Sorghum Grain Filling and Dry Down Dynamics for Hybrids Released Over the Past Six Decades in the US

P.A. Demarco, L. Mayor,[1] P.V.V. Prasad, C.D. Messina,[2] and I.A. Ciampitti

Summary

Sorghum (*Sorghum bicolor* L. Moench) is mainly grown in the Great Plains region of the United States, with the state of Kansas as the premier cropland for its cultivation. Over time, improvements in sorghum have been related to genetic and management interactions, however, scarcity of information on the grain filling and the dry down processes have been reported. This study characterizes grain filling and dry down dynamics for hybrids with different released years. Field trials were conducted during the 2018 and 2019 seasons in Kansas, testing 20 commercially available grain sorghum hybrids released between 1963 and 2017. Grain dry matter accumulation and reduction in grain moisture content were determined during the reproductive period, from grain filling to the physiological maturity of the crop. Across decades (hybrids), no changes in grain filling duration and rate were documented. Over the past 60 years, the rate of seed filling ranged from 0.56 to 1.34 mg grain/day, and the duration varied from 30 to 40 days for sorghum hybrids. The dry down duration ranged from 16 to 32 days and the rate of dry down ranged from -0.64 to -0.99% of moisture per day. Despite the lack of statistical differences in these grain filling traits, information about duration and rate are valuable guiding points for farmers in the US to better understand the potential fit of this crop into more intensified rotations.

Introduction

Sorghum (*Sorghum bicolor* L. Moench) is a widely cultivated crop in the central Great Plains region of the United States, with Kansas as one of the central states in terms of production and yields in the country (Rakshit et al., 2014; FAO, 2019). Over the past decades, improvements in grain yield due to genetic and management interactions have been reported for sorghum hybrids (Assefa and Staggenborg, 2010; Pfeiffer et al., 2019; Demarco et al., 2020). However, few details have been described regarding the grain filling and subsequent moisture loss (herein termed as "dry down") dynamics for US sorghum genotypes. After the critical period of the crop, which lasts for 10–15 days around flowering (Gambín et al., 2008), the period of grain filling, and then the water losses are of great importance for farmers due to the broader environmental factors that have an impact on the final yield. Identifying the duration and rate of these processes

[1] Corteva Agriscience, Wamego, KS.

[2] Corteva Agriscience, Johnston, IA.

for genotypes from different years of release and maturity can help farmers to better understand the potential fit of this crop into more intensified rotations.

The grain filling and grain water loss occur consecutively in the plant. Generally, dry matter accumulation is divided into three phases (Bewley and Black, 1986). The first part consists of an active cell division phase with a higher water concentration in the grains. The effective grain filling constitutes the second phase, in which there is a continuous accumulation of biomass in the grains. Once the grains have achieved their final maximum weight, the biomass accumulation has ended, reaching the third phase known as physiological maturity. From this point, dry weight remains stable, and the grains continue losing moisture until the percentage of water content is acceptable to harvest the crop.

We hypothesized that different hybrids released over the last six decades in the US will present different duration and rates of grain filling and moisture loss. Our overall objective was to characterize the grain filling and dry down dynamics for commercially available sorghum hybrids with different years of release in the US.

Procedures

Experimental Conditions

Field studies were conducted at Corteva Agriscience research stations in Kansas, USA, during the 2018 and 2019 growing seasons. The experimental design was a randomized complete block design (RCBD), with 20 sorghum hybrids and three replications each season. Sorghum hybrids, all from Corteva Agriscience, spanned six decades of genetic selection (from 1963 until 2017). Plots were 17.4 ft long by 30-in. row spacing, the experimental layout was arranged in plots of two rows for 2018, and eight rows during the 2019 season. Specific details of sowing date, harvest date, plant density, and other management information from each year of study are presented in Table 1.

During the grain filling period, one plant per plot was collected in intervals of 4 to 5 days to characterize seasonal dynamics of grain dry matter and moisture content. The panicle was separated from the rest of the fraction (leaf + stem) by cutting 1 cm below the first branch and placed in plastic bags to conserve grain moisture. Phenology was tracked daily in these individual plants before flowering and during the reproductive period. At the laboratory, 40 grains per panicle were sampled inside a humidity chamber by collecting 10 grains from each of four visually determined sections of the head. Fresh weight of the grains was first obtained, and then dry weight after drying those grains in an air-forced oven at 150°F until constant weight.

Statistical Analysis

Grain filling rate (GFR) and grain filling duration (GFD) were estimated fitting a bi-linear model [equations (1) and (2)] with grain dry weight modeled on a day-time basis from flowering to harvest maturity:

$$\text{Grain weight (mg/grain)} = a + b * d \quad \text{for } d<c \quad [1]$$
$$\text{Grain weight (mg/grain)} = a + b * c \quad \text{for } d>c \quad [2]$$

where d is the days after flowering, a is the y-intercept (mg/grain), b is the GFR (mg grain/day), and c is the total GFD (in days).

Dry down rate (DDR) and dry down duration (DDD) were estimated fitting a bi-linear model [equations (3) and (4)] with water content in percentage modeled on a day-time basis from physiological maturity (PM) to constant water content:

$$\text{Grain water content (\%)} = a + b * d \qquad \text{for } d<c \quad [3]$$

$$\text{Grain water content (\%)} = a + b * c \qquad \text{for } d>c \quad [4]$$

where d is the days after physiological maturity (PM), a is the y-intercept (WC %), b is the DDR (WC % per day), and c is the total dry down duration (DDD) in days.

Mixed-effects models were fitted with nlme (Pinheiro et al., 2018) package in RStudio (RStudio Team, 2016) for the traits measured.

Results

Over the last six decades, yield improvement in grain sorghum has been related mainly to increments in grain number per area rather than grain weight indicating that this physiological trait remained relatively stable across time (Demarco et al., 2020). Associated with grain weight, no changes in grain filling duration and rate were found for the years of release of our hybrids (Table 2). In our study, the grain-filling rate ranged from 0.56 to 1.34 mg grain/day, while the duration ranged from 30 to 40 days in length (Table 2). Likewise, Gizzi and Gambín (2016) reported no changes in grain weight for hybrids released from 1984 to 2014 and no changes in the duration of the seed filling period over time. This demonstrates that, as for maize (Otegui et al., 2015), there has not been a tradeoff between grain number and weight over time with yield selection in sorghum.

The rate of moisture content decline from physiological maturity to harvest did not present changes during the past decades, as well as the duration of the dry down period (Figure 1). Although the changes are not significant over time, the dry down duration ranged between 16 to 32 days and the rate of decrease in moisture content ranged from -0.64 to -0.99% of moisture per day (Table 2).

A comparison between hybrids from different decades is presented showing hybrids with a different rate but the same duration (Figure 2A and 2C), and different duration with similar rate (Figure 2B and 2D) of both dynamics under study. In panel 2A hybrids from 1981 and 1982 year of release present the same grain filling duration (36 days) but with a different rate, 1.02 mg grain/day for the hybrid from 1981 and 0.71 mg grain/day for the hybrid released 1982. Hybrids from 2007 and 2010 year of release, showed relatively the same grain filling rate (Figure 2B) 0.99 and 0.87 mg grain/day, respectively, but the duration was 34 for 2007 YR and 40 days after flowering for 2010 YR. The different durations between the two may be related to their relative maturity; the hybrid from 2007 is a mid-early relative maturity, while the 2010 hybrid is mid-late the difference to full bloom is 3 days, and 9 days for physiological maturity. In the dry down dynamics, hybrids from 1988 and 1997 are represented having similar dry down duration (22 and 23 days respectively from physiological maturity), and different rates (Figure 2C). Hybrids from 2007 and 2008 with similar rates of moisture lose approximately -0.70 grain WC % per day and have a difference of 9 days until the moisture content is constant.

Understanding how different sorghum hybrids reach their final grain weight is valuable not only for scientists, but also for farmers to select their genotypes and management strategies based on estimations of physiological maturity and dry down timings.

References

Assefa, Y., Staggenborg, S.A., 2010. Grain sorghum yield with hybrid advancement and changes in agronomic practices from 1957 through 2008. Agron. J. 102, 703–706. *https://doi.org/10.2134/agronj2009.0314*.

Bewley, D.J., Black, M., 1986. Seeds. Physiology of development and germination (Book). Plant, Cell Environ. 9, 356–356. *https://doi.org/10.1111/1365-3040.ep11611812*.

Demarco, P. A.; Mayor, L.; Tamagno, S.; Fernandez, J. A.; Prasad, P. V. Vara; Rotundo, J. L.; Messina, C. D.; and Ciampitti, I. A. (2020) "Physiological Changes Across Historical Sorghum Hybrids Released During the Last Six Decades," Kansas Agricultural Experiment Station Research Reports: Vol. 6: Iss. 5. *https://doi.org/10.4148/2378-5977.7925*.

FAO, Food and Agricultural Organization of the United Nations. 2019. Statistics of farming production. Sorghum. Available in *http://www.fao.org/faostat/en/#data/QC/visualize* consulted on June, 2021.

Gambín, B.L., Borrás, L., Otegui, M.E., 2008. Kernel weight dependence upon plant growth at different grain-filling stages in maize and sorghum. Aust. J. Agric. Res. 59, 280–290. *https://doi.org/10.1071/AR07275*.

Gizzi, G., Gambín, B.L., 2016. Eco-physiological changes in sorghum hybrids released in Argentina over the last 30 years. F. Crop. Res. 188, 41–49. *https://doi.org/10.1016/j.fcr.2016.01.010*.

Kansas Mesonet, 2017: Kansas Mesonet Historical Data. Accessed 30 June 2017, *http://mesonet.k-state.edu/weather/historical*.

Otegui, M.E., Borrás, L., Maddonni, G.A., 2015. Crop phenotyping for physiological breeding in grain crops: A case study for maize. Crop Physiol. Appl. Genet. Improv. Agron. Second Ed. 375–396. *https://doi.org/10.1016/B978-0-12-417104-6.00015-7*.

Pfeiffer, B.K., Pietsch, D., Schnell, R.W., Rooney, W.L., 2019. Long-term selection in hybrid sorghum breeding programs. Crop Sci. 59, 150–164. *https://doi.org/10.2135/cropsci2018.05.0345*.

Pinheiro, J., Bates, D., DebRoy, S., & Sarkar, D. (2018). R.C.T. 2018. nlme: linear and nonlinear mixed effects models. R. package version 3. R.F.S.C.R. 2018.

Rakshit, S., Hariprasanna, K., Gomashe, S., Ganapathy, K.N., Das, I.K., Ramana, O. V., Dhandapani, A., Patil, J. V., 2014. Changes in area, yield gains, and yield stability of sorghum in major sorghum-producing countries, 1970 to 2009. Crop Sci. 54, 1571–1584.

RStudio Team. (2016). RStudio: Integrated Development for R. RStudio, Inc. Boston, MA. *https://www.rstudio.com/*.

Brand names appearing in this publication are for product identification purposes only. No endorsement is intended, nor is criticism implied of similar products not mentioned. Persons using such products assume responsibility for their use in accordance with current label directions of the manufacturer.

Table 1. Field management and climate conditions during the 2018 and 2019 growing season

Location	Coordinates field trial	Year	Sowing date	Harvest date	Irrigation	Plant density	Max. Temp.	Min. Temp.	Precipitation
						plants/a	°F	°F	in.
Riley, KS	39°09’24.3”N 96°40’54.0”W	2018	6/7/2018	11/21/2018	Irrigated	70000	79.2	57.2	26.4
Riley, KS	39°09’12.1”N 96°40’03.7”W	2019	6/8/2019	11/8/2019	Dryland	70000	80.2	58.8	26.7

The minimum and maximum temperatures (Min. Temp. and Max. Temp., respectively) are the averages of minimum and maximum temperatures per day from planting to harvest for each site × year in Fahrenheit degrees (°F), respectively. The precipitation represents the accumulated rainfall from planting to harvest for all locations in inches. (Kansas Mesonet, 2017).

Table 2. Detailed results on grain filling rate (mg grain/day), and duration (days); dry down rate (WC % per day); and duration for all the hybrids under study

YR	Relative maturity	Days to FL	Days to PM	Grain filling rate	Grain filling duration	Dry down rate	Dry down duration
				mg grain/day	days	WC % per day	days
1963	Mid L	63	99	0.86	36	-0.70	26
1975	Mid	61	100	0.65	39	-0.69	22
1978	Mid	58	90	1.19	32	-0.95	18
1981	Mid	59	95	1.02	36	-0.65	27
1982	Mid L	63	99	0.71	36	-0.72	23
1983†	Mid	64	96	1.34	32	-0.66	32
1987	Mid L	67	105	0.56	38	-0.85	16
1988	Mid	61	97	1.07	36	-0.83	22
1989	Mid L	63	99	0.80	36	-0.67	26
1990	Mid E	58	93	0.82	35	-0.83	20
1992	Mid	60	92	1.16	32	-0.93	20
1997 A	Mid L	64	103	0.91	39	-0.68	23
1997 B	Mid E	57	87	0.93	30	-0.88	21
2003	Mid E	58	93	1.31	35	-0.99	19
2005	Mid	61	100	0.71	39	-0.64	24
2006	Mid L	62	94	1.22	32	-0.78	24
2007	Mid E	62	96	0.99	34	-0.70	29
2008	Mid	61	99	0.78	38	-0.69	20
2010	Mid L	65	105	0.87	40	-0.71	20
2013	Mid E	56	87	1.20	31	-0.77	24
2017‡	Mid	62	101	0.67	39	-0.71	19

†Hybrid included only in 2018 growing season.
‡Hybrid included only in 2019 growing season.
The YR represents the year of release of the hybrids, days to FL are the number of calendar days from planting to flowering; and the days to PM are the calendar days from planting to physiological maturity for all the hybrids.

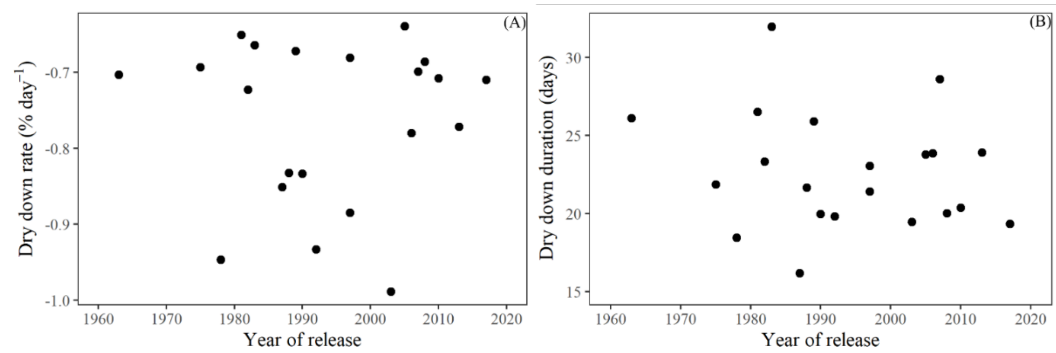

Figure 1. Grain dry down rate in water content percentage per day (A), and duration in days (B) related to the years of release of the hybrids.

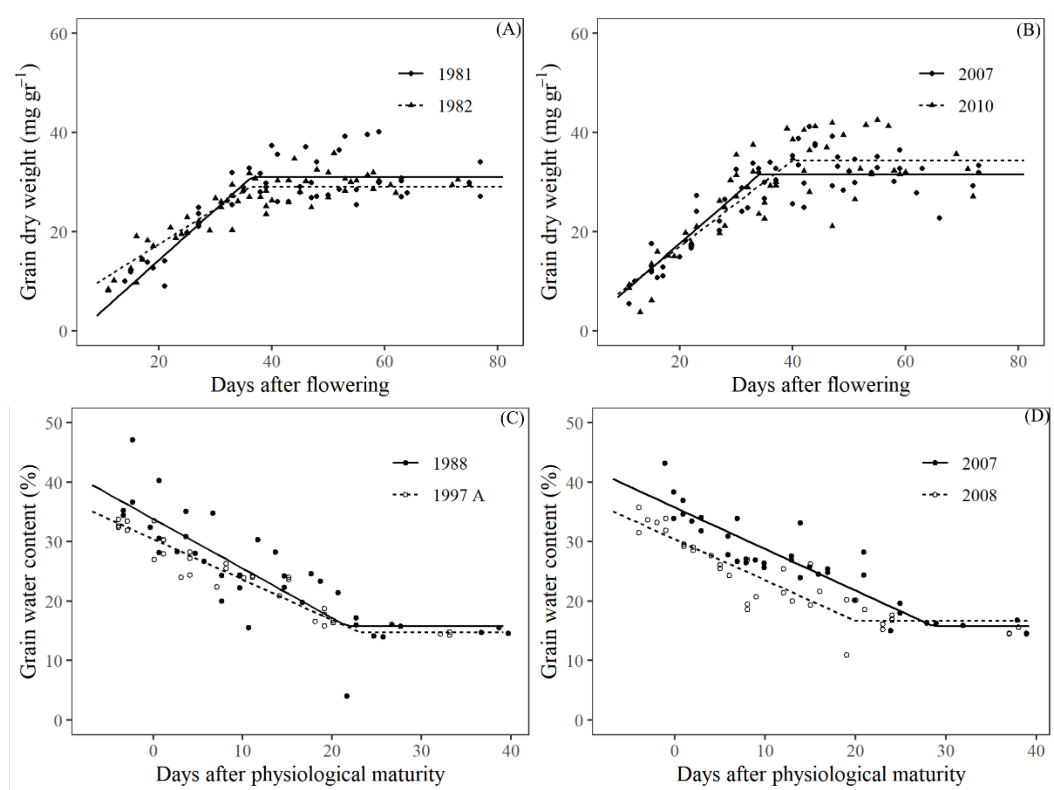

Figure 2. Grain filling dynamic in mg/gr of grain dry weight for different hybrids related to the days after flowering (A and B). Dry down dynamic in the percentage of grain water content in a relationship with the days after physiological maturity for hybrids from different years of release (C and D).