Global Journal of Agricultural Research
Vol.10, No.1, pp.91-100, 2022
Print ISSN: 2053-5805(Print),
Online ISSN: 2053-5813(Online)

Review on Key Bottlenecks of sorghum *(Sorghum bicolor L. Moench)* production and productivity

Netsanet Abera Muluneh[1] and Bewket Getachew Bekele [1]
[1]Ethiopian Institute of Agricultural Research, Pawe Agricultural Research Center, Pawe, Ethiopia

Citation: Netsanet Abera Muluneh and Bewket Getachew Bekele(2022) Review on Key Bottlenecks of sorghum (Sorghum bicolor L. Moench) production and productivity, Global Journal of Agricultural Research , Vol.10, No.1, pp.20-30

ABSTRACT: *Agricultural research has repeatedly failed to achieve the required effect for so many low-income farmers especially in Africa. Some of the reasons for the failure are due to knowledge gap of managing their crop production systems. As a result, there is a persistent need to look beyond the conventional farming system approach to increase production and productivity in sustainable ways. Farmers grow different crops for instance sorghum to win their day-to-day lives. Sorghum is an important cereal crop grown and consumed worldwide. In addition, its varieties are increasingly becoming very important and popular among resource-poor farmers due to their low cost. However, the production and productivity of sorghum is limited by key bottlenecks which could be referred as biotic and abiotic factors. Biotic factors, weeds, diseases, and insects are the most limiting factors which can lead to poor sorghum production and productivity. Unfavorable weather conditions can be considered as some of the abiotic factors. The combination of the two factors can result in a complete loss of yield. Therefore, it has become important to describe the key bottlenecks of sorghum production and productivity including management options.*

KEYWORDS: Sorghum, biotic and abiotic constraints, management options

INTRODUCTION

Sorghum biology

Sorghum (Sorghum bicolor L. Moench 2n=2x=20) is a tropical C4 plant belonging to the family Graminae [1]. This genus has many species and subspecies. There are several types of sorghum, including grain sorghums, grass sorghums (for animal hay and pasture), sweet sorghums, and broomcorn [2]. It is indigenous to Africa and Asia and is believed to have been domesticated in Sub-Saharan Africa particularly in the Nile basin from where; it spreads to other parts of the world [3]. Sorghum deviated from maize about 15 million years ago [4]. Because of its multiple purposes and its ability to survive unfavorable growing conditions, which is sometimes called a camel crop, sorghum will continue to feed the world's expanding populations [5]. It is the fifth major cereal crop in the world after wheat, rice, maize and barley [6]. Also, it is a subject of plant genomics research based on its importance as one of the world's leading cereal crops, a bio-fuel crop of high

Vol.10, No.1, pp.91-100, 2022
Print ISSN: 2053-5805(Print),
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and growing importance [7]. It has the ability to adapt to a wide range of environments and hence can be produced in the high lands, medium altitude and low land areas. Sorghum is widely produced more than any other crop, in the areas where there is moisture stress. In addition, sorghum will be the crop of the future due to the changing global climatic trends and an increase in the use of marginal lands for agriculture [8].

Economic importance of sorghum

World sorghum production is about 60 million tons annually from a cultivated area of 46 million ha. The most important producers are the United States, Nigeria, India, Sudan, Ethiopia, Burkina Faso, China, Tanzania and Niger [6]. More than 35% of sorghum is grown directly for human consumption and the rest is used primarily for animal feed and forage, alcohol production and industrial products [9]. It is of top importance that technological developments are used to increase productivity and sustainability of sorghum production and thereby provide a better quality of life for some of the poorest people on the continents of Africa, Asia and Latin America.

Sorghum performs relatively better than the other warm-season cereals in areas where the annual rainfall is in the range of 500-700 mm per year. It is an important crop even in East Africa where the average annual rainfall is greater than 700 mm per year. This importance result from the rain in sub-tropical Africa being irregular and characterized by brief periods of very high rainfall [10].

Major sorghum production bottlenecks

Sorghum crop is vulnerable to over 150 insect species from sowing to final harvest [11]. Grain sorghum yields are low, especially in African countries. These low yields of sorghum are attributed to a number of biotic stress and abiotic factors. The combination of these two important constraints to the production of sorghum accounts for over 2 million Ton per year of yield loss in Africa [12].

Abiotic constraints

The weather during the growing seasons appears to have an influence on sorghum production. Moreover, the lack of appropriate sorghum varieties that fit the current rainfall regime further contributes to reduced yield [13]. These and other abiotic factors hinder sorghum production leading to low yields.

Biotic constraints

Important Weed

Striga weeds

Striga is a major constraint in sorghum production, especially in Sub-Saharan Africa. At least two species of Striga that affect sorghum production are Striga hermonthica and Striga asiatica [14]. Striga hermonthica is the most important parasitic weed in sub-Saharan Africa and remains one of the most devastating biotic factors affecting sorghum production [15]. However, resistant sorghum cultivars that have been developed so far have shown a good level of resistance mainly based on low stimulant production [16]. Over the years, resistance could be broken and become susceptible suggesting the importance of continued efforts for developing resistance variety. Reports from [17] showed sorghum landraces as they are important sources of Striga resistant gens to develop resistant varieties. This could be a good opportunity to make further researches in the sorghum breeding program.

Important diseases

The major diseases which affect sorghum crops include Anthracnose, Zonate leaf spot, Grain mold, Turcicum leaf blight, and sorghum smuts.

Anthracnose

Anthracnose is an important fungal disease-causing substantial economic loss to yield. The disease was first reported from Togo in 1902 [18]. Then, it has been slightly distributed in most of the regions of the world where sorghum is grown. The disease mostly occurs in moderate to severe form on sorghum in Africa, India, and United States. Anthracnose can affect several plant parts causing symptoms for example seedling blight, leaf blight, and head blight. Leaf anthracnose affects photosynthetic photosynthesis up to 50% of losses or more. Under severe conditions, it may exceed beyond 80% on highly susceptible varieties [19]. The Infected mature stalks may develop reddish internal lesions that may be continuous or broken giving the stem a ladder-like appearance. The disease is most severe during extended periods of cloudy, warm, humid, and wet weather, especially when these conditions occur during the early grain-filling period [20]. The fungus can survive as mycelium in host residue, wild sorghum species, and some weeds and as conidia or mycelium on seed [21]. It can persist up to eighteen months in diseased residues on the soil surface however, the fungal mycelia survive for only a few days in the absence of residues [19].

There are known control methods that can be practiced with minimum cost. The best control method for anthracnose is the use of resistant cultivars. Cultural practices such as crop rotation with a species other than a host offer reasonable control [19]. Clean cultivation, elimination of crop residues and grasses on which the fungus can survive, and enhancement of the conditions that hasten the decomposition of host residues have also been used to control the disease [20], [21].

Zonate leaf spot

Zonate leaf spot is a common foliar disease of sorghum that is caused by Gloeocercospora sorghi. The incidence of this disease is highest in fields where grain sorghum or its close relatives are frequently grown [22]. The diseases can have a significant effect on grain sorghum yield. The fungus is dispersed by rain and water causing severe attacks in wet periods. It overwinters in sclerotia in soil and in infected plant debris. Symptoms of the disease are often described as very large which may extend 3 to 8 cm circular lesions that have alternating straw-colored and purple rings [23]. However, many of the initial lesions are purple blotches that may have light irregularly shaped spots in the centers. During warm wet periods, pink to salmon-colored spores may be visible on the lesions. It is known that lesions can appear within 12 hours after infection with purple blotches developing within 24 hours of infection [12], [22].

The disease pressure is reduced by practicing crop rotation and cultivation to control susceptible weed hosts for example johnsongrass and other weeds. Growing resistant varieties to the disease can be a possible solution to control it [24].

Grain mold

Grain mold is a major disease of rainy season sorghum and is common in many countries in Africa, Asia, North and South America. The disease is severe in Africa and Asia where white grain sorghum is more widely grown [25]. Improved short and medium-duration sorghum cultivars that mature during the rainy season in humid, tropical, and subtropical climates suffer more. Late-maturing photoperiod-sensitive sorghums generally escape grain mold as they flower and fill grain during dry weather [26], [27]. Production losses can go up to 100% depending on the cultivar and prevailing weather. Grain mold reduces the seed value of grain, the nutritive value of food and feed, and the cooking quality of the grain. Molded grains often contain mycotoxins some of which are harmful to human, animal, and poultry birds. Symptoms of grain mold vary with the severity of infection and grain development stages [28].

The first visible symptom is the pigmentation of spikelet tissues including sterile lemma, palea, lodicules, and glumes. In the case of severe infection anthers and filaments also develop symptoms of fungal colonization. Infection at anthesis results in the loss of caryopsis formation, blasted florets, poor seed set, and the production of small, shriveled grains. Under humid conditions, the pathogen grows quickly and may cover the entire grain with fungal growth before physiological maturity. The severely infected grains become soft and disintegrate [28]. The most obvious sign of mold infection on mature grain is the appearance of pink, orange, gray, white, or black mycelium on the grain surface. Discoloration of grain is more projecting on white grain than on brown/red grain sorghum [27].

There are some management options to reduce the effect of grain mold on yield. Colored grain sorghum varieties are getting less attack from this disease [27]. Crop rotation, timed planting and harvesting, drying the harvested panicles under natural air for three to five days, harvesting crops at the right maturity time and avoiding over-drying. Preventing insect damage to the stored products also can help the products not to be exposed. Finally, monitoring sorghum grain at all production, processing and storage stages is advisable for general control [25].

Turcicum leaf blight

Turcicum leaf blight is highly destructive and extremely affects sorghum grain and fodder yield as well as fodder quality [29]. It is caused by several fungi, including Exserhilum turcicum, and is widespread in many parts of the world [30]. The Disease development is favored by moderate temperatures which are averaged from 20° to 27°C and heavy dews or rain during the growing season. The disease can make its appearance early in the season and continue to develop throughout the growing season unless retarded by dry weather. If the disease becomes established on susceptible cultivars before panicle emergence, yield losses can approach 50 percent [29]. Turcicum leaf blight symptoms are characterized by the presence of long, elliptical, and necrotic lesions on the leaf lamina. The center of the lesion is straw in color and the margin is usually dark brown or tan lesion. These lesions can be 12 mm wide and 2.5 to 15 cm long [23].

The disease is controlled by the use of resistant cultivars and by rotation. However, rotation is made less effective if infected grasses persist in fields or in field margins [22]. The development of resistant varieties is the most economically feasible solution for disease management. Use of good-quality healthy seeds, crop rotation or intercropping with nonhost crops, clean cultivation before and after planting, cultural practices like adjusting dates of sowing, and proper tillage reduce leaf blight incidence [31]. Destruction of weeds, volunteer, wild sorghum, and alternate hosts help to reduce primary inoculum. Need-based use of fungicides with the right dosage and at the right time is beneficial. However, the use of disease-resistant cultivars is thought to be the best option [23], [32].

Insects

Sorghum midge

The sorghum midge is a widely distributed sorghum insect pest and one of the most damaging in Africa and the southern United States [19]. It occurs in almost all regions of the world where the crop is grown, except Southeast Asia. The adult sorghum midge is a 1.3 mm long, fragile-looking, orange-red fly, with a yellow head, brown antennae and legs, and gray membranous wings [33]. During the single day of adult life, each female lays about 50 yellowish-white eggs between the glumes of flowering spikelets of sorghum. The cylindrical eggs are 0.1 to 0.4 mm long and hatch in two to three days. When the adult emerges, the clear pupal skin remains at the tip of the spikelet [34]. The pupal period is completed in three days, whereas a generation is completed in 14 to 16 days. The insect's rapid development permits multiple generations to occur during a season and results in high infestation levels when sorghum flowering times are extended by a wide range of planting dates or sorghum maturities [19]. Sorghum midge diapause to overwinter as larvae in coverings in spikelets of host grasses, entirely sorghum and johnsongrass. The insect increases in abundance as the season progresses, especially if flowering sorghum continues to be available and decreases later in the season [35].

Damage to sorghum is caused by sorghum midge larvae feeding on the newly fertilized ovary, preventing kernel development and resulting in direct grain loss that can be great. Glumes of a sorghum midge-infested spikelet fit tightly together because no kernel develops. Typically, a sorghum panicle infested by sorghum midge will have various proportions of normal kernels scattered among non-kernel bearing spikelets depending on the degree of damage [35], [34].

Regarding monitoring, the presence of adults must be determined when assessing sorghum midge abundance in a field. To do this, fields should be inspected at midmorning when the temperature reaches approximately 30^{o}C. This is the peak time that sorghum midge adults are most abundant on flowering sorghum panicles because adult sorghum midge lives less than one day, each day new brood is present. This fact requires sampling almost daily during the time sorghum panicles are flowering. Sorghum midge adults can be seen crawling on or flying about flowering panicles. The simplest and most efficient technique for detecting and counting sorghum midge is careful, close inspection of all sides of randomly selected flowering panicles [36].

Concerning management, effective control of sorghum midge requires the integration of several practices to avoid and reduce sorghum midge abundance [36]. Early and uniform planting of sorghum, in a place where midge is problematic, is the most effective cultural management method to control midge. Planting varieties with uniform maturity early prevents the late flowering of

Vol.10, No.1, pp.91-100, 2022
Print ISSN: 2053-5805(Print),
Online ISSN: 2053-5813(Online)

panicles and avoids damaging infestations [19]. Cultural practices that promote uniform panicle exertion and flowering in a field also are important in sorghum midge management, in making treatment decisions, and in achieving acceptable levels of chemical control. Removing johnsongrass inside and outside the field with cultivation and/or herbicide applications also will help suppress the sorghum midge population. Deep plowing sorghum residue will also help kill some overwintering larvae, which will be reducing sorghum midge infestation in the next year. The use of resistant sorghum variety to sorghum midge provides an additional management tool [35].

The last option is the application of insecticide treatment depending on the number of adult sorghum midges during the sorghum flowering period. If adults still are present three to five days later, immediately apply a second insecticide treatment. Several insecticide applications at three-day intervals may be justified if sorghum midges are abundant [19].

Shoofly

The shoofly is a leaf-feeding insect that causes considerable losses of sorghum in most parts of Africa. It attacks sorghum from 5 to 25 days after seedling emergence It lays white elongated cigar-shaped eggs on the lower surface of the leaf [19]. Maggot emerges from the egg in two days, reaches the central whorl, cuts the central leaf, starts feeding on the decaying leaf tissue of the central whorl and damages the sorghum crop during the seedling stage. As a result, the central whorl dries off resulting in a typical deadheart [11]. It completes its life cycle in 17–21 days [37]. Many approaches have been used to minimize the losses caused by shoot fly, including agronomic practices, natural enemies, synthetic insecticides, and host plant resistance [37], but the implementation of all these practices is not always feasible. Stem borer larvae consume the leaf whorl after penetrating the main leaf veins. They then tunnel down through the upper part of the stem above the top node and feed on the stem pith. Subsequent desiccation of the central leaves results in dead heart formation and gives the plants a bushy appearance. This insect can complete 2 to 3 generations in a single cropping season [38], [37]. Most genotypes can escape the insect infestation if early planted.

Stalk borer

The stalk borers are an important constraint and often key insect pests of sorghum in other areas of the world. Several species of stem borers have been reported as pests of sorghum in different regions. The stem borer infestation is indicated by the appearance of small elongated windows in young whorl leaves where the young larvae have eaten the upper surface of the leaves. Later, the plants present a ragged appearance as the severity of damage increases [19]. The third-instar larvae migrate to the base of the plant, bore into the shoot, and damage the growing point resulting in the production of a deadheart. Normally, two leaves dry up as a result of stem borer damage. Larvae continue to feed inside the stem. Throughout the crop growth, extensive tunneling in the stem and peduncle leads to drying up of the panicle, to a partially chaffy panicle, or to peduncle breakage. Stem borer infestation starts about 20 days after seedling emergence, and deadhearts appear on 30-40-day-old crops [39]. Spotted stem borer, Chilo partellus is common in Asia and eastern and southern Africa. A female can lay up to 500 eggs in batches of 10-80 near the midrib on the undersurface of the leaves. Eggs hatch in 4 - 5 days. The larvae move to the leaf whorl and feed on tender leaves resulting in leaf scarification and shot-holes. Third-instar larvae move to the base of the plant and bore into the shoot [19].

The damage to the growing point results in the production of a typical deadheart [40]. During the off-season, the larvae undergo diapause in plant stalks and stubbles. With the onset of rains, the larvae pupate and the adults emerge in 7 days [39]. The following control options: use of resistant variety, cultural, mechanical, and physical control are very important. The best option is the use of resistant variety to stem borer. Early seedbed preparation before planting reduces extreme damage. Field sanitation (removal of vegetation such as common grasses) can limit overwintering insect pests. The use of chemical control should be the last option to control the stalk borer [41], [39].

Storage Pests

Sorghum is normally more susceptible to insect attack in storage than other grain crops because of its exposed nature of seed [42]. Insects that damage sorghum during storage are polyphagous, and some insect pests of stored products can attack the grain in the field and continue feeding in the warehouse. Storage pests for example weevils, lay eggs inside seeds while moths oviposit on the grain surface [43]. The short life cycles of many storage pest species and their ability to produce multiple generations per year enable them to cause high losses, especially in warmer climates [19]. Feeding of the insects on sorghum results in perforated, crushed kernels, and weight loss. Besides causing grain weight loss, larval feeding inside seeds causes reduced seed viability. The loss of dry matter as the result of damage by insects in sorghum reduces ethanol yields and also can affect the milling quality of the kernels and physicochemical properties of the flour [43].

To minimize the losses due to storage pests, sanitation is crucially important to reduce the initial pest population and prevent the development of any insect pests in crop products. Before bringing a new crop into the store. Cleaning and removing infested materials, preventing mixing of new grain with old during storing, fumigating the storage materials with insecticide, use of resistant varieties are very important measures for controlling these pests. Sorghum varieties where the glumes cover the grain tend to be more resistant before threshing [44], [45].

CONCLUSION AND RECOMMENDATIONS

Agriculture plays an important role in the development of the economy through its impact on the overall economic growth, households' income generation and food security. Thus, crop improvement and increasing production and productivity using different techniques are vital. Production, productivity, and grain and forage quality of sorghum are adversely affected by many constraints worldwide. Among the key constraints of sorghum production are losses resulting from poor management. Sorghum is still important and may be considered as a substitute food and cash crop. Taking into account the challenges that the globe is faced, it is predicted that different approaches will have the potential for increasing sorghum production and productivity. Of these, maintain and strengthen the development of new, well-adapted sorghum cultivars with high yield potential and the genetic capacity to withstand major biotic and abiotic stresses is very important.

There should be a need to continue the breeding efforts, and strengthening the national research institutions in the use of modern plant breeding approaches and methodologies in developing resistant varieties as well as the use of integrated pest management practices to tackle the crop production bottlenecks. This review paper can help researchers, breeders, university students, large and small-scale farmers to take it as a reference on their respective crop breeding and production program.

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Vol.10, No.1, pp.91-100, 2022
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