GROWTH AND PRODUCTION OF SORGHUM AND MILLETS

P.V. Vara Prasad and **Scott A. Staggenborg**
Department of Agronomy, Kansas State University, Manhattan, KS 66506, USA

Keywords: Barnyard millet, crop management, drought stress, finger millet, foxtail millet, genetic resources, growth and development, kodo millet, proso millet, sorghum.

Contents

Summary

Sorghum and millets are important crops for food security in semi-arid and arid regions due to their high nutritional quality, tolerance to stresses (abiotic and biotic) and their performance in marginal lands with relatively low fertility. Utility of these crops is diverse (food, brewing, feed, forage, fodder, biofuel, and building material). In Africa and Asia sorghum grain is mainly used as food, while, in the United States and Australia it is used to feed cattle. More recently in India and Africa, it is being used as poultry feed.

Sorghum and millets are also gluten free and can be important food sources to millions of people who are intolerant to gluten (celiac disease), including diabetic patients, in both developed and developing countries. Sorghum also shows high potential as a bioenergy crop due to its high biomass production, photoperiod sensitivity and sweet stalks. Millets have a wide range of crop cycles, and some have even a very short cycle, which makes them fit quite well in several cropping systems.

Under subsistence farming sorghum and millets are grown with limited resources. However, both crops generally respond well to fertilizer inputs and can provide interesting economic yield benefits. Despite high yield potential, the productivity of sorghum and millets in farmers' fields is low, mainly since these crops are being pushed to more marginal farmlands.

Sorghum and millets will continue to play a key role in providing food security in subsistence cropping systems of Asia and Africa, and in improving economic returns to large farmers in the assured rainfall regions of the world. Research and extension activities towards crop improvement, intensified cropping systems and improved management of soil, water, nutrients and weeds will help produce higher yields.

1. Introduction

Sorghum and millets are important food crops in semi-arid and arid regions of Africa and Asia, where they perform rather well under harsh climatic conditions in marginal lands with low fertility. Besides their function as a food crop to the local populations they are also used, especially in developing countries, as cattle and bird's feed, forage and fodder, and more recently as bioenergy crops.

Sorghum is a staple cereal food crop for more than 500 million people. Sorghum grain is mostly consumed for food purpose (55%) as flat bread and porridges in several countries of Asia and Africa. In dry season the sorghum stalks are used as feed for livestock, especially in Asia. In America, grain sorghum is an important animal feed in addition to forage sorghum.

Millet is a collective term commonly referred to a number of small seeded annual grass grain crops. Millet production is generally limited to fields with low soil fertility and poor rainfall conditions. Although millet production is only about 2% of the world cereal production, it is an important staple food crop in semi-arid regions. Asia and Africa account for about 95% of the total millet production in the world. Asia accounts for 40% of millet production, mainly contributed by India and China. Africa accounts for 55% of total production, mainly concentrated in Nigeria, Niger, Burkina Faso, Mali, and Kenya.

Very limited quantities of millet are produced in developed countries primarily for high value specialty markets for human nutrition or bird feed. The most common species of millet include pearl millet (*Pennisetum glaucum*), finger millet (*Eleusine caracana*), proso millet (*Panicum miliaceum*), foxtail millet (*Seteria italica*), little millet (*Panicum sumatrense*), barnyard millet (*Echinochloa colona*) and kodo millet (*Paspalum scrobiculatum*).

Sorghum and millet's genetic resources are conserved at many centers around the world. One of the major organizations which maintain sorghum and millet germplasm and that has a global mandate for sorghum and millet improvement is the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) located in Patancheru, Andhra Pradesh, India. At global level sorghum germplasm collections consists of about 168,500 accessions. ICRISAT has the largest single collection of sorghum (about 22% of the global total germplasm) with a total of 36,774 accessions from 91 countries. This collection is estimated to represent about 80% of the variability present in sorghum. Other organizations include the National Plant Germplasm System (NSPS) in USA, Ethiopia, Sudan, South Africa, India, and China.

Despite the large accessions of sorghum, only a very small proportion (<3%) is being used by crop scientists in crop improvement programs. ICRISAT also conserves, characterizes, and promotes utilization of millets that have regional and location-specific importance and are classified as under-utilized crops. ICRISAT's gene bank holds the single largest collection of pearl millet (21,596 accessions), finger millet (5,949 accessions), foxtail millet (1535 accessions), proso millet (842), barnyard millet (743), kodo millet (658) and little millet (466). Although this collection is large the quest for collection is a continuing process, and ICRISAT continues its efforts of collecting new germplasm.

In addition to ICRISAT, few other institutions which hold sorghum and millet collection include the National Center for Genetic Resource Preservation (Fort Collins, Co, USA), the International Bureau of Plant Genetic Resources (Rome, Italy), National Bureau of Plant Genetic Resources (NBPGR), New Delhi, Project Directorate of Sorghum Research (PDSR, Hyderabad) and All India Coordinated Projects on Pearl Millet (Mandor, Rajasthan), Small Millets (Bangalore, Karnataka).

Sorghum and millets have C_4 type of photosynthetic pathway. This C_4 photosynthetic pathway allows sorghum and millets to be more efficient in water use, radiation use, and nutrient use, thus allowing them to survive in harsh climatic conditions (drought, high temperatures and nitrogen stress). The C4 plants have a specialized leaf anatomy called Kranz anatomy. This is characterized by the presence of chloroplasts in mesophyll cells and vascular bundle sheath cells, both of which take part in photosynthesis. The primary function of this Kranz anatomy is to enrich carbon dioxide around Rubisco, thus reducing photorespiration.

The vascular bundles of C4 plants are surrounded by concentric cylinders called vascular bundle sheath, whose cells are packed with chloroplasts, and the sheath is surrounded by mesophyll cells which also posses chloroplasts. In C_4 leaves, the outer mesophyll contains enzyme phospho*enol*pyruvate (PEP) carboxylase and other enzymes involved in Hatch and Slack cycle (C_4 cycle) and bundle sheath cells contain ribulose 1,5-bisphosphate carboxylase-oxygenase (Rubisco) involved in Calvin cycle (C_3 cycle).

Mesophyll cells carry out the initial steps of CO_2 fixation through PEP carboxylase to produce the four carbon organic acid oxalo-acetate. These four carbon organic acid is transported into bundle sheath cells where it is decarboxylated to release CO_2 close to Rubisco which participates in the regular Calvin cycle.

2. Sorghum

2.1. Origin, Spread and Importance

Sorghum (*Sorghum bicolor* L. Moench) is the fifth most important cereal crop in the world after wheat (*Triticum aestivum* L), rice (*Oryza sativa* L.), maize (*Zea mays* L.), and barley (*Hordeum vulgare* L.). The center of origin of sorghum is believed to be near Lake Chad in Africa. This crop was first domesticated about 7000 BP in West Africa. Thereafter, it reached India about 1500 BC and China by 900 AD. Cultivated sorghum was first introduced to America about 100 years ago.

Worldwide, grain sorghum is produced on 43.8 million ha, with an estimated total production in 2007 of 64.6 million tons. Major sorghum production areas include the great plains of North America, Sub-Saharan Africa, northeast China, and the Deccan plateau of central India. Important sorghum producing countries in the world are India, Nigeria, Sudan, United States, Niger, and Mexico.

Many of the tropical sorghums are short-day plants and their response to day length is an important adaptation. However, the selection of early-maturing varieties and hybridization helped its spread in the USA. This country is the worlds' largest exporter of grain sorghum, and its share in world trade is about 70%. Important sorghum producing states in United States include Kansas, Texas, Oklahoma, Nebraska, New Mexico, and Missouri. Kansas is the largest producer of grain sorghum in the United States contributing 40% of its total production.

Figure 1. Hybrid grain sorghum field in Manhattan, Kansas, US.

Sorghum has multiple uses as grain, forage, fodder, and more recently as bioenergy crop. In Asia and Africa, sorghum grain is consumed by humans or as animal feed; stalks are used as animal fodder, or as housing material. It is a major staple food crop in much of Africa and in Asia, especially in India (specifically Maharashtra and Karnataka states). Sorghum grain has a high nutritive value, with 70-80% carbohydrate, 11-13% protein, 2-5% fat, 1-3% fiber, and 1-2% ash. Protein in sorghum grain is gluten free and, thus, it is a specialty food for people who suffer from celiac disease (intolerant to food with gluten), including diabetic patients.

Sorghum whole grain or grain with pericarp can be boiled and consumed. Generally grain is ground into flour and made into porridge (in Africa) or flat unleavened bread (in India). Sorghum grain is used for brewing beer in parts of Africa, and for alcoholic wine in China. In the United States, Australia, and parts of Southern America, sorghum grain is used mainly as animal feed. The grains have to be processed; because if swallowed whole, due to the waxy coating on the grain, it makes digestion difficult. The simplest and least expensive method to feed sorghum grain is after grinding.

Sorghum is also grown as forage crop and can be fed to cattle directly or be preserved as hay or silage. In recent years sorghum is also being considered a dedicated bioenergy crop, particularly sweet stalk sorghum (sweet sorghum) and photoperiod sensitive high biomass sorghum.

2.2. Botany

Sorghum is classified under the family of *Poaceae*, tribe *Andopogoneae*, subtribe *Sorghinae*, genus *Sorghum*. All cultivated sorghum belongs to *Sorghum bicolor* subsp. *bicolor*. The morphological characteristics of sorghum differ, based on the variety and environment in which it is grown. Sorghum is a perennial by nature and, hence, a very suitable multi-cut forage crop, but where the end product is grain it is grown as an annual rain fed crop.

Sorghum is an erect plant with a solid stem, which can grow from 0.8 m to 5 m high depending mainly on its photoperiod sensitivity. The sorghum leaf has a prominent mid-rib; typical leaf blades are on average 8-12 cm wide and 50-90 cm long. Leaf sheath and stem are often covered with a waxy bloom. The plant can tiller depending upon the variety (or hybrid), temperature conditions and nitrogen supply. Sorghum has an extensive fibrous root system which can grow as deep as 3m.

Figure 2. Diversity in panicle size, compactness and grain color in sorghum.

Sorghum bicolor (L.) Moench is divided into five major races : bicolor (b), guinea (g), caudatum (c), kafir (k) and durra (d); and 10 intermediate races with all combination of basic races : guinea bicolor (gb), caudatum bicolor (cb), kafir bicolor (kb), durra bicolor (db), guinea caudatum (gc), guinea kafir (gk), guinea durra (gd), kafir caudatum (kc), durra caudatum (dc), and kafir durra (kd). These classifications are mainly based on the type of panicle, spikelet, shape, and glumes (Fig. 2).

Bicolor sorghums have open, loose panicles of medium size with small grains which are completely covered by large, closed glumes; these are grown throughout Africa and widespread in Asia. Guinea sorghums have long, loose panicles with small to medium grain which is flattened, twisted, and oval in shape, and are covered with open glumes; these are grown in West Africa.

Caudatum sorghums have panicles of variable shape with asymmetrical grains, flat on one side and convex on the others, and covered with glumes which are shorter than the grain; these are widely grown in Chad, Sudan, north-eastern Nigeria and Uganda. Kafir sorghums have compact panicles that are cylindrical in shape with elliptical grain tightly enclosed by glumes that are shorter than the grain; they are widely grown in southern Africa. Durra sorghums have highly compact panicles with an erect or curved peduncle with globular grain that is tightly enclosed by small wrinkled glumes; these are mainly grown in East Africa, Middle East, and India. Various intermediate races have combination of characteristics of the main races.

2.3. Growth and Development

Description of developmental stages and their approximate duration from sowing for typical grain sorghum crop are given in Table 1 and Figure 3.

2.3.1. Germination and Seedling Development

Under optimum soil moisture and temperature conditions, germination occurs in 3 to 5 days and seedlings emerge in about 5 to 10 days. Seed germination begins with an absorption of moisture. As the seed swells, the coat breaks and the radicle and coleoptile emerges. The radicle grows downwards into the soil and forms the first primary seminal roots. The seed remains at the place of sowing and the mesocotyle elongates; a first node is formed at the base of the coleoptile just below the ground level. The coleoptile grows and emerges above ground and remains as a sheath at the base of the seedling.

Developmental Stage	Growth Stage	DAE	Visual Characteristics
0	GS1	0	Emergence, coleoptile visible at soil surface
1	GS1	5	Collar of 3rd leaf visible
2	GS1	10 – 15	Collar of 5th leaf visible
3	GS1	25 – 30	Growing point differentiation (approx. 8th leaf visible) or panicle initiation; growing point above soil surface; potential number of kernels per head determined between growth stage 3 and 4; may have lost 1 to 3 leaves from the bottom of the plant
4	GS2	35 – 50	Final leaf (flag leaf) visible in whorl; last 3 leaves may not be expanded
5	GS2	40 – 55	Booting; head extended into flag leaf sheath; potential head size has been determined
6	GS2	55 – 65	Flowering (bloom); 50% of plants flower
7	GS3	65 – 80	Soft dough; grain can be easily squeezed between the fingers; 8 to 10

			functional leaves; one half of the grain weight accumulated
8	GS3	80 – 90	Hard dough; cannot squeeze grain between fingers; three-fourths of the grain dry weight has accumulated
9	GS3	90 – 110	Physiological maturity; dark spot at the tip of the kernel; maximum total dry weight accumulated; grain has 25 to 35% moisture

Table 1. Grain sorghum developmental stages, approximate time intervals between growth stages (days after emergence, DAE) and identifying characteristics (Based on Vanderlip and Reeves, 1972, and Rao *et al*., 2004).

-
-
-

Bibliography

Anon. (1998). *Grain Sorghum Production Handbook*. Kansas State University Agricultural Experiment Station and Cooperative Extension Service, Kansas State University, KS, US. [Provides detailed information of management practices of sorghum in United States].

Maiti, R. (1996). *Sorghum Science*. Science Publishers, Inc., Lebanon, NH, USA. [Provides comprehensive knowledge of all aspects of sorghum].

Prasad, P.V.V., Pisipati, S.R., Mutava, R.N. and Tuinstra, M.R. (2008). *Sensitivity of Grain Sorghum to High Temperature Stress during Reproductive Development*. Crop Science, 48: 1911-1917. [Identifies flowering and 10 prior to flowering as most sensitive stages to short periods of high temperature stress].

Rachie, K.O. and Majumdar, J.V. (1980). *Pearl Millet*. The Pennsylvania State University, University Park, USA. [Provides comprehensive details on all aspects of pearl millet].

Rao, S.S., Seetharama, N., Kumar, K. and Vanderlip, R.L. (2004). *Characterization of Sorghum Growth Stages*. National Research Center for Sorghum, Rajendranagar, Hyderabad, India. [Describes growth stages and management guide at each growth stages of sorghum development].

Smith, C.W. and Frederiksen, R.A. (2000). *Sorghum: Origin, History, Technology and Production*. John Wiley & Sons, Inc., New York, USA. [Provides comprehensive monograph knowledge on all aspects of sorghum].

Vanderlip, R.L. and Reeves, H.E. (1972). *Growth Stages of Sorghum* [*Sorghum bicolor* (L.) Moench]. Crop Science, 64: 13-16 [Provides detailed description of growth stages of grain sorghum].

Biographical Sketches

P.V. Vara Prasad is an Associate Professor in Crop Ecophysiology in the Department of Agronomy at Kansas State University. He holds a PhD in Agriculture from The University of Reading, United Kingdom. His research mainly focuses on stress physiology of food crops and developing crop management strategies for efficient use of inputs. He teaches two graduate level courses: Crop Physiology and Advanced Crop Ecology. He has on-going international research programs in West Africa and India. Dr. Prasad has published more than 50 peer reviewed journal articles and book chapters, and served as a reviewer for more 20 different international journals. He was a former editor of Communications in Biometry and Crop Science and currently serves in the editorial board of African Journal of Agricultural Research. He is an active member of American Society of Agronomy, Crop Science Society of America, Soil Science Society of America, American Society of Plant Biology, and International Society for Agricultural Meteorology.

Scott A Staggenborg is a Professor of Cropping Systems in the Department of Agronomy at Kansas State University. He holds a PhD in Agriculture from Texas Tech University, USA. His current research focuses on designing efficient cropping systems and on the development of improved crop management practices to improve crop productivity. He has published more than 20 peer reviewed journal articles and several extension publications. He currently serves as an Associate Editor for Agronomy Journal and has reviewed manuscripts for several international journals. He is an active member of the American Society of Agronomy and Crop Science Society of America.