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# PHYSIOLOGICAL BASIS OF YIELD DIFFERENCE IN GRAIN SORGHUM (*Sorghum bicolor* L. MOENCH) IN A SEMI-ARID ENVIRONMENT

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## ABSTRACT

In order to compare sorghum genotypes for grain yield using phenology, morphology and physiological growth indices, an experiment was conducted at Seed and Plant Improvement Institute (SPII) in 2009 growth season. Results showed genotypes $KGS_5$ and $KGS_{31}$ produced the highest and lowest grain yield and biomass respectively. With respect to the yield components, genotypes $UT_{378B}$ and $ICSV_{274}$ had the highest number of grains panicle$^{-1}$ and 1000-grain weight, respectively. Also the three top genotypes including $KGS_5$, $KGS_{15}$ and $KGS_{23}$ had the highest leaf number at 28 days after planting (DAP), which indicated better radiation capture in the early season. Plant height variation also revealed that genotypes $KGS_5$ and $ICSV_{274}$ were the shortest (122.87 cm) and the tallest (165.59cm) genotypes, respectively. Significant differences were observed in case of growing degree days necessary to achieve milk stage and soft-dough stage, so that genotypes $KGS_{31}$ and $KGS_5$ were the earliest and latest genotypes with respect to these stages. Significant differences existed between genotypes in case of all studied growth physiological indices at canopy closure except for leaf area index and relative growth rate. Overall, it could be concluded that the most important and effective trait in achieving high grain yield in sorghum is high harvest index (HI).

**Keywords:** grain sorghum, crop ideotype, potential yield, growth analysis.

## 1. INTRODUCTION

Sorghum is the fifth most important cereal crop in the world and is the dietary staple of more than 500 million people in more than 30 countries (ICRISAT 2009). It is grown on 40000 ha in Iran. Sorghum is a water efficient crop which makes it an important cereal in semi-arid and arid environments where water is the main limiting factor of production. However, it must compete economically with other cereal crops, and to meet this challenge, the yield of sorghum must increase significantly.

Options for increasing agricultural productivity are limited. Expansion of agriculture into areas not presently cultivated will, according to Tilman *et al*. (2002), result in global environmental change characterized by ecosystem simplification and species extinctions. Scarcity of water will impact a large proportion of the world's population during the next 50 years and limit agricultural uses (Vörösmarty *et al*., 2000). Production capacity is deteriorating due to soil depletion/erosion and other factors (Mann 1997; Vasil 1998). The need for more food and limitations in both new land and conventional technology all point to the need for crop improvement as a major means to significantly increase world food production (Mann, 1997; Vasil, 1998; Moffat, 2000). As a result, understanding physiological basis of sorghum yield is critical for the rationale design of agricultural practices as well as breeding strategies. Richards (1996) proposed that, by targeting the components contributing to greater yield, we should be able to select for them more easily and efficiently and be able to identify the most appropriate germplasm to use as parents. Contributing components to sorghum yield could be divided into three parts: (a) yield components, (b) morphological traits, and (c) physiological traits.

Yield differences in sorghum are associated with panicles per square meter or panicles per plant, kernels per panicle and kernel weight (Maman *et al*., 2004). Since yield components are interrelated, have compensatory effects, and develop sequentially at different growth stages, they could be used to characterize yield variations and to expand physiological understanding of crop morphology. Maman *et al*. (2004) found that sorghum grain yield is highly correlated with all the abovementioned yield components. However, selection according to the yield components only, does not give a detailed insight into the physiological basis of the yield difference.

In sorghum, the number of leaves per plant and plant height are among the two most important morphological traits. Leaf number is an important determinant of a sorghum plant leaf area, since it sets the initial benchmark of green leaf area per plant (Borrell *et al*., 2000a). So, if a sorghum plant can maintain higher number of leaves at the grain filling period and as a consequent higher photosynthesis, it may yield more. This is especially the case where the carbohydrate is a main harvest component (Thomas and Smart 1993). From a physiological standpoint, there are two main approaches in order to achieve higher grain yields; that is, increase in harvest index (HI) and increase in dry matter accumulation (Specht *et al*., 1999). Grain yield of sorghum may be also described as a function of dry matter accumulation and the amount of the dry matter partitioned to the grain. Assuming there is no water limitation, biomass production is the product of the solar radiation over the duration of the crop period (Q), corrected for the amount of intercepted radiation by the crop canopy (I), and the conversion of this chemical energy into plant dry matter (RUE) (Richards 2000). This can simply be expressed as:

$$Biomass = \sum_{sowing}^{harvest} Q \times I \times RUE \qquad (1)$$

From equation (1) it is seen that the ways to increase total biomass are as follows: First, to increase the duration of crop photosynthesis so that there is an increase in total solar radiation received. The second term in equation (1), the amount of radiation intercepted by the canopy, is the component of biomass production that is perhaps most amenable to genetic manipulation. The development of leaf area more quickly early in the season and an appropriate leaf area index (LAI) can contribute to this term (Soufizadeh *et al*., 2006). Delayed leaf senescence or stay-green is also associated with yield improvement of sorghum (Borrell *et al*., 2000a, b). Green leaf area at physiological maturity (GLAM) has proved to be an excellent indicator of stay-green in this crop (Borrell *et al*., 2000a). This characteristic can be assessed visually by counting the number of green leaves at this stage. Wanous *et al*. (1991) found that GLAM was correlated with visual rating of green leaf number ($r$ = 0.95) for sorghum under drought. Rajcan and Tollenaar (1999a) showed that the stay-green characteristic of a newer maize hybrid compared with an older hybrid was associated with a larger source/sink ratio during the grain-filling period. A further step in understanding the physiological basis of yield improvement in this crop is to determine the dry matter allocated to the different plant organs. It has been proved that a crop genotype that invests more photosynthetic assimilates in leaf mass can yield more under potential condition (Soufizadeh 2005). Such partitioning pattern can best results in higher grain yield if it accompanies with a higher HI. Higher HI indicates a better partitioning of dry matter into reproductive organs. Studies of historical genotypes often show that genetic improvement in yield potential has resulted from increases in HI (Lawes, 1977; Austin *et al*., 1980; Peng *et al*., 2000; Riggs *et al*., 1981), which is associated with ideotype characters, e.g., short stature in wheat (*Triticum aestivum* L.) and the uniculm habit in maize (*Zea mays* L.) and sunflower (Sedgley 1991). So, increasing the HI at a given biomass is a promising breeding goal. Information on physiological basis of yield improvement in sorghum is limited compared to other cereals such as wheat, barley and maize.

The objective of the present study is to provide a morpho-physiological perspective on sorghum yield improvement to be used in designing a sorghum ideotype in the future.

## 2. MATERIALS AND METHODS

Field experiment was conducted in 2009 at the research field of the Seed and Plant Improvement Institute at Karaj (35° 56′ N, 50° 58′ E), Iran. The climate of the region is classified as cold and semi-arid. Weather data (rainfall, maximum, minimum and average temperatures) were recorded daily at a weather station near the experimental site. Total annual rainfall of the site was 275mm. Mean annual air temperature was 14 to 16°C. The soil is well-drained, with no salinity problem, and the texture is sandy clay. The soil was sampled pre-planting at a depth of 30cm and before the application of fertilizers. Briefly, the soil contained 5 g kg$^{-1}$ organic carbon, 5 g kg$^{-1}$ total N, 8.2 mg kg$^{-1}$ P (Olsen), 295 mg kg$^{-1}$exchangable K and had a pH 7.5 and electrical conductivity 7.2 ds m$^{-1}$. Fertilizers were broadcasted before sowing providing 250 kg P ha$^{-1}$ as ammonium phosphate and 100 kg N ha$^{-1}$ as urea while at the four-leaf stage another 100 kg N ha$^{-1}$ were added. Irrigation was required to obtain appropriate grain yield, since precipitation was low during the sorghum growing period and temperature was high (mean temperature 27.52°C). Throughout the experiment, weeds were periodically removed by hand when necessary. A full disease and insect control program was employed by spraying the recommended fungicides and insecticides as required and at no time during the experiment did these factors appear to constrain yield. No symptoms of mineral element deficiencies were observed in the experiment.

Ten sorghum genotypes were planted in a randomized complete block design with four replications. Each plot consisted of five rows, 0.6m apart and 7m long. The site was plowed, disked and land-leveled in early spring 2008. Genotypes were over-seeded on 18th May and thinned to 16.6 plants m$^{-2}$ at the two-leaf stage. Plant morphological characteristics including plant height and leaf number were measured every two-weeks on four-randomly tagged sorghum plants. Measurements started at two-weeks after emergence. Plant height was determined by measuring the distance between the crown and the tip of the longest leaf or panicle. Leaf number was determined by counting the number of all leaves out of fully expanded leaves. The means of the leaf number and plant height were subjected to quadratic polynomial curve fitting to describe the relationships between each trait and time. The polynomial curves were fit using Microsoft Excel.

To determine the most important phenological stages of sorghum genotypes including emergence, stem elongation, booting stage, milk stage and soft-dough stage, observations were made on the four tagged plants in each plot. The phenological stages were recorded when 50% of the plants had reached the corresponding stage. Since different air temperature between different locations may confound phenological stages comparisons, we therefore calculated the time necessary to reach each of the phenological stages on the basis of degree days (ºC d) as follows:

$$^{\circ}Cd = \left[\left(\frac{T_{\max} + T_{\min}}{2}\right) - T_B\right] \times D \qquad (2)$$

where $T_{max}$ and $T_{min}$ are the maximum and the minimum daily air temperature (ºC), $T_B$ is the base temperature equal to 10ºC, and D is days.

Plant growth analysis was done at canopy closure. Four plants from the two inner rows of each plot were cut at the soil surface and transported to laboratory where plant height, leaf number, leaf area, leaf dry matter (LDM), stem dry matter (SDM), and panicle dry matter (PDM) were determined. The plants were separated into leaves, stems and panicles. Leaf area was determined by running all the leaves through a leaf area meter (Leaf Area Meter ΔT, England), and leaf area index (LAI) was calculated as leaf area per unit soil area (Brown 1974). Leaves, stems, and panicles were then oven dried separately in an electrical oven at 70ºC for 72 hours to obtain LDM, SDM, PDM and total plant dry matter (TDM). Using these data, we calculated crop growth rate (CGR), net assimilation rate (NAR), leaf area ration (LAR), leaf weight ratio (LWR), and stem weight ratio (SWR). The CGR (g unit area$^{-1}$ day$^{-1}$) was calculated as the change in TDM per day by means of the following equation:

$$CGR = \frac{W_2 - W_1}{SA(t_2 - t_1)} \tag{3}$$

where $W_1$ and $W2$ are the former and latter plant weight, $t_1$ and $t_2$ are the corresponding days, and $SA$ is the soil area in m$^2$ occupied by the plants at sampling.

The $CGR$ can also be expressed by the following equation:

$$CGR = NAR \times LAI \tag{4}$$

Using Equation (5) (Yusuf *et al*., 1999), measured LAI values and calculated CGR values from Equation (4) (Machado *et al*., 2002), NAR (rate of dry matter increase per unit leaf area per day) was calculated as:

$$NAR = \frac{CGR}{LAI} \tag{5}$$

LAR, LWR and SWR were calculated as indices indicating biomass partitioning using the following formulas:

$$LAR = \frac{LA}{TDM} \tag{6}$$

$$LWR = \frac{LDM}{TDM} \tag{7}$$

$$SWR = \frac{SDM}{TDM} \tag{8}$$

where $LA$ is leaf area in cm$^2$.

Measurements of radiation was taken in each plot above ($I_0$) and below ($I$) the canopy at the canopy closure. Two measurements (one perpendicular to the row direction and the other along the row direction) were made on each plot using a light quantum sensor (Sun Scan System ΔT, England) between 1100 and 1300 h under clear sky. A canopy extinction coefficient ($k$) was calculated for each plot using the following equation:

$$k = \frac{-\ln \frac{I}{I_0}}{LAI} \tag{9}$$

Radiation interception ($I_i$) by the canopy was then obtained according to the Beer's law as follows:

$$I_i = I_0\left(\exp^{(-k.LAI)}\right) \tag{10}$$

Radiation use efficiency (RUE) was calculated by dividing TDM by radiation intercepted (Monteith 1977).

At maturity, all the plants from a 7.2m$^2$ area in each plot were harvested by cutting at the soil surface for the determination of grain yield and biological yield. Yield components: panicles m$^{-2}$, spikelets panicle$^{-1}$, grains spikelet$^{-1}$ and grain weight were determined from a 5-plant sample taken randomly from the harvested area. Grains m$^{-2}$ was calculated by multiplying panicles m$^{-2}$ by grains panicle$^{-1}$. Harvest index (HI) was derived as the proportion of grain yield to biological yield.

Yield and yield components, plant growth indices and the GDD necessary to reach each of the phenological stages were subjected to analysis of variance using the GLM procedure in SAS (SAS Institute 2000). The assumptions of variance analysis were tested by ensuring that the residuals were random, homogenous, with a normal distribution about a mean of zero. If the assumptions of variance analysis were not adequately met, appropriate data transformation was used. Means were separated using Duncan's multiple range test (DMRT) set at 0.05.

## 3. RESULTS AND DISCUSSIONS

### 3.1. Yield and yield components

Grain yield and biological yield differed significantly between genotypes (Table-1). KGS$_5$ produced the highest grain yield (9895.8 kg ha$^{-1}$) which was more than 1.5 times that of the lowest yielding genotype KGS$_{31}$. The highest biological yield, however, belonged to the genotype KGS$_{23}$ (51023 kg ha$^{-1}$). Similar to the grain yield, genotype KGS$_{31}$was ranked the lowest regarding this trait. Genotype KGS$_{11}$ and KGS$_5$ had the highest HI, respectively, so that significant differences existed between these two genotypes and the other ones. High HI of these genotypes could be explained through their lower biological yield. In other words, one of the reasons of high grain yield in genotype $KGS_5$ was its high HI. It should be noted that there still exists a great gap between HI obtained in the present study and those observed in other studies. Hammer and Broad (2003) reported a HI between 0.47 and 0.57 for grain sorghum. So, it can be concluded that grain yield of sorghum genotypes studied in the present study could be further increased by increasing HI; that is, a plateau has not been yet achieved in the grain yield of Iranian grain sorghum.

**Table-1.** Mean values of grain yield, biological yield, harvest index and primary yield complements in different grain sorghum genotypes.

| **Genotypes** | **Grain yield** (kg $ha^{-1}$) | **Biological yield** (kg $ha^{-1}$) | **HI** (%) | **Grain number panicle$^{-1}$** | **1000-grain weight** (g) |
|---|---|---|---|---|---|
| $KGS_5$ | 9895.8a* | 41072 abc | 24.54a | 2879.3 abc | 27.28ab |
| $KGS_{23}$ | 9633.9 ab | 51023a | 18.99b | 2510.8bc | 26.58ab |
| $KGS_{15}$ | 9589.3ab | 47026ab | 20.17b | 2906.3abc | 24.13ab |
| $KGS_{11}$ | 9378abc | 35659c | 27.29a | 2744.3abc | 23.5ab |
| $ICSV_{274}$ | 9041.7bc | 45894ab | 20.40b | 3303.3ab | 29a |
| $UT_{378B}$ | 8943.5bcd | 49514a | 18.89b | 3466.7a | 27ab |
| $KGS_{25}$ | 8779.8cd | 47673ab | 18.63b | 2445.8bc | 27ab |
| $KGS_{12}$ | 8229.2de | 42637abc | 19.47b | 2124.5c | 20.43b |
| $KGS_{24}$ | 7982.1e | 40841abc | 19.12b | 2298.5c | 28.26ab |
| $KGS_{31}$ | 6348.2f | 38502bc | 16.90b | 2366.9c | 22.16ab |

* Means in each column followed by the same letter are not significantly different ($P<0.05$) using Duncan's Multiple Range Test.

Panicles plant$^{-1}$, grains panicle$^{-1}$ and 1000-grain weight were significantly different between genotypes (Table-1). The highest number of grains panicle$^{-1}$ was observed in the exotic genotypes $UT_{378B}$ and $ICSV_{274}$, while genotype $KGS_5$ was ranked fourth with respect to this yield component. Genotype $KGS_{12}$ had the lowest number of grains panicle$^{-1}$. Grains panicle$^{-1}$ of genotype $KGS_5$ and $KGS_{15}$ were still high enough to explain their high grain yield. This showed that grains panicle$^{-1}$ could be considered as an important component in achieving high grain yield in sorghum. Contrary to this observation, high grains panicle$^{-1}$ in the exotic genotypes did not result in priority in their grain yield. This is attributable to their significantly lower HI compared to the genotype $KGS_5$. Significant difference observed between genotypes $ICSV_{274}$ and $KGS_{12}$ only in case of 1000-grain weight (Table-1). High yielding genotype $KGS_5$ also had a satisfactory 1000-grain weight (27.28g), again emphasizing on the critical role of this trait in achieving high grain yield. Similar to the grains panicle$^{-1}$, genotype $ICSV_{274}$ superiority in this yield component did not considered with superior grain yield. Significant difference was observed between genotypes with respect to grains m$^{-2}$ (Table-1). Genotypes $KGS_{15}$ and $KGS_{24}$ had the highest and lowest grains m$^{-2}$, respectively. Higher grains m$^{-2}$ in the genotype $KGS_{15}$ is due to its superiority in case of panicles plant$^{-1}$ and good performance with regard to the grains panicle$^{-1}$. Interestingly, the genotype $KGS_5$ performed very weak with respect to this trait (Table-2), so that its grain m$^{-2}$ was lower than many of the low yielding genotypes.

Panicles m$^{-2}$ differed significantly between genotypes. Genotype $KGS_{15}$ produced the highest number of panicles m$^{-2}$ (25.27) which was significantly different with genotypes $UT_{378B}$, $KGS_{11}$, $KGS_5$, $ICSV_{274}$ and $KGS_{24}$. Genotypes $KGS_{15}$ and $KGS_{23}$ which were among the three high yielding genotypes had also high panicles m$^{-2}$. Such patterns, however, was not the case in genotype $KGS_5$, so that this genotype performed weak with respect to this trait. Van Oestreum and Hammer (2008) found that panicles m$^{-2}$ had an important role in achieving high grain yield in sorghum through affecting grains m$^{-2}$. Successful performance of the genotype $KGS_5$ although its low panicles m$^{-2}$ was largely due to its high HI, indicating a better partitioning pattern of photosynthetic assimilates to grains.

In general, goods performance of genotypes $KGS_{15}$ is mainly attributable to their high panicles m$^{-2}$ and high grains panicle$^{-1}$ (expect for the genotype $KGS_{23}$ in the second yield component).

**Table-2.** Mean values of secondary yield complements in different grain sorghum genotypes.

| Genotypes | Spikelet number spike$^{-1}$ | Grain number spikelet$^{-1}$ | Grain number m$^{-2}$ | Spike weight (g plant$^{-1}$) |
|---|---|---|---|---|
| $KGS_5$ | 57.33cde* | 50.14abcde | 48700c | 78.27bc |
| $KGS_{23}$ | 72.33a | 34.64de | 57609bc | 70.87cd |
| $KGS_{15}$ | 63.83bc | 45.75bcde | 73077a | 66.78cd |
| $KGS_{11}$ | 56.25cde | 48.62abcde | 49468c | 65.19cd |
| $ICSV_{274}$ | 51.33e | a64.27a | 53369bc | 93.44a |
| $UT_{378B}$ | 66.83ab | 62.50ab | 66132ab | 92.38ab |
| $KGS_{25}$ | 55.25de | 43.99ade | 51912bc | 69.1cd |
| $KGS_{12}$ | 60.25bcd | e33.52e | 50284c | 48.32e |
| $KGS_{24}$ | 43.41f | 52.77abc | 34596d | 65.97cd |
| $KGS_{31}$ | 50.25ef | 51.77abcd | 50106c | 56.16de |

* Means in each column followed by the same letter are not significantly different ($P<0.05$) using Duncan's Multiple Range Test.

### 3.2. Morphological traits

Green leaf number (hereafter referred to GLN) variation showed a sigmoid pattern during the growing season (Figure-1). The GLN was highest at canopy closure that occurred about 70 to 75 days after planting (DAP). Such pattern could guarantee sufficient production of photo assimilates at the beginning of reproductive stage. The highest GLN early in the season (28DAP) belonged to the genotypes $KGS_5$, $KGS_{23}$ and $KGS_{15}$. Since leaf area per plant is the product of leaf number per plant by area per leaf, thus production of more leaves means an earlier coverage on the ground and better radiation interception by the crop. High yields of the aforementioned genotypes is thus to some extent due to better radiation interception by the crop canopies. Richards (2000) stated that the crops with greater leaf area at the beginning of the growing season yield better since they use radiation more effectively. From canopy closure onward, GLN decreased. However, the reduction differed between genotypes, so that the genotype $KGS_5$ could maintain the highest GLN at 110 DAP. The genotype $KGS_{31}$ was ranked lowest in this case. Such pattern supports the differences observed in the grain yield very well. Since, leaf area per plant is correlated with leaf number, thus maintaining higher GLN at the grain filling period in the genotype $KGS_5$ had caused longer photosynthesis period and more contribution of the green leaves to the grains. This explanation is supported by the results observed in caused 1000-grain weight. Many researchers have emphasized on the important role of stay-green characteristic in achieving high grain yield in sorghum (Borrell *et al*., 2000 a and b).

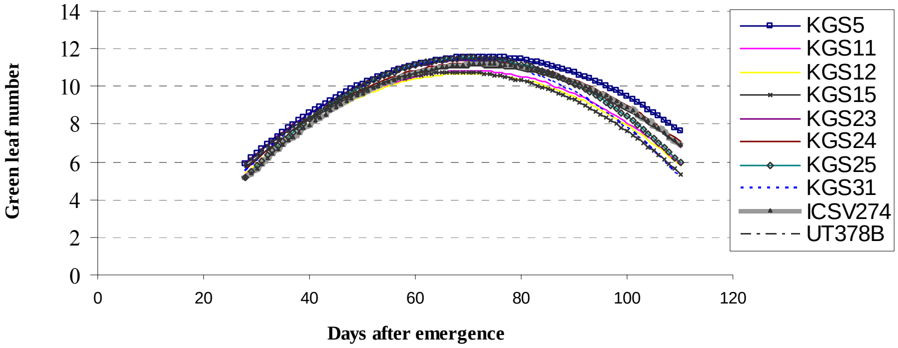

Figure1. Changes trend of green leaf number in growth season in different grain sorghum cultivar

Generally and according to what observed in the present study, the ability to maintain higher GLN at late grain filling period is one of the most contributing and promising traits in obtaining satisfactory grain yield in sorghum.

An increasing pattern was observed for plant height from the beginning of the growing season till canopy closure (Figure-2). However, considerable differences existed between genotypes with respect to the slope of the increase in plant height and the maximum achieved plant height. The only genotype could produce higher height (24.47 cm) was $KGS_{31}$. It doesn't have good radiation use efficiency in case of the low production of leaf number. The genotypes had specific differences in this trait which were $KGS_5$ and $ICSV_{274}$, had the lowest (122.78 cm) and the highest height (165.59cm), respectively. It indicates the key role of appropriate height to reach suitable yield. So, lower and thicker height has direct relationship with HI and also grain yield. The genotype $KGS_{31}$ showed the high height with the low of grain yield.

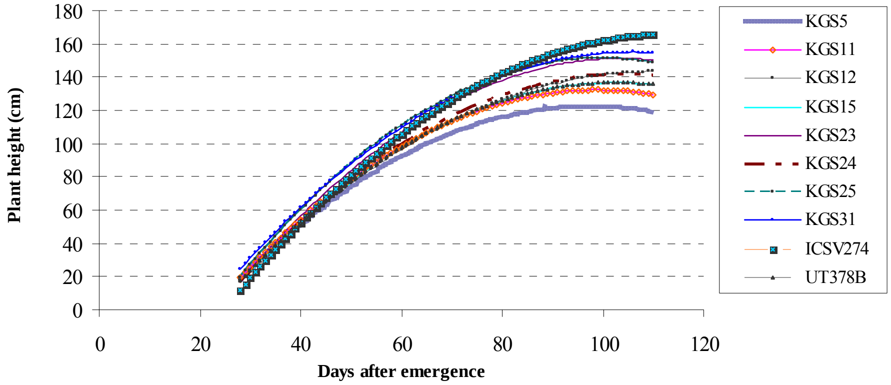

Figure2. Changes trend of plant height in growth season in different grain sorghum.

### 3.3. Phenological stage

Experimental result indicated significant differences in reaching three stages of development (Table-3). Two genotypes $KGS_5$ and $KGS_{23}$ which had the highest grain yield, reached to three leaves stages more rapid than genotypes $KGS_{24}$, $UT_{378B}$, $KGS_{25}$, $ICSV_{274}$, $KGS_{15}$ and $KGS_{31}$. It indicated that these two genotypes didn't face on warm and dry weather in summer in case of growing up sooner. In contrary of three former phenological stages, significant differences in growth degree days to exist between genotypes regarding milk stage and soft dough initiation. Therefore, the genotype $KGS_{31}$ reached more rapidly to this stage than the genotype $KGS_5$. Longer flowering period is an advantage for genotype, because it provides the flexibility power for facing to inappropriate condition. It means that, plant can decrease the negative effect of stress in early flowering stage. So, longer flowering period in sorghum is one of the important characters to reach an appropriate grain yield.

**Table-3.** Mean values of phenological stages in different grain sorghum genotypes based on Growing Degree Days (GDD).

| Genotypes | GDD to emergence stage | GDD to 3 leaves stage | GDD to booting stage | GDD to milk stage | GDD to soft dow stage |
|---|---|---|---|---|---|
| $KGS_5$ | 178.022a* | 720.38a | 981.35a | 1359.5a | 1423.7a |
| $KGS_{23}$ | 171.200a | 715.80a | 906.80a | 1317.9ab | 1380.9b |
| $KGS_{15}$ | 178.033a | 722.53a | 906.80a | 121.4bc | 1380.9b |
| $KGS_{11}$ | 171.200a | 715.35a | 906.80a | 1359.5a | 1423.7a |
| $ICSV_{274}$ | 171.200a | 722.53a | 981.25a | 1291.48abc | 1359.5bc |
| $UT_{378B}$ | 171.200a | 734.18a | 906.80a | 121.4bc | 1331.77cd |
| $KGS_{25}$ | 178.033a | 727.28a | 906.8a | 1190.5d | 1317.2d |
| $KGS_{12}$ | 171.200a | 715.60a | 906.8a | 1359.5a | 1423.7a |
| $KGS_{24}$ | 184.867a | 748.55a | 906.8a | 1220.1cd | 1317.9d |
| $KGS_{31}$ | 170.200a | 722.13a | 906.80a | 1170.7d | 1331.77cd |

* Means in each column followed by the same letter are not significantly different (P<0.05) using Duncan's Multiple Range Test.

### 3.4. Physiological indices

Mean comparison of LAI in sorghum genotypes is shown the significant differences (Table-4). The highest of this trait belonged to genotype $KGS_{31}$ (4.93), but it produced the lowest grain yield. On the other hand, the genotype $KGS_5$ was ranked in medium in LAI, which had the highest grain yield. In other words, having inappropriate canopy architecture and leaf angles cause to decrease of grain yield in spite of large leaf area. It is completely clear in genotype $KGS_{23}$ which was ranked in case of grain yield and LAI, respectively second and third. Also, variance analysis declared the significant differences among sorghum genotypes incase of LAR (Table-4). So that, the genotype $KGS_{31}$ had the highest LAR namely 0.023 $cm^2$/gr. It's observed that partitioning of photosynthetic matter to leaves, could help increasing of grain yield. It can be concluded that the genotypes produced either low grain yield or low LAR. Genotypes had the significant differences in LWR (Table-4), which showed the genotype $KGS_5$ had the highest LWR about 0.39. Also, it's observed that two genotypes $KGS_{15}$ and $KGS_{23}$ were ranked in high level which emphasized of photosynthetic matter partitioning to leaves is so important. Table-4 showed the highest and the least amounts of CGR belonged to $ICSV_{274}$ and $KGS_{15}$, respectively. The same pattern was shown in LAI trend. Evans (1993) reported that the LAI before canopy closure is affected on CGR. The genotype $KGS_5$ showed less CGR than genotype $ICSV_{274}$ cause of declining the NAR in this genotype. Genotype $KGS_5$ was ranked high in LAI and LAR. Also, genotypes $KGS_{12}$, $UT_{378B}$ and $KGS_{24}$ had the highest amount of NAR, respectively (4.24, 4.04, and 3.81) (Table-4).

**Table-4.** Mean values of physiological indices in different grain sorghum genotypes.

| Genotypes | LAI | LAR | LWR | CGR | NAR | SWR | TDM |
|---|---|---|---|---|---|---|---|
| $KGS_5$ | 4.39ab | 0.0221ab | 0.39a | 12.87cd | 2.95b | 0.48996b | 821.4b |
| $KGS_{23}$ | 4.8a | 0.01923bc | 0.34abc | 14.08cd | 3.43ab | 0.53163ab | 1039.6ab |
| $KGS_{15}$ | 3.76b | 0.018bc | 0.34abc | 11.91d | 3.37ab | 0.51458ab | 1039.6b |
| $KGS_{11}$ | 3.54b | 0.018bc | 0.26c | 12.67cd | 3.78ab | 0.55287ab | 1039.6b |
| $ICSV_{274}$ | 4.85a | 0.019bc | 0.309bc | 19.42a | 3.52ab | 0.56652a | 1039.6ab |
| $UT_{378B}$ | 4.8a | 0.017c | 0.3004bc | 19.09ab | 4.04a | 0.53135ab | 1039.6a |
| $KGS_{25}$ | 4.76a | 0.021ab | 0.304bc | 14.39cd | 4.04b | 0.55054ab | 1039.6b |
| $KGS_{12}$ | 3.8b | 0.021c | 0.35ab | 15.87bc | 4.04a | 0.4928b | 1039.6ab |
| $KGS_{24}$ | 4.17ab | 0.021c | 0.27bc | 16.02bc | 4.04ab | 0.55364ab | 1039.6b |
| $KGS_{31}$ | 4.93a | 0.021a | 0.33abc | 13.46cd | 4.04b | 0.57157a | 1039.6b |

* Means in each column followed by the same letter are not significantly different ($P<0.05$) using Duncan's Multiple Range Test.

There was no relationship between grain yield and NAR. This could indicate that the CGR was high enough in genotypes $KGS_{12}$ and $KGS_{24}$ for increasing NAR. This result was similar to genotypes $KGS_5$ and $KGS_{15}$ which received the low of CGR. In addition, the low SWR was belonged to genotypes with high grain yield. So that, genotypes $KGS_{31}$ and $KGS_{12}$ was ranked the highest and the lowest in SWR (Table-4). This result indicates that the less amount of assimilates part to stem in some genotypes with high grain yield. The genotypes $UT_{378B}$ and $ICSV_{274}$ were ranked high in TDM that comply with the high in LAI and CGR (Table-4). Since, increasing amount of dry matter in flowering stage is so important to achieve high grain yield, then the divers result about TDM is caused by it. Also, partitioning assimilates to stem rather than leaves is a negative points. The pattern of increasing in RUE and TDM is similar to each other. It showed the highest and the lowest genotypes in both of them were $UT_{378B}$ and $KGS_{11}$ respectively. Ferraris and Edwards (1986) indicated that increasing RUE is associated with more weight and high height in crops. Also, the similar leaves size in genotype $UT_{378B}$ caused the appropriate distribution of radiation in canopy. Scientists showed that the reason of differences between old and new what genotypes in radiation intercept the less is of leaves angel in new genotypes (Yunusa *et al*., 1993). In addition, low amount of RUE was belonged to $KGS_{11}$ cause of less IPAR through the less LAI.

### 4. CONCLUSIONS

In this experiment, some genotypes had high grain yield while had not high biomass. It indicated that it can be possible to increase yield by increasing biomass. It reported that, HI is a restricting factor in sorghum grain yield. It showed that it can be possible to increase HI by breeding programs in some genotypes with high biomass. In addition, numbers of grain per panicle and 1000-grain weight are important to produce high grain yield. Moreover, for access to high radiation use efficiency, it's necessary to produce of more leaves at early season in sorghum. Number of leaves and LAD are important factors to increase the grain yield. In sorghum longer flowering period provides flexibility talented facing to unfavorable conditions that is important for yield increase. Also, photosynthesis partitioning to leaves, produce high yield by effecting on LAR and LWR. But remobilization of assimilates to stem causes of decrease of HI and sorghum grain yield.

In general, ideotype of sorghum characteristics include: high grain yield, high HI, high number of grain in panicle, high 1000-grain yield, producing high number of leaves, the longer LAD, increasing of flowering period and portioning more photosynthesis matter to leaves.

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