and genotypes.

The results showed that there was non-significant variation in spectral reflectance between heat and heat reduced irrigation stress for normalized difference vegetation index (NDVI). The lowest NDVI values were observed under drought stress. The decreased absorption by water stress is reported by Gregory (1993). He found that reflectance visible wavelengths increased consistently in stressed leaves. Infrared reflectance was comparatively unresponsive to stress, but increased at 1.400-2.500nm with severe leaf dehydration and the accompanying decreased absorption by water. Nieves, *et al.* (2000) suggested for durum wheat under Mediterranean conditions, the usefulness of NDVI for predicting green area and grain yield is limited to environments or crop stages.

Data in Tables (5, 6) show the amount of genetic variability for the traits under study in each of the three environments, showing sufficient variability within genotypes (Appendices 1, 2 and 3) and suggesting these traits could be used as selection criteria in bread wheat genotypes as reported by (Ortiz Ferrara *et al.*, 1989).

Association of grain yield and several physiological traits across three stressed environment

Data in Table 7 showed the simple linear correlation coefficients for grain yield, its components and some physiological traits across three stressed environments (heat stress, heat reduced irrigation, drought stress). Each trait was correlated against itself across the three environments.

Positive and significant correlation coefficients were found across environments for most studied traits (Table 7). Certain traits showed highly, positive significant correlation coefficients only when comparing them in heat vs heat reduced irrigation environments, e.g. canopy temperature depression (CTD) at morning during vegetative stage, RLWC during early grainfilling stage and peduncle thickness, length and extension. However the correlation coefficients for canopy temperature depression in afternoon during vegetative stage, osmotic potential, relative leaf water content during grainfilling stage, leaf rolling, and stem carbohydrate were non-significant. Similar findings were reported by Ibrahim *et al.* (1994). Three phonological traits (days to flag leaf emergence, anthesis, and maturity), and to certain extent harvest index, showed stability across three environments**:** early heat stress, terminal heat stress and continuous heat stress. Ortiz ferrara and Assad. (1989); Nachit, *et al.* (1989) estimated abiotic stress tolerance to drought, heat, and cold. They found significant positive correlation coefficients with most morph-physiological traits.

Results of the first International Heat Stress Genotype Experiment (1st IHSGE) carried out by CIMMYT, confirmed that the relative performance of genotypes for grain and biological yields was well correlated between hot environments in Tlaltizpan, Mexico and Wad Medani, Sudan, where temperature, moisture availability and soil fertility were much the same (Reynolds and Acevedo, 1991). Nevertheless selection for the existence of a drought resistance mechanism is best achieved under a level of stress which will differentiate between the genotypes which possess the mechanism and the ones that do not (Lewis and Christiansen, 1981). Wheat germplasm that typically performs well under heat stress is not necessarily useful under drought stress. (Reynolds *et al.*, 2001).

This result suggests that, when breeding for one environment or another, partitioning to the economic sinks should be considered as well as economic yields.

Data in Table 8 showed the association of each trait with yield under different environment. Positive and highly significant simple correlation coefficients were found between yield and grain/m^2, grain filling rate, and canopy temperature depression (CTD), under the three environments, indicating that these traits can be used as selection indices across environments.

Indeed, in the heat stress environment, the best correlation between CTD in the afternoon and yield was attained at vegetative or grainfilling stages. The usefulness of the CTD measurement in the morning in the drought stress and heat reduced irrigation environment prior to heading and grainfilling is clear. There are high positive significant correlation coefficients between g/m^2 and grain filling rate, and CTD under the three environments.

Positive and high significant correlation coefficients were observed between yield and biomass, light interception and plant height, under drought stress. In contrast negative and significant correlation was found between grain yield and stem carbohydrate during maturity stage, indicating the important role of these traits for selection under this condition.

Positive and significant correlation coefficients were found between yield and thousand-kernel weight, relative time of grain filling, stomatal conductance, chlorophyll content, light interception, plant height and normalized difference vegetation index NDVI, under heat stress. Thus they could be important traits under such environments.

Rudorff and Batista, 1990 reported that the potential of spectral data to estimate grain yield of wheat growing in tropical regions vegetation index obtained at booting to beginning of flowering stages related quite well to the final grain yield (coefficients of determination r^2= 0.82-0.93). Nieves, *et al.*, (2000) found that in rainfed conditions, the spectral reflectance indices measured at any crop stage were positively correlated ($P < 0.05$) with LAI and yield.

Positive and significant correlation coefficients were found between yield and percentage grainfilling, peduncle length and extension, stem carbohydrate accumulated after anthesis, and stem dry weight. Nonetheless negative correlation were observed between yield and days to anthesis, and stomatal conductance under heat reduced irrigation. Positive significant correlated is indicated between grainfilling rate and stem carbohydrate accumulation under heat reduced irrigation, compared to the two other environments (Heat stress and Drought stress). These present results indicated the important role of such traits for selection under this environment.

Similar findings were reported by many researchers, (e.g. Tahir *et al*., 1999). Perry and D'Antuano (1989) reported that grain/m^2 and grain per spike were strongly and positively correlated with grain yield, but there was week negative correlation between thousand grain weight and yield. Reynolds *et al*. (1998) and Elmourid *et al*. (1989) reported that CTD are valuable indicators of stress tolerance in winter cereals, they can be used to study the comparative adaptation and tolerance of wheat and barley genotypes under stress. Similar results were reported by (Richards *et al*., 2001 Ortiz and Assad, 1989).

Nizamaddin and Morshall, (1989) found that grain yield reduction due to drought was the lowest for tall wheat lines, intermediate for semi-dwarf lines, and the highest for dwarf lines, this was confirmed by (Fisher, 1985; Fisher *et al.*, 1998; Rajaram, 1994).

Coefficient of determination (R^2) for grain yield estimation

Coefficient of determination (R^2) of the same traits measured under three stress environments (Table 9), suggested that grain/m^2, grainfilling rate, light interception, spike/m^2, plant height, canopy temperature depression, could be used to predict performance under drought stress.

While grain/m^2, grain filling rate, % grain filling, heading, anthesis, plant height, stem carbohydrate after anthesis, canopy temperature depression (CTD), relative leaf water content (RLWC), peduncle length and extension, stomatal conductance could used to predict performance under heat reduced irrigation.

Whereas grain/m^2, grain filling rate, GF%, canopy temperature depression, normalized difference vegetation index (NDVI), peduncle length, chlorophyll, plant height, light interception and 1000 grain weight, could be used to predict performance under heat stress environment.

From above results it is clear that, grain/m^2, grain filling rate, canopy temperature depression and light interception play an important role in explaining the variation in grain yield under stress conditions. This result was in line with the findings of Richards *et al*., 2001; Perry and D'Antuano, 1989 Sayre *et al.* (1997). He zhong and Rajaram (1994) reported that grain-filling rate is more temperature sensitive than days to anthesis and duration of grain filling. Reynolds *et al*., 1997, reported, when comparing traits measured on segregation generation ($F_{2:5}$) bulks with subsequent yield in generation ($F_{5:7}$)lines, performance were better predicted by CTD than it was by yield, when both were measured on bulks

Table 2. Mean squares of genotypes, environments and their interaction for grain yield and its components, and some physiological traits measured on 25 bread wheat genotypes grown at Obregon (Mexico) during season 2001/2002.

Source of variance	Genotypes (G)	Environments (E)	G x E
trait DF	24	2	48
Grain yield (kg/ha)	12443.71***	144853.32**	2404.50***
1000 grain weight (g)	75.73***	10706.15***	10.17***
Grain no./m^2	13387719.18***	7044376.71*	2845190.16***
Grain filling rate (g/m^2/day)	15.45***	81.77**	3.230***
Anthesis (days)	34.60***	9437.17***	3.51***

Maturity (days)	94.90***	15280.02***	6.67***
Plant height (cm)	663.60***	402.02*	61.86***
Grain filling (%)	0.003***	0.013***	0.000***
Light interception (%)	271.66***	3043.07*	37.42**
Stem carbohydrate (%)	7.01***	166.78**	4.06***
Rolling (1 -10)	14.94***	51.21***	2.92*
+Osmotic potential (mmol/kg) 1	27314.00***	1655987.0***	23301.00***
2	8099.00*	99628.0***	7398.00***
3	59417.0***	3031611.0***	54506.00***
Relative leaf water content (%)	31.9***	3150.9***	17.5**

*, **, *** Significant at 0.05, 0.01, 0.001 probability level, respectively.

+ 1, 2, 3, Osmotic potential measured (1, 10) days before irrigation and one day after irrigation, respectively.

Table 3. Mean grain yield (t/ha) for genotypes grown at Obregon (Mexico) in different environments(2001/2002).

Genotypes no.	Genotypes	Environments					
		Drought stress	Rank	Heat stress	Rank	Heat reduced irrigation	Rank
1	W15.92	1.92 cdefgh	15	1.22 fghi	16	0.56 ijklm	26
2	CROC_1/AE.SQUARROSA (224)//OPATA	1.86 cdefgh	16	1.62 def	11	0.51 jklm	27
3	PUB94.15.1.12	2.13 bcdefgh	12	1.98 bcd	7	0.98 cdefghi	12
4	MEX94.27.1.20	2.51 abcd	4	1.93 bcde	8	1.09 bcdefg	9
5	PRINIA	2.06 bcdefgh	13	0.79 ijk	26	0.67 ghijkl	21
6	SW89.5193	1.06 i	25	0.40 jkl	27	0.38 klm	28
7	JUN/GEN	2.17 bcdefg	9	0.49 kl	29	0.68 ghijkl	20
8	SYN/OPATA	1.57 fghi	20	2.09 bc	4	0.77 fghijk	16
9	BABAX	2.06 bcdefgh	14	1.27 fgh	15	1.23 bcde	6
10	WEEVIL-1	2.59 abc	3	0.88 hijk	23	0.92 defghij	13
11	FIRETAIL	1.44 ghi	23	1.80 cde	9	1.50 b	2
12	OR791432/VEE#3.2	2.27abcdef	8	1.19 fghi	18	0.64 ghijklm	24
13	PFAU/VEE#9//URES	1.81 defgh	18	0.79 ijk	25	0.71 fghijkl	18
14	GIM/LIRA	1.41 hi	24	0.24 l	30	0.21 m	30
15	MEX94.15.34	1.48 ghi	22	1.05 hi	20	0.71 fghijkl	19
16	OAX93.24.35	1.54 fghi	21	0.86 hijk	24	0.77 fghijk	15
17	MEX94.2.18	1.83 defgh	17	1.14 ghi	19	0.67 ghijkl	21
18	MEX94.2.19	2.28 abcdef	7	2.35 b	2	1.23 bcde	7
19	PASTOR/3/ALTAR 84/AEGILOPS SQUARROSA (TAUS)//OPATA	2.96 a	1	2.94 a	1	2.38 a	1
20	WEEBILL4	2.73 ab	2	1.52 efg	13	1.33 bcd	4
21	PASTOR//HXL7573/2*BAU	2.48 abcd	5	0.96 hij	21	1.31 bcd	5
22	OAX93.24.35	1.65 efghi	19	0.92 hijk	22	0.76 fghijk	17
23	PUB94.15.	2.16 bcdefg	10	1.97 bcd	6	1.09 bcdefgh	10
24	MEX94.12.	2.32 abcde	6	2.18 bc	3	1.15 bcdef	8
25	ATTILA	2.15 bcdefg	11	2.03 bcd	5	1.43 bc	3
26	IWA 8608663	-		1.20 fghi	17	0.63 hijklm	25
27	URES/JUN/KAUZ	-		1.55 efg	12	0.99 cdefghi	11
28	KAUZ*2/TRAP//KAUZ	-		1.76 cde	10	0.85 efghij	14
29	IWA 8606251	-		0.56 jkl	28	0.27 im	29
30	SYN/OPATA	-		1.30 fgh	14	0.65 ghijklm	23

(-) Genotypes not grown in this environment.

Means followed by the same letter(s) in the same column are not significantly different at the probability level of 0.05, according to Duncan's Multiple Range Test.

Table 4. Mean grain yield and some important traits measured from combined analysis over environments using 25 bread wheat genotypes at Obregon (Mexico) during the cropping season 2001/2002.

Genotypes no.	Grain yield (g/m^2)	Rank	1000-grain weight (g)	Rank	Grain no./ m^2	Rank	Grain filling rate (g/m^2/day)	Rank	Anthesis (days)	Rank	Maturity (days)	Rank
1	123 fghi	16	28.6 fgh	21	4219 efghi	15	4.912 defghi	15	67.5 de	13	91.83 fg	17
2	133 efghi	15	30.32 efg	15	4170 efghi	16	4.61 efghi	17	68.5 cd	10	96.17 d	6
3	170 bcdef	8	37.83 a	1	4490 defgh	13	5.493 defg	12	70 ab	3	100.5 b	3
4	184 bcd	6	35.44 abc	4	5274 cde	6	5.955 cde	6	69 bc	9	99.17 c	4
5	117 ghi	18	35.17 bc	6	3224 i	23	3.98 ij	22	70.33 a	1	98.17 c	5
6	68 jk	24	34.83 c	7	1910 j	25	2.877 jk	24	69.67 abc	5	92.67 efg	12
7	111 ghij	20	26.63 hi	24	3997 fghi	19	4.26 ghi	19	64.67 gh	22	89.33 i	23
8	148 bcdefghi	12	33.22 cd	11	4534 defgh	12	5.193 defghi	14	65.67 fg	18	93.5 e	8
9	152 bcdefghi	11	34.82 c	8	4758 cdefg	9	5.802 cdef	8	65.5 gh	14	91.5 gh	18
10	146 cdefghi	13	33.65 cd	9	4323 efghi	14	5.758 cdef	10	67.67 de	11	92.33 efg	14
11	157 bcdefgh	10	30.69 ef	14	5789 c	4	5.777 cdef	9	62.67 i	24	90.17 i	20
12	137 defghi	14	28.76 fgh	20	4637 defgh	11	5.538 defg	11	69.67 abc	6	93.17 ef	10
13	110 hij	21	28.05 fghi	22	3913 fghi	20	4.205 ghi	20	66.82 ef	15	92.17 efg	15
14	62 k	25	25.99 I	15	1987 j	24	2.668 k	25	67.33 de	14	87.17 j	25
15	108 ijk	22	31.8 de	13	3480 hi	22	3.877 ijk	23	65.67 fg	17	92.83 efg	11
16	106 ijk	23	29.08 fgh	19	3852 ghi	21	4.118 hij	21	70 ab	2	95.17 d	7
17	122 ghi	17	29.53 efg	17	4158 efghi	17	4.828 defghi	16	65 gh	20	89.33 i	22
18	195 b	2	29.12 fgh	18	7074 b	2	6.952 bc	4	64.33 h	23	92.17 efg	16
19	276 a	1	33.3 cd	10	9006 a	1	10.36 a	1	62.33 i	25	89.00 i	24
20	186 bc	5	35.29 bc	5	5516 cd	5	7.35 b	3	67.67 de	12	92.5 efg	13
21	158 bcdefg	9	32.02 de	12	4942 cdefg	8	6.122 cd	5	64.83 gh	21	90.17 i	21
22	111 ghij	19	27.67 ghi	23	4122 efghi	18	4.443 fghi	18	69 bc	8	93.33 e	9
23	175 bcde	7	37.56 ab	3	4719 cdefg	10	5.387 defgh	13	70 ab	4	101.8 a	1
24	189 bc	3	37.57 ab	2	5062 cdef	7	5.877 cde	7	69.5 abc	7	101.0 ab	2
25	187 bc	4	30.03 efg	16	5952 b	3	7.59 b	2	65.83 fg	16	90.33 hi	19

Means followed by the same letter(s) in the same column are not significantly different at the probability level of 0.05, according to Duncan's Multiple Range Test.

Table 4. (Continued).

Genotype	Plant height (cm)	Rank	light interception (%)	Rank	Stem Carbohydrate (%)	Rank	Rolling (1-10)	Rank
1	61.0 ij	23	67.96 ghij	20	6.283 cdefg	15	5.000 cdef	17
2	68.5 efgh	15	78.96 abc	5	4.050 h	25	4.667 efg	19
3	86.5 ab	3	81.67 a	2	7.300 abcd	5	2.167 hi	24
4	86.5 ab	2	79.40 ab	3	6.783 bcde	6	2.333 hi	23
5	65.0 hi	21	68.96 fghi	19	5.967 cdefg	17	4.833 def	18
6	42.0 k	25	55.53 k	25	6.667 bcde	9	3.000 ghi	21
7	71.0 defg	12	66.45 hij	21	4.633 gh	24	6.667 abcd	4
8	67.3 fghi	16	72.96 defg	13	6.433 bcdef	12	5.333 abcdef	11
9	66.8 fghi	18	74.57 bcdef	10	6.783 bcde	7	6.167 abcde	8
10	65.7 ghi	20	70.90 efghi	16	5.783 defg	18	6.833 abc	3
11	76.3 cd	7	63.31 l	23	7.633 abc	4	6.667 abcd	5
12	61.8 ij	22	69.77 efghi	18	5.650 defgh	20	3.833 fgh	20
13	67.0 fghi	17	69.97 efghi	17	8.483 a	1	5.500 abcdef	10
14	57.9 j	24	57.39 k	24	6.533 bcdef	11	6.500 abcde	6
15	81.7 bc	6	72.33 efg	14	5.683 defgh	19	6.167 abcde	7
16	74.7 de	10	74.62 bcdef	9	5.167 efgh	21	5.000 cdef	16
17	83.5 ab	5	72.08 efgh	15	4.867 fgh	22	7.167 a	1
18	70.6 efgh	14	78.37 abcd	6	6.383 bcdefg	13	5.167 bcdef	14
19	75.0 d	9	74.69 bcdef	8	6.650 bcde	10	5.833 abcde	9
20	75.6 d	8	73.21 defg	12	6.350 bcdefg	14	5.333 abcdef	13
21	70.9 efgh	13	66.15 ij	22	7.667 abc	3	7.000 ab	2
22	73.3 def	11	75.14 bcde	7	4.850 fgh	23	5.167 bcdef	15
23	88.2 a	1	82.08 a	1	8.067 ab	2	2.000 i	25
24	85.2 ab	4	79.15 abc	4	6.683 bcde	8	2.500 hi	22
25	66.8 fghi	19	73.60 cdefg	11	5.967 cdefg	16	5.333 abcdef	12

Means followed by the same letters) in the same column are not significantly different at the probability level of 0.05, according to Duncan's Multiple Range Test.

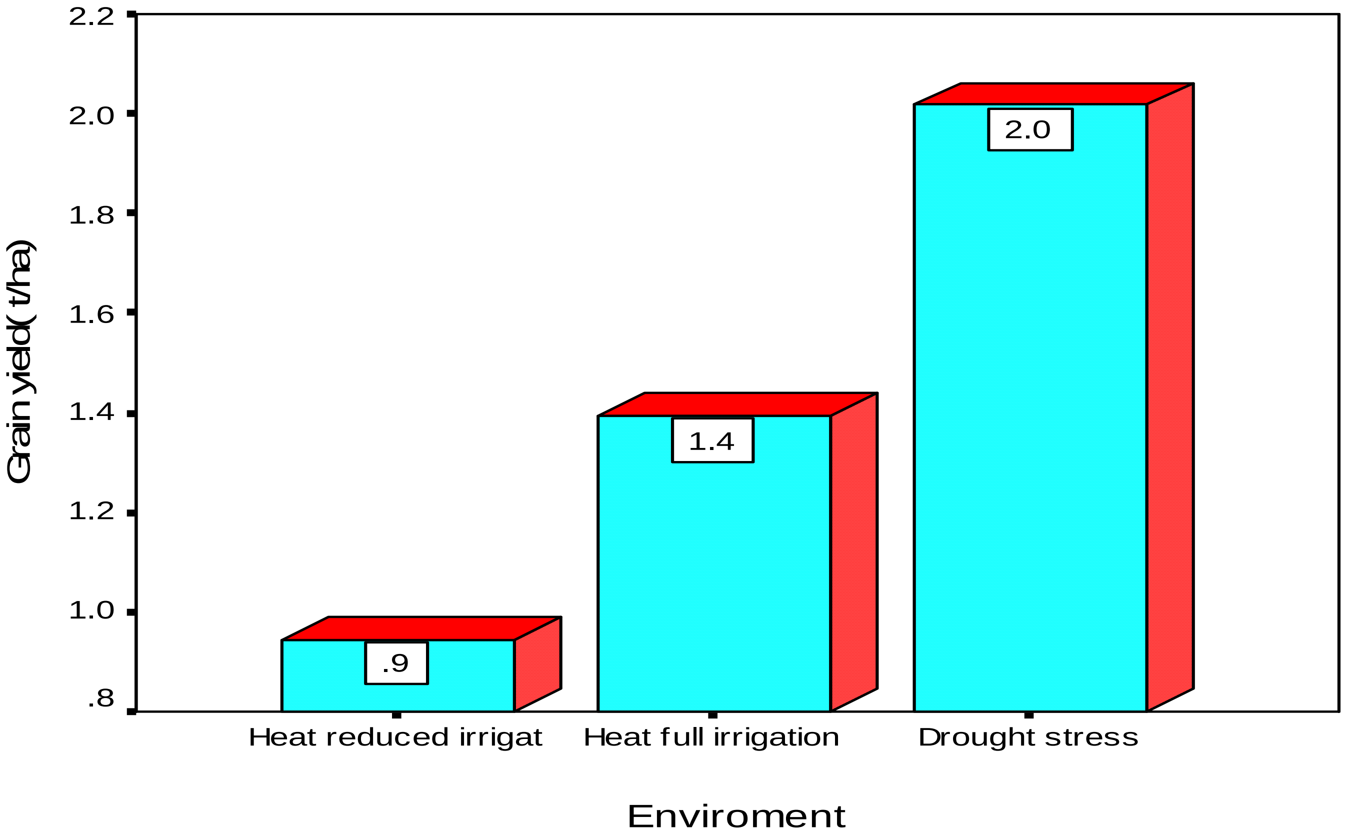

Fig .2. Effect of environment on means grain yield of bread wheat genotypes.

Table 5. Mean grain yield and its components under different environments for genetically diverse stress tolerant spring wheat genotypes grown at Obregon (Mexico), 2001/2002.

Environment	Yield (t/ha)	Average kernel wt (g)	Grains/m^2 (no.)	Days to heading	Days to flowering	Days to maturity	Grain filling Rate	% time in grain filling
Drought	2.02 a	47.8 a	4230 a	*	83 a	113 a	6.72 a	0.27 b
Heat stress	1.37 b	29.0 b	4700 a	60 a	62 b	88 b	5.28 b	0.30 a
Heat reduced irrigation	0.90 c	20.1 c	4690 a	57a	59 c	82 c	4.93 c	0.27 b

* Traits not measured in this environment.

Means followed by the same letter(s) in the same column are not significantly different at the probability level of 0.05 according to Duncan's Multiple Range Test.

Table 6. Mean of some physiological and morphological traits under different environments for genetically diverse stress tolerant spring wheat genotypes grown at Obregon (Mexico), 2001/2002.

Environment	Canopy Temperature Depression ^{0}C				Light interception (%)	Chlorophyll content	Stomatal Contuctance (mm/m^2/s)		Leave rolling	Relative leaf water content (%)		Osmotic Potential (mmol/kg)		Osmotic Adjusment(mmol/kg)	
	V.am	V.pm	G.am	G.pm		(Spad units)	1	2		Booting	Grain filling	E.GF	GF	1	2
Drought	-5.73a	-3.3b	-3.55a	-3.52a	80.6 a	45.2b	*	*	5 ab	74.4c	75.1b	758.6a	846.7a	401.7a	590.5a
Heat stress	-4.7b	-5.0a	-3.5a	-2.9 b	70.6 b	45.4b	0.09 b	0.01 b	4 b	89.9a	82.2a	418.8c	382.6c	*	*
Heat reduced irrigation	-3.5c	-3.2b	-2.2b	-2.1 c	66.2 c	49.0a	0.20 a	0.10 a	6 a	85.8b	81.6a	475.9b	472.2b	77.8b	89.6b

* - Parameter not measured in this environment.
V. am: Vegetative stage (morning).
V. pm: Vegetative stage (afternoon).
G. am: Grain filling (morning).
G. pm: Grain filling (afternoon).
1 & 2 : Stomatal conductance measured after 4 and 18 days from last irrigation grain filling stage, respectively.
G. F. : Grain filling stage.
E. GF.: Early grain filling stage.
1& 2 :Osmotic adjustment measured 22 and 28 days after irrigation.
Means followed by the same letter(s) in the same column are not significantly different at the probability level of 0.05 according to Duncan's Multiple Range Test.

Table 6. (Continued).

Environment	Peduncle			Plant height (cm)	Stem carbohydrates (%)	Normalized difference vegetation index		
	Length (cm)	Extension (cm)	Thickness (mm)			Red	Green	White-red
Drought	*	*	*	71.0 b	4.4 c	0.57 b	0.54 b	0.23 b
Heat stress	23.2 b	5.8 b	2.1 a	70.1 b	6.8 b	0.64 a	0.57 a	0.27 a
Heat reduced irrigation	24.2 a	8.9 a	2.0 a	74.7 a	8.3 a	0.63 a	0.57 a	0.27 a

* Traits not measured at these environments.

Means followed by the same letter(s) in the same column are not significantly different at the probability level of 0.05 according to Duncan's Multiple Range Test.

Table 7. Simple linear correlation coefficients of the some pair of wheat traits under different a biotic stressed environments.

Correlation	Grain yield	1000 kernels weight	Grain/m^2	Grain filling rate	Anthesis	Maturity	% grain filling
Heat vs heat-reduced irrigation	0.74**	0.47*	0.74**	0.73**	0.92**	0.90**	0.79**
Heat vs drought stress	0.52**	0.73**	0.54**	0.40*	0.65**	0.81**	0.58**
Heat reduced vs drought	0.68**	0.68**	0.63**	0.71**	0.71**	0.84**	0.47**

*, ** Significant at r_{tab}= 0.38 and 0.49, respectively.

Table 7. Continued.

Correlation	Plant height	%Light interception	Chlorophyll content	Canopy Temperature Depression							Osmotic potential		Relative water content (RLWC)	
				v.am 1	v.pm 2	Average 3	G.am 4	G.pm 5	Average G 6	General 7	E.G.F	G.F	E.G.F	G.F
Heat vs heat -reduced irrigatior	0.74**	0.82**	0. 52**	0.55**	0.33	0.53**	0.53**	0.51**	0.53**	0.57**	0.13	-0.07	0.49**	0.34
Heat vs drought stress	0.83**	0.53**	0.56**	-0.10	0.00	-0.10	-0.03	0.79**	0.70**	0.59**	-0.11	-0.01	0.33	0.37
Heat reduced vs drought	0.79**	0.75**	0.62**	0.27	0.00	0.29	-0.12	0.66**	0.64**	0.56**	0.22	-0.03	0.24	0.22

*, ** Significant at r tab= 0.38 and 0.49, respectively.

G.F : Grain filling stage.

E.G.F : Early grain filling stage.

Table 7. (Continued).

Correlation	G.F rolling	G.F r.ndvi.	G.F g.ndvi.	CHO-stem	Stem dry weight	Stomata conductance	Peduncle		
							Thickness	Length	Extension
Heat vs heat -reducec Irrigation	0.69**	0.85**	0.83**	0.05	0.53**	0.31	0.88**	0.83**	0.74**
Heat vs drought Stress	0.28	0.73**	0.65**	0.10	0.49**	-	-	-	-
Heat reduced vs Drought	0.60**	0.68**	0.63**	0.19	0.48*	-	-	-	-

*,** Significant at r_{tab} = 0.38 and 0.49, respectively.

-Traits not measured at these environments.

Table 8. Correlations between grain yield and different traits expression under a biotic stressed environments for 30 bread wheat genotypes.

Trait	Environments		
	Drought stress	Heat stress	Head reduced irrigation
Grain Yield			
Thousand-grain weigh	0.25	0.44*	-0.01
Grain/m^2	0.95**	0.94**	0.91**
Grain filling rate	0.90**	0.98**	0.98**
Biomass	0.87**	-	-
Anthesis	-0.06	-0.28	-0.54**
Maturity	0.10	0.05	-0.29
%Grain filling	0.25	0.69**	0.65**
Canopy temperature depression	0.49**	0.72**	0.48**
Light Interception	0.71**	0.45*	0.14
Chlorophyll	-0.06	0.42*	0.01
Stomatal conductance	*	0.37*	-0.39*
Leaf rolling	0.02	-0.34	0.15
Relative leaf water content	0.02	0.28	-0.32
Osmotic potential	-0.27	-0.34	-0.17
Osmotic Adjustment	0.22	-	0.19
Peduncle thickness	-	-0.11	0.08
Peduncle length	-	0.36	0.47*
Peduncle extension	-	0.29	0.49**
Plant height	0.41*	0.39*	0.33
Stem-CHO anthesis	0.09	-0.15	0.43*
Stem-CHO maturity	-0.45*	-	-
12- stem dry weight	-	0.11	0.39*
r-ndvi	0.32	0.64**	0.26
g-ndvi	0.20	0.67**	0.27
wr.ndvi	0.23	0.54*	0.05

*,** Significant at r_{tab} = 0.38 and 0.49, respectively.
-Traits not measured at these environments.

Table 9. Coefficient of determination (R^2) of the grain yield by some traits measured under drought, heat stress irrigation and heat reduced irrigation environments.

Trait	Coefficient of determination (R^2)		
	Drought	Heat reduced irrigation	Heat irrigation
1000 Grain weight	0.063	0.095	0.193*
Grain/m^2	0.91***	0.833***	0.892***
Harvest index	0.113	-	-
Spike/m^2	0.244*	-	-
GFR	0.818***	0.95***	0.953***
Heading	-	0.23**	0.058
Anthesis	0.004	0.294**	0.077
Maturity	0.01	0.016	0.002
Plant height	0.165*	0.12*	0.154*
%GF	0.062	0.386***	0.48***
Light interception	0.508***	0.112*	0.2*
Chlorophyll content	0.004	-	0.177*
Stem carbohydrate	0.009	0.189*	0.022
Rolling	4.973	0.021	0.117*
CTD x	0.242*	0.226**	0.523***
Osmotic Adjustment	0.007	0.035	-
RLWC	0.021	0.104*	0.079
r-ndvi	0.101	0.067	0.413***
g-ndvi	0.041	0.075	0.452***
wr-ndvi	0.063	0.095	0.287**
peduncle thickness	-	0.007	0.012
peduncle length	-	0.224**	0.133*
peduncle extension	-	0.245**	0.087
stomata conductance	-	0.154*	0.064

*, **, *** Significant at 0.05, 0.01, 0.001 probability levels, respectively.
- Parameter not measured in this environment.

CONCLUSSIONS

Results indicated that the relative performance of the genotypes were greatly influenced by environmental variation. Grain yield under drought stress environment was higher than under heat stress or heat reduced irrigation. High temperature significantly decreased grain yield by decreasing kernel weight and reduced the rate of grainfilling after anthesis.

Results also conferred that %grainfilling is greatly affected by heat stress (Table 5). In contrast relative leaf water content during grainfilling was negatively affected by drought stress. Chlorophyll content was maintained under heat reduced irrigation (Table 6).

Grain/m^2, grainfilling rate, and CTD can be used as selection indices across environments.

Under drought stress environment some criteria are useful selection tools. These include, increased grain /m^2, rapid grain filling rate, increased biomass, high CTD during grain filling or prior to heading in the morning, high light interception, increased plant height, and lower accumulation of carbohydrates during maturity stage.

Under heat stress the criteria of importance are increased kernel weight, increased grain/m^2, rapid grain filling rate, highly CTD during grain filling, increased %grain-filling, increased light interception, high chlorophyll content, increased stomatal conductance, increased plant height, and increased normalized difference vegetation index (NDVI).

Under the third environment heat reduced irrigation, increased grain/m^2, rapid grain filling rate, early days to flowering, increased %

grain filling, high CTD during vegetative or grain filling in the morning, longer and extended peduncle, increased accumulation of carbohydrates after anthesis, increased stem dry weight after anthesis and reduced stomatal conductance are important characters.

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Appendix 1. Means of some important physiological traits measured under Heat irrigation experiment for 25 bread wheat genotypes grown at Obregon (Mexico), season 2001/2002.

Genotypes	GFR g/m2/d	%GF	Light Int %	CHO stem	CTD-X ^{0}C
1	5.03	0.29	62.01	6.35	3.72
2	6.29	0.30	82.61	6.40	4.86
3	6.78	0.33	81.37	6.60	4.83
4	6.90	0.33	78.73	5.90	4.53
5	3.43	0.29	65.95	5.25	3.64
6	2.73	0.27	60.41	11.80	3.57
7	2.15	0.29	60.77	6.45	3.97
8	7.24	0.33	71.83	7.30	4.69
9	5.16	0.31	70.09	7.30	4.24
10	3.59	0.30	65.51	6.15	3.90
11	6.99	0.32	59.42	8.00	3.88
12	5.25	0.27	60.82	7.45	4.17
13	2.73	0.31	65.62	7.05	3.90
14	1.45	0.22	51.38	5.85	3.59
15	3.79	0.32	73.65	6.25	4.01
16	3.53	0.27	73.91	5.70	4.09
17	4.49	0.30	71.06	6.40	3.92
18	8.38	0.31	77.32	5.85	4.55
19	11.58	0.31	73.40	5.45	4.45
20	6.17	0.28	64.32	5.25	4.31
21	3.81	0.30	56.28	6.10	3.59
22	3.92	0.27	77.73	4.50	4.28
23	5.86	0.34	82.29	6.85	4.50
24	6.78	0.34	78.20	6.40	4.60
25	7.86	0.30	77.69	7.25	4.36
26	4.50	0.28	80.25	10.00	4.34
27	5.91	0.29	67.31	8.25	4.48
28	6.10	0.33	62.67	6.60	4.55
29	2.03	0.26	79.88	8.10	4.15
30	4.66	0.26	84.49	6.85	4.41
Mean	5.17	0.30	70.57	6.79	4.20
C.V%	13.25	2.88	4.38	23.40	2.69
P-value	0.00	0.00	0.00	0.03	0.00
P-L.SD	1.51	0.02	6.85	2.47	0.26

Appendix 1. (Continued).

Genotypes	OP	OP	RLWC %	RLWC %	rndvi	gndvi	wrndvi
1	514.04	474.48	91.23	91.74	0.65	0.50	0.26
2	361.08	390.21	92.24	91.83	0.79	0.60	0.36
3	365.15	335.86	90.99	91.77	0.80	0.59	0.31
4	435.19	372.32	90.20	87.67	0.78	0.57	0.32
5	429.67	380.02	81.47	92.39	0.61	0.48	0.24
6	506.04	380.48	92.88	90.99	0.66	0.51	0.28
7	456.70	430.45	89.69	88.91	0.53	0.41	0.18
8	445.77	387.09	92.99	87.85	0.74	0.57	0.31
9	434.81	448.56	97.10	89.45	0.63	0.49	0.26
10	393.80	354.26	94.72	92.47	0.52	0.41	0.20
11	413.66	379.72	92.18	92.02	0.63	0.48	0.24
12	429.70	421.95	95.69	90.26	0.62	0.48	0.27
13	435.98	358.75	94.03	91.53	0.61	0.46	0.21
14	427.02	390.21	92.64	85.17	0.50	0.40	0.16
15	456.51	461.92	88.61	92.39	0.66	0.49	0.26
16	373.37	403.88	93.43	91.60	0.72	0.55	0.30
17	453.41	415.61	84.48	91.69	0.61	0.45	0.19
18	440.98	291.75	94.38	90.88	0.78	0.59	0.32
19	473.52	370.20	91.10	86.05	0.74	0.56	0.27
20	403.50	348.41	90.77	87.52	0.67	0.50	0.26
21	421.37	362.87	92.28	85.63	0.63	0.47	0.23
22	494.91	381.60	91.99	87.47	0.75	0.56	0.30
23	379.48	287.74	94.49	91.15	0.78	0.58	0.32
24	456.52	372.70	94.55	90.35	0.77	0.57	0.31
25	414.76	347.11	96.05	90.67	0.73	0.55	0.29
26	409.12	392.57	83.96	87.07	0.77	0.58	0.36
27	393.66	392.30	86.92	91.26	0.70	0.54	0.32
28	441.23	403.45	94.77	91.95	0.69	0.51	0.26
29	465.27	339.91	96.68	88.65	0.73	0.54	0.34
30	427.76	431.61	86.20	89.67	0.76	0.57	0.38
Mean	431.80	383.60	91.62	89.94	0.68	0.52	0.28
C.V%	6.64	7.97	2.62	1.89	4.43	4.07	6.14
P-value	0.00	0.00	0.00	0.01	0.00	0.00	0.00
P-L.SD	64.26	67.35	5.40	3.85	0.06	0.04	0.04

Appendix 2. Means of some important physiological traits measured under Heat reduced irrigation experiment for 25 bread wheat genotypes grown at Obregon (Mexico), season 2001/2002.

Geno-types	GFR g/m2/d	%GF	CHO-A %	Light Int %	CTD-X ^{0}C
1	2.57	0.26	6.95	62.51	2.82
2	2.21	0.28	6.85	72.80	2.89
3	3.73	0.30	7.65	78.51	2.96
4	4.35	0.29	8.15	74.15	2.86
5	2.92	0.27	6.35	57.15	2.46
6	1.79	0.25	7.25	48.19	2.16
7	3.14	0.29	4.85	57.16	2.69
8	3.21	0.31	8.60	63.98	3.01
9	5.42	0.30	7.75	69.93	2.86
10	4.67	0.27	7.75	62.62	3.31
11	5.41	0.35	8.05	56.07	2.80
12	3.30	0.25	5.85	65.58	2.84
13	3.45	0.25	10.55	60.89	2.56
14	1.39	0.20	9.80	49.03	2.10
15	3.01	0.29	8.10	65.45	2.53
16	3.86	0.25	6.35	72.36	2.61
17	3.30	0.27	6.75	62.94	2.58
18	5.35	0.29	9.10	72.67	2.90
19	9.68	0.31	11.45	67.84	3.01
20	6.22	0.27	8.70	70.75	2.89
21	5.70	0.29	11.30	63.88	2.50
22	3.69	0.25	6.35	66.50	2.88
23	4.03	0.30	9.45	75.62	2.60
24	4.27	0.31	8.20	71.97	2.86
25	6.68	0.27	10.30	66.80	2.87
26	2.67	0.27	6.60	74.62	2.62
27	4.25	0.29	11.55	54.28	2.97
28	3.96	0.28	13.55	58.71	2.52
29	1.60	0.17	8.35	84.28	2.64
30	2.91	0.24	7.00	77.93	2.83
Mean	3.95	0.27	8.32	66.17	2.74
C.V%	14.61	2.06	17.84	4.93	4.69
P-value	0.00	0.00	0.00	0.00	0.00
LS.D	1.20	0.01	3.09	6.79	0.29

Appendix 2. (continued)

Genotypes	Osm Pot	Osm Pot	RLWC	RLWC	rndvi	gndvi	wrndvi
1	509.09	729.68	85.61	89.08	0.55	0.55	0.29
2	369.33	712.62	84.11	83.75	0.75	0.67	0.39
3	401.96	575.28	83.98	85.51	0.69	0.62	0.35
4	388.43	583.40	79.41	83.27	0.73	0.63	0.35
5	419.64	605.67	83.67	86.20	0.60	0.58	0.32
6	384.09	623.68	83.22	89.99	0.59	0.57	0.33
7	463.45	640.66	82.80	82.44	0.57	0.55	0.28
8	466.09	640.82	81.01	83.82	0.63	0.60	0.33
9	570.05	591.94	84.45	85.94	0.66	0.61	0.34
10	507.77	631.71	80.84	89.07	0.59	0.57	0.30
11	500.21	717.72	80.87	87.28	0.59	0.58	0.28
12	521.45	644.16	81.52	87.57	0.62	0.59	0.32
13	444.68	684.32	81.01	87.05	0.58	0.55	0.29
14	515.65	601.44	68.02	83.82	0.42	0.48	0.21
15	552.36	806.71	81.64	88.45	0.62	0.58	0.30
16	494.81	640.72	82.03	84.31	0.64	0.60	0.32
17	558.05	753.66	79.31	84.53	0.58	0.55	0.27
18	521.18	685.32	80.73	83.50	0.71	0.64	0.36
19	458.95	629.15	83.97	88.77	0.70	0.63	0.35
20	529.66	604.92	78.79	89.76	0.63	0.58	0.32
21	451.11	591.43	77.21	79.42	0.63	0.58	0.29
22	419.84	623.87	77.69	81.79	0.61	0.58	0.31
23	487.98	627.52	85.23	80.03	0.70	0.63	0.34
24	419.45	632.65	85.77	88.32	0.69	0.62	0.34
25	447.33	724.19	83.96	88.08	0.69	0.61	0.33
26	475.78	786.20	82.04	85.83	0.72	0.64	0.35
27	481.51	569.14	83.75	88.78	0.62	0.58	0.33
28	497.65	692.30	73.58	76.69	0.56	0.54	0.26
29	461.62	683.92	87.09	90.09	0.76	0.66	0.43
30	476.33	605.69	84.17	90.61	0.73	0.64	0.38
Mean	473.18	654.68	81.58	85.79	0.64	0.59	0.32
C.V%	7.59	4.87	3.23	2.86	3.16	2.08	3.73
P-value	0.00	0.00	0.00	0.00	0.00	0.00	0.00
P-LS.D	79.83	72.61	5.48	5.53	0.04	0.03	0.03

Appendix 3. Means of some important physiological traits measured under drought stress experiment for 25 bread wheat genotypes grown at Obregon (Mexico), season 2001/2002.

Genotypes	GFR g/m2/d	%GF %	Light Int %	CHO-A %	CHO-Mat %	CT-X ^{0}C
1	7.47	0.25	81.65	3.85	35.97	23.80
2	5.45	0.29	81.75	2.75	30.28	23.85
3	5.92	0.30	83.72	7.00	32.08	23.55
4	6.59	0.30	85.59	6.00	32.16	23.55
5	5.07	0.29	84.15	5.55	22.60	24.20
6	4.52	0.24	60.40	4.05	44.01	24.45
7	7.60	0.27	80.71	2.55	24.97	23.75
8	5.11	0.28	80.59	2.65	28.07	23.90
9	6.78	0.26	82.91	6.35	31.39	23.80
10	8.46	0.25	83.89	3.05	31.84	23.90
11	4.89	0.27	73.80	5.40	28.53	23.70
12	7.82	0.25	80.32	4.70	34.34	23.95
13	5.74	0.27	79.83	7.40	31.69	24.00
14	4.41	0.26	69.89	3.65	33.47	24.05
15	3.58	0.28	76.16	3.80	31.56	23.95
16	5.64	0.28	79.15	3.80	29.17	23.90
17	7.07	0.26	81.89	2.85	24.48	24.00
18	7.33	0.31	83.02	4.75	24.13	23.90
19	10.10	0.28	82.68	2.80	22.85	23.90
20	9.53	0.25	84.51	5.45	25.50	23.65
21	9.74	0.27	81.38	4.10	29.03	23.80
22	6.32	0.26	82.35	2.55	27.60	23.65
23	6.74	0.30	87.73	7.65	30.90	23.60
24	6.96	0.29	88.36	5.65	31.22	23.60
25	8.14	0.24	78.50	2.80	28.62	23.80
Mean	6.68	0.27	80.60	4.45	29.86	23.85
C.V %	7.28	1.89	2.28	21.94	11.62	0.59
P-value	0.00	0.00	0.00	0.00	0.02	0.00
P-LS.D	1.17	0.01	4.33	2.07	8.23	0.30

Appendix 3. (Continued)

Genotypes	Osmotic potential	Osmotic potential	RLWC %	RLWC %	rndvi	gndvi	wrndvi
1	865.50	1073.50	81.26	77.68	0.73	0.64	0.38
2	919.50	1104.50	81.31	82.11	0.79	0.67	0.41
3	841.00	975.00	77.13	77.84	0.79	0.67	0.43
4	820.00	999.00	76.32	77.43	0.82	0.69	0.44
5	842.00	887.00	78.66	81.17	0.81	0.70	0.43
6	877.50	1051.50	75.82	72.87	0.73	0.64	0.37
7	850.00	996.00	76.05	73.39	0.76	0.67	0.41
8	848.00	1121.00	76.76	74.79	0.74	0.65	0.38
9	887.50	944.00	78.30	79.33	0.78	0.68	0.42
10	807.50	1002.50	80.13	79.59	0.77	0.67	0.40
11	807.00	1060.50	71.17	72.36	0.73	0.65	0.39
12	927.00	979.00	75.63	74.72	0.77	0.66	0.39
13	845.50	1091.00	76.42	73.12	0.77	0.67	0.41
14	902.50	1042.00	68.25	75.40	0.77	0.66	0.39
15	923.50	902.00	69.14	75.22	0.76	0.66	0.39
16	907.50	1083.00	74.99	71.63	0.78	0.66	0.42
17	917.00	1000.50	73.70	74.31	0.80	0.68	0.42
18	821.00	864.00	63.94	67.94	0.75	0.66	0.38
19	818.50	936.00	71.86	76.42	0.79	0.68	0.40
20	897.50	1008.00	78.67	70.93	0.80	0.69	0.42
21	866.00	1121.00	73.77	60.82	0.77	0.67	0.40
22	926.50	1091.00	71.83	74.68	0.78	0.66	0.40
23	912.50	946.00	70.70	80.08	0.80	0.67	0.43
24	886.50	987.00	65.53	72.11	0.81	0.67	0.44
25	853.00	1055.00	71.89	80.87	0.76	0.65	0.37
Mean	870.80	1012.80	74.37	75.07	0.77	0.66	0.40
C.V %	4.50	6.89	2.80	4.05	2.02	1.91	3.37
P-value	0.04	0.03	0.00	0.00	0.00	0.00	0.00
P-LS.D	80.93	144.11	5.05	6.81	0.03	0.03	0.03