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Cereal production in Africa: the threat of certain pests and weeds in a changing climate—a review

Joshua Benjamin[1*], Oluwadamilola Idowu[2], Oreoluwa Khadijat Babalola[3], Emmanuel Victor Oziegbe[4], David Olayinka Oyedokun[4], Aanuoluwapo Mike Akinyemi[5] and Aminat Adebayo[6]

Abstract

Cereals are the most cultivated and traded crops for food, feed, and industrial uses worldwide. Among other producing regions, Africa hosts 27% of the world's total cereal production. Like other staple crops, the production of cereals such as maize, rice, wheat, millet and sorghum in Sub-Saharan Africa is threatened by herbivorous pests and weeds leading to significant losses. The fall armyworm insect (*Spodoptera frugiperda*) reduces maize production by 21–53%, while the stem borers (*Busseola fusca*) account for 82% of all maize losses in Kenya. About 50% of yield loss in maize has been attributed to *Imperata cylindrica* infestations in Nigeria if not controlled. Parasitic weeds such as *Striga spp.* infest over 64% of cereal-cultivated lands in Africa resulting in yield losses of up to 10–100% loss. Granivorous birds such as *Quelea spp.* are responsible for an average of 15–20% cereal production damage in semi-arid zones of Africa. Rodents such as the multimammate rat also pose a threat causing 48% yield losses on maize fields across Sub-Saharan Africa. With a changing climate resulting in drought and flooding, the threat of these cereal pests is likely to intensify. Hence, this review presents an elaborate overview of current pathogens whose threat to cereal production in Africa might increase due to changing climatic conditions.

Keywords Cereals, Biotic threats, Insects, Weeds, Rodents, Sub-Saharan Africa

Introduction

Africa is a continent known for its blend of tropical, semi-arid and arid vegetation with varying climate conditions covering an area of more than 30 million km^2 and is second in size only to Asia [1]. It is home to the world's second-largest extent of continuous rainforest, the Congo Basin and the Namib desert. Its characteristic predictable weather, diverse soil types and rich vegetation cover make it very suitable for cultivating and producing many stable crops, such as legumes, cereals, tubers, vegetables and fruits [2]. However, its relatively humid and arid climate across different agricultural regions creates a convenient environment for diverse pests and pathogens of crops to thrive. These pests and pathogens, as biotic stressors, are considered great threats to plant health and might include various living organisms, such as fungi,

*Correspondence:
Joshua Benjamin
joshua.benjamin@stud.uni-goettingen.de; benjaminjoshua1997@gmail.com
[1] Max Planck Institute of Immunobiology and Epigenetics, Stübeweg 48 Zimmer 1, 79108 Freiburg im Breisgau, Germany
[2] International Institute of Tropical Agriculture, Ibadan, Nigeria
[3] Department of Plant Breeding and Seed Technology, Federal University of Agriculture Abeokuta, Abeokuta, Nigeria
[4] Department of Crop Protection and Environmental Biology, University of Ibadan, Ibadan, Nigeria
[5] Crop and Horticulture Department, University of Ibadan, Ibadan, Nigeria
[6] Department of Agricultural Extension and Rural Development, University of Ibadan, Ibadan, Nigeria

bacteria, viruses, nematodes, herbivores, parasitic plants, and weeds [3]. These biotic factors individually or synergistically impact plants' normal development and productivity, subjecting them to stresses that make them more vulnerable [4]. For example, plant bacteria and viruses cause localized and systemic harm that results in chlorosis and stunting [5]. Parasitic microbes such as nematodes feed on plant tissue and are the main source of soil-borne illnesses that result in nutritional deficiencies, stunted development, and wilting [6]. By feeding on plant tissues, herbivores such as insects, mites, birds, and rodents induce substantial damage to crops by inhibiting plant growth [7]. Parasitic plants such as mistletoe, dodder, and witchweed attach themselves to host plants and tap into their vascular systems to obtain nutrients, further impacting the host plant's growth and productivity [8]. Weeds compete with crops for resources, reducing yields and increasing management costs [9]. Global agricultural production is severely impacted by these biotic stressors (pests and diseases) which cause estimated losses of up to $220 billion annually [10]. With a world population, there is increased pressure to improve crop yields and production [11], and biotic stress management will become even more crucial.

All staple crops in Africa are affected by many plant pathogens and the cereal family is not exempted from their impact. Belonging to the grass family (Gramineae), cereals are plants cultivated for their edible seeds [12]. More cereal grains than any other type of crop are produced worldwide and offer more dietary energy. Hence, they are referred to as staple crops [13]. The majority of crops cultivated and traded historically for food, feed, and industrial uses across the world were cereals in their wide category [14]. Globally, 6,006 million acres of land were used to harvest 2.719 million tonnes of grains in 2019. On total cropland, these amounts correspond to a respective 60% and 50% of the world's food output [14]. Among other producing regions, Africa plays host to 27% of the world's total cereal production [14]. The northern African region is predominantly involved in wheat production while the eastern and southern regions recognizably produce large quantities of maize and millet [15]. However, Ethiopia, Nigeria and Egypt are the top 3 highest-producing cereal countries in Africa (Fig. 1).

Nutritionally, cereals are rich sources of carbohydrates, dietary fibre, vitamins, and minerals [16] and serve as major components of diets in Africa. For example, maize is a good source of thiamine, niacin, and folate, while sorghum is rich in iron and potassium [17]. Rich in calcium, magnesium, and zinc, millet is a relatively important cereal as well as rice, which is a good source of B vitamins and iron [18, 19]. Various cultures and communities in different regions of Africa are notable global producers and consumers of diverse cereals, such as maize,

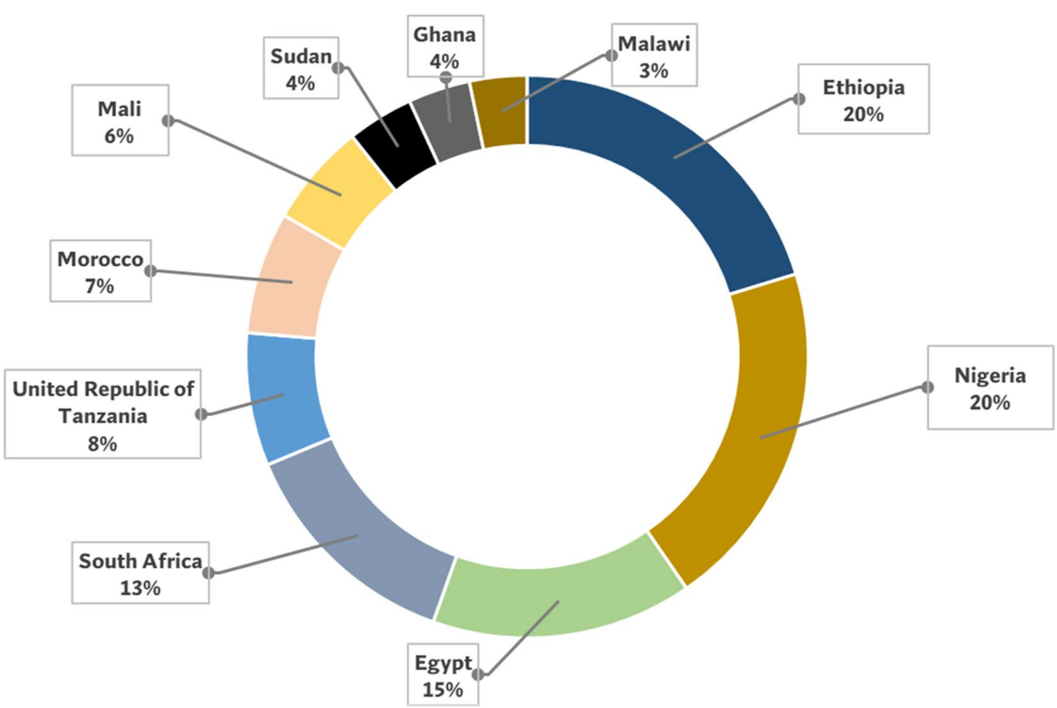

Fig. 1 Top 10 producing countries of total cereal in Africa. In terms of total production of cereals in Africa, Ethiopia and Nigeria are leading. Source [14]

sorghum, millet, rice and wheat [15]. Each of these cereals has unique nutritional and culinary characteristics that make them suitable for various purposes [20]. Cereal grains are mashed in tropical Africa and used to make thick porridges, called by diverse names across the continents. One of these thick porridges, known as fura, is a semi-solid dumping cereal meal that is popular in West Africa, notably in Nigeria, Ghana, and Burkina Faso [21].

Maize (*Zea mays*), Africa's most widely grown cereal, is used for various purposes (Fig. 2) [13]. In East and Southern Africa, maize is the primary staple food and is consumed in multiple forms, including maize flour, meal, and porridge [17]. In West Africa, maize is also a staple food, but it is often consumed as a snack in roasted or boiled maize cobs [22]. Maize is also used as a source of animal feed, an essential ingredient in producing beer and other alcoholic beverages [23]. Sorghum (*Sorghum bicolor*) is the second most-grown cereal in Africa, particularly in arid and semi-arid regions. Sorghum is used as a source of food for humans and animals [24, 25]. In East Africa, sorghum is used primarily to produce a traditional alcoholic beverage known as "chang'aa," while in West Africa, it is used to produce a popular beer known as "dolo". Sorghum is also used as a source of syrup and animal feed [26]. Millet (*Pennisetum glaucum*) is another cereal widely grown in Africa, particularly in the Sahel region. as a source of food for humans and livestock, and it is often consumed as porridge or a side dish [27]. Millet also produces a traditional alcoholic beverage known as "tchapalo" in West Africa. Rice (*Oryza* sativa) is widely grown in Africa, particularly in West Africa. It is used mainly as a staple food and is often consumed with a stew or sauce [26, 28]. Rice is also used to produce a variety of traditional dishes, including jollof rice, biryani, and paella [29]. Wheat (*Triticum* spp.) is also grown in Africa but is not as widely consumed as other cereals. Wheat mainly produces bread, cakes, and other baked products [30]. It is also used to make pasta, couscous, and bulgur. Wheat straw is used as a source of animal feed [31]. Barley (*Hordeum vulgare*) is another cereal grown in Africa, although it is not as widely consumed as other cereals. Barley is mainly used in the production of beer and other alcoholic beverages [32]. Fonio (*Digitaria exilis*) is a lesser-known cereal that is native to West Africa. It is used mainly as a food source for humans, and it is often consumed as porridge or a side dish [33].

The economic impact of pests and weeds on cereal production in Africa is significant. These losses can be attributed to reduced yields, quality, and marketability of cereal crops, as well as increased costs associated with disease and pest control measures [34]. Annual cereal grain losses associated with *Striga hermontica* across Africa are about 4.1 million metric tonnes [35]. With fewer resources and technology at their disposal, smallholder farmers, who make up most cereal producers in Africa, are particularly vulnerable to biotic stresses [36]. For example, a study indicated that without any control measures in place, the fall armyworm can lead to a significant reduction of approximately 21–53% in annual maize production [37]. This reduction would result in economic damages ranging from US$2481 to US$6187 million across 12 African countries that cultivate maize, which include Nigeria, Ghana, the Benin Republic, Zambia, Ethiopia, Cameroon, etc. [37]. Rodents, such as rats and mice, can also cause significant damage to stored

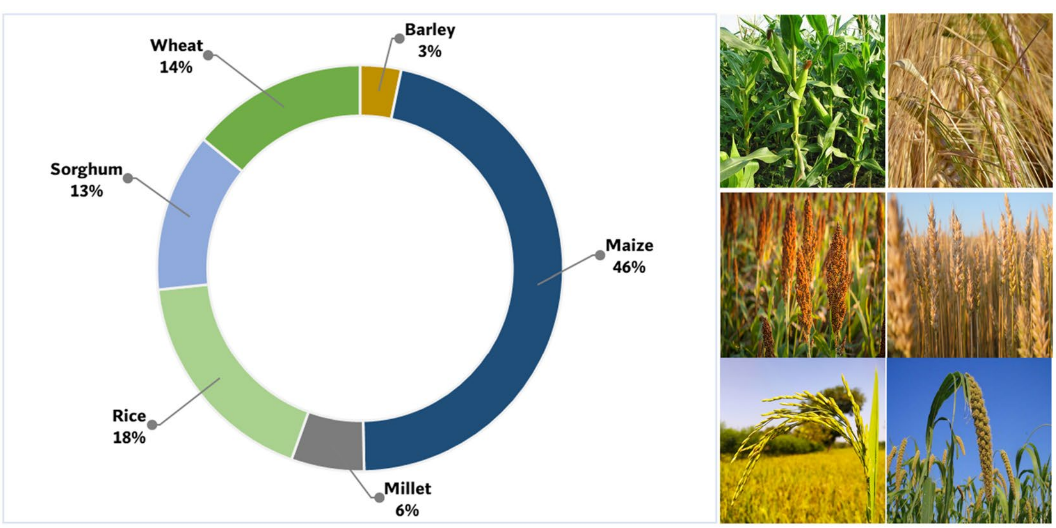

Fig. 2 Percentage production of different cereal crops in Africa. Maize is the most cultivated and produced cereal crop Source [14]

cereal grains [38], leading to post-harvest losses and reduced marketability.

Hence, the issue of pests and weeds is critical across all regions of Africa. The severity of this issue is exacerbated by several factors, such as the quick spread of pests, climate change, and the lack of effective control measures. This review provides a robust overview of the immediate threats posed by biotic stress on cereals in Africa's tropical climate. Through an analysis of the most recent scientific research, we have identified the major pests affecting cereals in this region and explored the underlying causes of their spread. By understanding the challenges posed by biotic stress on cereals, effective and sustainable strategies for reducing its impact on agricultural production, can be developed. Ultimately, this will help to ensure food security and enhance the livelihoods of farmers in Africa's tropical climate.

Insects threatening African cereal production

Insects are the leading cause of crop losses in cereals around the world. According to Saldivar and Garcia-Lara, the direct losses are proportional to the quantity of dry matter consumed by insect pests. Insect pests have a negative impact on crop productivity; some pests may even destroy the entire crop, resulting in a complete loss of crop yield. In addition to reducing agricultural yield, pests can also impact crop yield quality [39]. Losses attributed to insect pests have been documented to vary considerably across crops and regions of the world [40]. Based on estimates by the Food and Agriculture Organization of the United Nations (FAO), about 40% of global crop production is lost annually due to insect pests. Annually, plant health issues account for a global economic loss of over $220 billion [10]. Among all other staple crops, cereals such as maize, sorghum, wheat, millet, and rice are threatened by several voracious insect pests including stemborers, aphids, planthoppers, thrips, armyworms, and termites in Africa [41]. Another FAO report estimates that insect pests cause 19–30% of global cereal losses [42]. Globally, 18–20% of annual crop productivity is destroyed by arthropods at a cost of more than $470 billion [43]. Approximately 13–16% of losses occur in the field, with greater losses in developing nations [43].

Stemborers

Stem borers represent the most prevalent and damaging group of insect pests of cereal crops. They are widely recognized as one of the limiting factors of cereal production around the world. They are present in the field from the time the crop germinates until it reaches maturity. Most stem borers on cereal crops in Africa are lepidopterans and dipterans. Stem borers cause havoc on cereal crops including rice, sorghum, maize, and millet. The most detrimental developmental stage of the pest is the larval stage [44]. Several species of stem borers have been reported as causing severe damage to cereal crops in Africa. The maize stalk borer, *Busseola fusca*, has an economic impact on maize and sorghum while maintaining its population on alternative hosts. In addition, the spotted stem borer, *Chilo partellus*, is regarded as one of the most destructive stemborers of sorghum and maize [44], it also causes extensive damage to rice in some African nations. According to Togola, et al., the African striped rice borer, *Chilo zacconius*, is one of the most prevalent rice stem borer species in humid forest and savanna zones. The pink stem borer *Sesamia calamistis* is generally less significant as a pest of cereal crops in Africa than *Busseola fusca* and *Chilo partellus* but may be locally abundant. Its primary hosts are sorghum, maize, and rice. In the past, *Eldana saccharina* appeared to be a minor insect pest in Africa, except for sugarcane. In several African nations, however, it has recently become more significant in other crops such as maize, rice, and sorghum [44]. In South Africa, *B. fusca* and *C partellus* are the only important stem borers of maize and sorghum [46]. In East Africa, *C. partellus*, *E. saccharina*, *B. fusca*, and *Sesamia calamistis* have been identified as important and widely distributed maize and sorghum stem borers [45]. In West Africa, *Chilo zacconius* and *S. calamistis* are the most economically significant stem borers of rice [46]. For example, stem borers are generally responsible for sorghum yield reductions and losses range from 50% to 60% in Southern Africa, 15% to 88% in East Africa, and 11% to 49% in West Africa [47].

Originating from Asia and considered the most devastating pest of maize and sorghum in eastern and southern Africa, the spotted stem borer *Chilo partellus* (Swinhoe) (Lepidoptera: Crambidae) is quickly spreading out into higher altitudes from warmer lowlands across different national borders within Africa [48]. First reported in Malawi, this cosmopolitan pest has expanded its invasion into other maize-producing countries, such as Tanzania, South Africa, Ethiopia, Mozambique, Uganda, and Zimbabwe [46]. In these countries, the 3-week life cycle and shorter diapause time of *C. partellus* give it a competitive advantage causing it to displace native stem borers, such as *B. fusca* and *C. orichalcociliellus* [46]. Boring its way into the stem, the larvae initiates feeding leading to the formation of stem tunnels which impact grain filling and yield. Damage to the crop is usually two weeks after the emergence of seedlings and continues until harvest. Under drought conditions of less biomass, the losses caused by the spotted stem borer are more severe and devastating [49].

On the other hand, the African maize stem borer *Busseola fusca* (Fuller) (Lepidoptera: Noctuidae) is renowned as the most destructive insect pest of maize and sorghum in Africa [50, 51]. Females lay 100 to 800 flattened eggs in bathes on leaves which then hatch after one week. Migrating into the whorl, they begin feeding on tender leaves within the whorl alone; differentiating them from other stem borers like those in the *Chilo* genera. Upon development, the larvae, at the 4th instar stage, move down to the lower regions of the plant to penetrate the stem from beneath [51]. Their feeding activity creates tunnels while destroying meristematic tissues; at the same time, the larvae ensure that an exit is created to facilitate its emergence as an adult after 30–45 days of pupation. Consequently, symptoms of damage include weakened stems which can easily break during severe wind intensities, plant stunting as a result of the disrupted process of translocation of dissolved nutrients, immature senescence of young leaves, reduced grain quantity and possibly the death of the plant during high infestation [46, 52]. *B. fusca* is found in every part of Sub-Saharan Africa except Zanzibar and Madagascar [51, 53]. Irrespective of the agro-ecological zone, whether it is at sea level or up the highlands (at a maximum of 1500 m above sea level), or from the humid forest to the dry savannah zones, *B. fusca* is predominant in maize/sorghum fields [51]. Apart from its main host crop, *B. fusca* also attacks more than 15 species of wild grasses such as *Panicum maximum*, *Cynodon* and *Echinochloa* species which are competitive weeds to cereals. Hence, many generations of *B. fusca* can be sustained on these alternate hosts, making them more dangerous over time and difficult to control [51]. Crop losses due to *B. fusca* significantly vary across various regions of Africa. On average, about 14% losses have been observed in maize fields in Kenya. Monocropping systems of maize fields in the humid forest zones of Cameroon have experienced up to 40% estimated losses [54].

Feeding and stem tunnelling by borer larvae causes crop losses due to destruction of the growing point, early leaf senescence, interference with metabolite translocation, malformation of the grain, stem breakage, and plant stunting [55]. Stemborer infestations result in yield losses ranging from 10% to 88% [46], of the potential grain yield, depending on pest population density and the phenological stage of the crop at the time of infestation. In Sub-Saharan Africa, stem borers can cause 20–40% crop loss during cultivation and 30–90% crop loss post-harvest and storage [55]. How much damage is caused by the stem borer depends on the borer species, the plant's growth stage, the number of feeding larvae, and the plant's response to the feeding. In Ghana, yield losses yield loss as high as 40% have been attributed to *B. fusca* infestations while 22–25% damage by the pest has been recorded in late-planted maize in Tanzania [56]. Yield losses of 12% for every 10% of plants infested were reported in Tanzania and Kenya [57]. In Kenya, *B. fusca* accounted for 82% of all maize losses [58].

Fall armyworm

Spodoptera frugiperda (Lepidoptera: Noctuidae), also called the fall armyworm (FAW), is an insect pest that is native to the Americas. In the last four years, it has invaded and spread all over Sub-Saharan Africa [59]. The fall armyworm invaded Africa for the first time in early 2016, specifically Nigeria, Sao Tomé, and Principe [60]. Since it was introduced, FAW has become a serious threat to the productivity of cereal crops, such as maize and sorghum, which are two of the most important staple foods for smallholder farmers. This threatens food security in Africa [61], and it is also a serious threat to food and nutrition security [59]. It then spread to other African countries, such as Kenya, Uganda, Rwanda, Ethiopia, and Tanzania. By April 2018, FAW had taken over and spread throughout Sub-Saharan Africa and Sudan [62]. FAW has recently been found in Egypt [63]. The fact that FAW is in North Africa makes it much more likely that FAW will spread to Europe through migration. FAW has also taken over several countries in Asia and Australia [64, 65]. As a polyphagous pest that attacks many food crops and forages [66], the FAW larvae have voracious appetites and cause serious damage to plants [37]. Eggs oviposited by the female moth on the distal side of the maize leaf hatch into the first and second instar larvae which start feeding on that leaf, crawling their way into the leaf whorl, still feeding, leading to the unfurling of leaves and eventually, extensive defoliation. As plants mature, FAW larvae often start feeding on the ear. Finally, the larvae pupate in the soil. Pupation lasts 8–30 days until the adults emerge [67]. If conditions are suitable, the life span of adult moths can be up to 14 days during which they migrate to distant new areas. In warm climates, FAW completes its entire life cycle in 3 to 4 weeks, but in cold climates, it takes considerably longer [67]. However, in contrast to other lepidopteran pests, prolonged freezing temperatures are a threat to the survival of FAW. Without any proper management in Africa, crops such as maize, sorghum and rice can be severely ravaged by FAW with possible economic losses of around $13 billion annually [37].

The outbreak of FAW is a major setback in Africa as it causes enormous damage to maize crops, the prime staple food for more than 300 million farmers in Africa [37, 68]. Current estimates from 12 African countries suggest an annual loss of 4.1–17.7 million tons of maize due to FAW [69]. Farm-level estimates from Ghana and

Zambia suggest a yield loss of 22–67% [37], 47% in Kenya [70] and 9.4% in Zimbabwe [71] due to FAW infestation. About 9.6 million maize-producing smallholders in Ethiopia are threatened by repeated outbreaks of the FAW. Recent reports propose that a quarter of the 2.9 million ha of land cultivated for maize production is plagued by FAW, resulting in huge losses of about 134,000 tons of maize [72]. Such losses could have fed about 1.1 million individuals. In addition, fall armyworm damage on sorghum has been reported in Burkina Faso, Mali, Northern Nigeria, Niger, and Chad. Infestation in the whorl of sorghum can reduce grain yields by 55–85%. Hence, FAW has been jeopardizing food security throughout Africa [60], where it poses a serious threat to food and nutrition security [59].

Rice gall midge

The African rice gall midge, *Orseolia oryzivora* Harris and Gagne, (Diptera: Cecidomyiidae), is considered the most destructive insect pest of lowland and irrigated rice [73]. Native to Africa, and first reported as a minor pest in Sudan, it has become a major pest widespread in countries, such as Nigeria, Sudan, Niger, Senegal, Benin, Burkina-Faso, Gambia, Guinea, Malawi, Mali, Sierra Leone, Togo, Tanzania and Zambia [74]. *O. oryzivora* larvae mainly attack the tillers during the vegetative stage of rice and destroy the growing primordia. Long cylindrical and silvery-white galls are formed aftermath of larval infestations preventing the development of more leaves or panicles from the infested tillers [75]. As little as a 1% increase in infestation can cause a 2.9% yield loss in rice. Severe infestations of *O. oryzivora* in rice fields induce 20–100% yield losses [76]. In 1988, a major outbreak of the insect pest in the savanna zone of Nigeria resulted in 45–80% disease incidence and severity followed by massive yield reductions in some rice fields. Subsequent outbreaks began to occur frequently in major rice-growing areas of Nigeria, Burkina Faso and Mali [74]. In Burkina-Faso, about 70% of damage to rice tillers has been reported in its western and southwestern regions where weather conditions are favourable and rice plants are extensively cultivated (Table 1) [77].

Weeds threatening African cereal production

A plant that grows where it is not wanted is a weed. Weeds have the potential of causing up to 34% loss or more in yield and quality [3]. The destruction caused by weeds is through competition for space and soil nutrients, harbouring of pests and serving as a reservoir for pathogens [3]. Among the major constraints that affect crop productivity, weeds are the most destructive [86]. The level of destruction caused by weeds to cereal yield and quality depends on many factors, including density, species, distribution, availability of resources and management practices [87]. In Africa, Some of the common weeds that affect cereals in Africa are witchweeds (*Striga spp.*), spear grass (*Imperata cylindrica*), the purple nutsedge (*Cyperus rotundus* L.), bermudagrass (*Cynodon dactylon* L. Pers.), goosegrass (*Eleusine indica* L. Gaertn.), and crabgrass (*Digitaria spp.*) [87]. *Striga spp.*, commonly called the witchweeds, is regarded as the most challenging weeds in Sub-Saharan Africa [88]. In Africa, the species are about 23 in number [87] including *Striga hermonthica*, *Striga asiatica*, *Striga gesnerioides*, and *Striga asperata* [89]. They cause devastating losses in maize, rice and millet [90]. Popularly called speargrass in Nigeria, *Imperata cylindrica* is a noxious weed that is invasive and fire-resistant [80]. It is an important weed of rice and maize. Other weeds such as the bermudagrass, the purple nutsedge and the jungle grass *Echinochloa colona* are also potential weed threats to different cereals in Africa given the drastic climate change events. This review looks at both non-parasitic and parasitic weeds which are the most destructive weeds of cereals in Africa.

Grassy weeds

Non-parasitic weeds are considered those that compete with the crops without relying on the host for survival. Three important grassy weeds of major concern globally which could become a much more serious threat to cereal production in Africa include the spear grass, the Bermuda grass, the purple nutsedge and *Echinochloa* weed species.

The spear grass, *Imperata cylindrica*, is a dominant tropical grass native to Southeast Asia and East Africa with wide distribution in tropical zones of Asia, West Africa, and Latin America [91]. In West Africa, it extends from Senegal to Cameroon stretching into the arid parts of Sudan. Similarly, large stands of *I. cylindrica* have been observed from Egypt to Ethiopia [92]. Propagation is by seeds (for long-distance dispersal and colonization) and vegetatively by rhizome extension (for short-distance dissemination and population expansion). This gives it a high competitive advantage, for nutrients (especially phosphorus, nitrogen and potassium) and water resources, over many crops including two of its main hosts—maize and upland rice [93]. An estimated 50% yield loss in maize has been attributed to spear grass infestations in Nigeria if not controlled. Similarly, another report has shown that without a minimum of four weeding cycles, massive reductions in maize yield are likely to occur in derived savanna areas of Nigeria [92].

The bermudagrass, *Cynodon dactylon* (L.) Pers. is a perennial grass, rated the second worst weed in the world having purportedly originated in Africa and has become a cosmopolitan species with predominance in

Table 1 Some documented cereal pests in Africa, their host crops, countries affected, and losses incurred

Pest category	Pest names	Cereal crop affected	Areas found/ affected	Losses
Insects	Stemborer *Busseola fusca, Chilo partellus, C. zacconius, Sesamia calamistis*	Rice, sorghum, maize and millet	South, East and West Africa and the ocean islands [46]	In Ghana, yield losses as high as 40% have been attributed to *B. fusca* infestations. Damages of 22–25% damage by the pest have been recorded in late-planted maize in Tanzania [56]
	Fall armyworm (FAW) *Spodoptera frugiperda*	Maize and sorghum	Nigeria, Sao Tomé, Principe, Kenya, Uganda, Rwanda, Ethiopia, and Tanzania [60]	Annual losses in maize of 4.1 to 17.7 million tonnes [69]
	African rice gall midge, *Orseolia oryzivora*	Rice	Nigeria, Sudan, Niger, Senegal, Benin, Burkina-Faso, Gambia, Guinea, Malawi, Mali, Sierra Leone, Togo, Tanzania and Zambia [74]	Severe infestations of *O. oryzivora* in rice fields induce 20–100% yield losses [76]
Weeds	Witchweed *Striga hermonthica*	Maize, pearl millet, sorghum and rice	Eastern Africa includes Kenya, Uganda, Sudan, Rwanda, Tanzania, Ethiopia and Burundi [78]	Yield losses of 21% and 62% in lowland rice were recorded in Cote d'Ivoire and Kenya, respectively [79]
	Striga asiatica	Sorghum, pearl millet, rice	West Africa and East Africa [79]	Yield losses of 80% loss in rice in Madagascar [79]
	Imperata cylindrica	Rice and maize	West Africa (Nigeria, Benin, Sudan, Cote d'Ivoire) [80]	Causes up to 50% loss in maize [80]
Rodents	*Mastomys natalensis* (multimammate rat)	Maize, rice, and sorghum	Mainly in Sub-Saharan Africa [81]	An average of 48% yield losses can be caused by an outbreak of this rat on maize fields (Swanepoel et al., 2017)
Birds	Quelea species-billed quelea (*Quelea quelea*) Red-headed quelea (*Q. erythrops*)	Barley, finger millet, rice, sorghum, and wheat. Except for maize [83]	Ethiopia, Kenya, Cameroon, Nigeria, Senegal, Somalia, South Africa, and Uganda [84]	An average of 13.2% of damage is caused by quelea birds to rice production [85]

almost every continent from the tropics to the temperate climatic zones [94]. Adapted to a broad range of soils and climates, it is known for its aggressive, persistent and noxious behaviour exhibiting a high dispersal rate, rapid establishment and strong tolerance to naturally occurring disturbances such as fire and grazing [95]. Possessing ground runners and underground rhizomes, *C. dactylon* forms dense mats which enable it to rapidly colonize areas and maintain its competitive dominance [96]. At the same time, its ability to secrete allelopathic substances against other neighbouring plants can help *C. dactylon* to successfully outcompete crop species, especially those belonging to the grass family-like cereals [96]. In Africa, its main host crops are maize, rice and pearl millet. In northern and eastern Namibia, the expansion of the Bermuda grass has become a threat to local farmers who cultivate the pearl millet [94].

The purple nutsedge (*Cyperus rotundus* L.), is considered the most troublesome, dominant and persistent grassy weed whose natural habitat spans across the tropical and subtropical agro-ecological regions of the world [97]. Although native to India, it has naturalized well in Africa and has been reported to infest many staple crops in East and West Africa [97, 98]. Its incredible and aggressive ability to withstand adverse climatic conditions sets it apart as a menace to diverse agroecosystems causing 20–90% yield losses in more than 50 crops primarily maize, rice, sugarcane and cotton [97]. Yield losses of up to 42–50% have been recorded in upland and lowland rainfed rice plantations [99]. Propagated vegetatively, *C. rotundus* emerges from a single tuber (positioned within 15 cm of soil depth) which branches into a broad network of underground rhizomes which then develop into new tubers [100]. High weed density of *C. rotundus* can effectively outcompete vigorous plants, such as maize for water, light and nutrients, especially at the early growth stage of the crop [97]. *C. rotundus* is widespread all over the African continent. Maize and rice, two major cereals being produced in several African countries, are the main host crops of the noxious weed *C. rotundus*. Although little is known of the economic impact of *C. rotundus* in most African regions, one report in Ghana highlighted 46% yield loss in *C. rotundus*-infested maize fields which were not pre-treated with the glyphosate herbicide [100].

Two of the most important *Echinochloa* weed species are *Echinochloa crus-galli* (L.) Beauv., and *Echinochloa colona* (L.) Link. Both species are annual, short-day, and summer C4 grasses ranked as the third and fourth most weeds, respectively [101]. Their propagation is through the production of a lot of seeds which also exhibit dormancy while building up within the seed bank of the soil; hence making them very difficult to control. These grasses are highly competitive against several crops, especially rice, maize and sorghum and are well known to develop biotypes that rapidly develop resistance to selective and non-selective herbicides, such as glyphosate and atrazine, making them more problematic [102, 103]. Globally, 10–79% of rice yield losses occur as a result of competition with *Echinochloa* species [104]. However, they differ in their growth patterns, as *E. colona* is usually smaller in size and more branched at the base as well as grows in a more dispersed way compared to *E. crus-galli* [105]. Native to India, the jungle grass *Echinochloa colona*, has become a very dangerous and serious threat in various cropping systems around the tropics and the subtropics. It is globally distributed in Africa, Asia and Australia and well-reported in different types of rice systems, either dry-seeded, wet-seeded or transplanted types [103]. *E. colona* typically mimics rice during the early stage of seedling and is often accidentally transplanted with rice seedlings into fields. Hence, at the seedling stage of rice, it might be difficult to spot the weed until it is fully grown with a strong competitive advantage [103]. Although it is present in many countries of Africa, it is more widespread in Mozambique, Tanzania, Kenya and South Africa. It has been considered the most dominant weed of rice in Kenya [105].

However, there is no robust documented record of the economic impact of these weeds on the production capacity of different cereal plantations in Africa. This is a huge gap that warrants rapid attention by researchers in the field of weed ecology. However, many researchers have focused on the medicinal/pharmaceutical potential of these weeds as well as their ability to serve as sinks for bioremediation. Possibly these scientific adventures could serve as a weed management strategy of huge profitability.

Parasitic weeds

The witchweeds: Striga species

Striga species are arguably regarded as the most devastating and competitive weeds challenging the production of cereals such as sorghum, maize, pearl millet, finger millet and rice in Africa. *Striga spp*. is an annual plant that belongs to the family *Scrophulariacea*e [106]. Among the 23 species of *Striga* in Africa, three are economically important in this context—*S. hermonthica*, *S. asiatica* and *S. gesnerioides* [107]. The first two species are the most important weed problems of rice in West Africa and East Africa, respectively [79]. *S. hermonthica* is found in free-draining uplands while *S. aspera* may be found on hydromorphic soils. *S. forbesii* is found in lands with higher rainfall and affects irrigated plants [79]. They act as hemiparasites, whose lifecycle harmonizes with the life cycle of the host plant. Through structures called the haustorium, they attach to host roots via penetration and take up nutrients from the host leading to the appearance of stress symptoms, such as stunted growth, chlorosis, wilting and total loss of crops in cases of high invasion [88]. The infestation of witchweed would not only reduce the ability of the plant to photosynthesize but also make it more susceptible to pests and diseases [87]. A single plant of the witchweed can produce about 500,000 seeds which can remain viable in the soil for 20 years [88]. The dispersal of parasitic weeds is mostly from contaminated crop seeds from local markets [79]. In addition, their pervasiveness is due to their ability to tolerate changing and extreme climatic conditions [79]. The witchweeds can be found in about 42 African countries [89]. In Sub-Sahara Africa, *Striga* is estimated to cause cereal losses of up to US $7 billion and Ethiopia, Mali and Nigeria have an annual estimated loss of US$ 75 million, US$85 million and US$1.2 billion, respectively [78]. Data show that over 50 million hectares of arable land used for cereal cultivation have been invaded by *Striga spp*. About 75% of losses in grain have also been reported due to the effect of these parasitic weeds [88]. In addition, farmers who record about 80% losses from this invasion eventually have to vacate the affected farmland [88]. Striga infests over 64% (17 million ha) of cereal-cultivated lands resulting in yield losses of up to 10–100% loss [108]. An alarm has been raised by researchers from Africa Rice Centre (AfricaRice), the International Rice Research Institute (IRRI) and Wageningen University that the impact of parasitic weeds on rice production in Africa threatens food security, livelihoods of resource-poor small-scale farmers and the consumers [109]. It is therefore important for farmers to grow cereal varieties that have been identified as resistant or tolerant to certain parasitic plants and combine this with efficient agronomic measures.

Rice vampire weed

Rice vampire weed, *Rhamphicarpa fistulosa*, is another hemiparasite which is endemic to Sub-Saharan Africa and most adapted to wet soils [110]. Although previously considered a minor weed pest, the threat caused to rice production has gruesomely increased over the years and has thus become a major thorn in the flesh in the cultivation of the crop on which millions of Africans depend [111]. *R. fistulosa*'s increasing production constraint is widespread affecting over 35 countries in the continent including giant rice producers, such as Nigeria, Tanzania, Madagascar, and Cote d'Ivoire. Like *Striga spp.*, *R. fistulosa* is a persistent weed pest owing to its wide host range, seed prolificity, and facultative parasitism. Hence, the weed becomes relatively difficult to control [110]. Yield losses by *R. fistulosa* are estimated at an average of 60% with a high regional economic loss reaching US $175 million yearly. As of 2013, rice vampire weed caused a monetary loss of at least US $17.3 million and US $7.1 million to the Nigerian and Tanzanian rice markets, respectively [111]. In the Benin Republic, a pest incidence of 16% was recorded with an estimated yield loss of 63% [79]. An integrated approach to weed management remains the best bet to curb the recurrent losses inflicted by this parasitic weed. It will also help prevent the imminent spread of the species into previously unaffected areas.

Other pests threatening African cereal production

Aside from the foregoing common biotic stressors of crops in Africa, several others abound whose occurrence, although not as prevalent, certainly causes a significant economic decline in our agricultural potential. Belonging to this group are, but are not limited to, the following: rodents and birds.

Rodents

Most rodent pests in African farms attack cereal crops both on the field and in storage. More than 400 rodent species have been identified in Africa. However, only 5% of them are known to be pests of crops. *Mastomys natalensis* (multimammate rat) and, to a lesser degree, *Arvicanthis spp.* (grass rats) are the most dominant of Sub-Saharan Africa's rodent pests. They are most implicated in rodent population outbreaks [112]. Others include *Cricestomys giambianus*, *Thryonomys spp.*, *Lemniscomys spp.*, etc. *M. natalensis* is known for its notorious activity as a key pest to cereal production in Sub-Saharan Africa [81]. Intense outbreaks of *M. natalensis* are linkable to rainfall patterns in the tropics [113]. Such outbreaks are undoubtedly followed by grievous crop losses in such regions. Cereal crops majorly attacked by the multimammate rat are maize, rice, and sorghum, with maize fields being the most attacked. Swanepoel et al., 2017 reported that an average of 48% yield losses can be caused by an outbreak of the pest on maize fields. Damage can, however, skyrocket to 80–100% losses during sowing and seedling stages in acute outbreaks. In Tanzania, damage between the sowing and seedling stages can exceed 40% in rice. Economic losses of 34–100% on maize crops tend to occur during outbreaks in Kenya [82].

Birds

Granivorous birds have been considered threats to various cultivated kinds of cereal across Africa for centuries despite limited evidence to prove this fact [114]. Several bird species are known to cause significant damage to different cereal crops in Sub-Saharan Africa which include Weaver species such as *Ploceus cucullatus*, *P. melanocephalus* and Quelea species, such as *Quelea*

quelea and *Q. erythrops* [84]. The impact of these birds cannot be underestimated with the Global Rice Science Partnership (GRiSP) identifying them as the second most prominent biotic limiting factor in African rice production after weeds [85]. An average of 13.2% of the potential rice production is annually lost to bird damage during the wet seasons with economic losses of €7.1 million, even though the majority of the damage occurs in the dry season [85]. Bird species such as Village Weavers *Ploceus cucullatus* and African Mourning Doves *Streptopelia decipiens* were observed to be responsible for almost 60% of seed losses on sorghum fields in western Kenya [114]. Specifically, the Red-billed Quelea is arguably the most notorious pest bird species in the world with characteristic high populations, broad aerial coverage and a unique preference for grassy seeds [84]. Despite the use of avicides by farmers, the quelea birds cause an average cereal production damage of 15–20% and economic losses of $ US 79.4 million in semi-arid zones of Africa. They attack all cereal crops—barley, finger millet, oat, rice, teff, sorghum, and wheat except maize (due to its large seeds) [83].

Current management practices

Management practices adopted in Africa against cereal pests are highlighted. These practices, sometimes, take into account the concurrent management and integration of strategies, the regular monitoring of pests and natural enemies and the use of thresholds for decisions, many different interpretations of IPM are possible due to the variety of alternatives [115]. There have been different pest management practices employed in Africa that have been effective. Natural enemies have been explored to control certain cereal pests. In the last century, the pearl millet head miner became a serious pest in Mali, Burkina Faso, and Niger. Comprehensive chemical control was not an economically viable alternative. Hence, biological control was investigated as a potential solution. The parasitic wasp (*Habrobracon hebetor*) found in Senegal proved very effective against the cereal head miner as a natural enemy. After extensive testing, wasp-rearing and release started in 2006. [116]. In addition, in Eastern and Southern countries of Africa, different species of lepidopteran stem borers have been a serious menace to cereal production. A parasitoid, *Cotesia flavipes*, has been introduced from Pakistan as a means to biologically control stemborers such as *Chilo partellus* and was able to cause a 32–55% decrease in stem borer densities [46]. Another strategy being adopted as a control measure against certain cereal pests is the push–pull technology which includes modifying the behaviour of natural enemies and insect pests to make certain places undesirable and to draw beneficial insects towards the crop [117]. For example, in East Africa, one of the major pests of maize is the stemborers (*Busseola fusca*). Yet, the Napier grass (*Pennisetum purpureum*) attracts stem borers to lay eggs on the grass rather than the maize crops while legumes such as *Desmodium* species act as repellent driving stem borers away. These push–pull techniques involve changing the behaviour of natural enemies and insect pests to deter beneficial insects from certain areas and attract them to crops [118]. The African fertilizer tree system indirectly affects the suppression of pests because of altered agroecological practices. Continuous maize farming is switched over to mixed systems in Malawi, Tanzania, Mozambique, Zambia, and Zimbabwe with a variety of nitrogen-fixing bushes. The FTS produce systems that quadruple maize yields and, as a side effect, reduce *Striga* population density by addressing issues with soil fertility and reducing reliance on expensive fertilizers, over 300,000 farmers have adopted the FTs system in Africa [119]. Intercropping cereal with other non-host crops is another strategy being used to combat pests. The cultivation of many crop species on the same piece of land is known as intercropping [120], and it has indeed proved effective in the reduction of pest infestation during on-farm cultivation. For example, in Western Kenya, researchers have established 20% yield gains of maize by intercropping *Striga*-resistant maize with *D. uncinatum*, a nitrogen-fixing fodder legume, to overpower *S. hermonthica* emergence in plots surrounded by rows of Napier grass to trap stem borers [121]. Again in Western Kenya, a new technology has been adopted to control *Striga* populations. This technology involves coating imidazolinone-resistant (IR) maize varieties with the imidazolinone herbicide, imazapyr. has proven to be very effective in controlling *Striga* on farmer fields [122]. However, to effectively control weeds, it is important to adopt an integrated approach which can involve proper tillage, soil solarization practices, repeated weeding, the use of fast-growing crops (weed-competitive cultivars) and, as a last resort, the use of very selective herbicides. An important weed management practice that has not been fully explored in Africa is soil solarization which uses polyethylene film. For example, soil solarization has been reported to reduce vegetative growth and tuber production of *C. rotundus* by up to 95% [97] which can apply to similar grass weed species such as *Cynodon dactylon* and *Imperata cylindrica*. Birds as well as rodents are, however, controlled by mainly traditional protective methods such as manual bird scaring (flags and scarecrows), trapping and poisoning, use of chemical or visual repellents as well as destroying the nests and collecting eggs [123].

Climate change and the future challenges of cereal pests in Africa

Climate change is no new concept within the global space and has been characterised by a rise in global temperatures, changing precipitation patterns, elevated CO_2 levels and extreme weather events. Although its impacts are not evenly distributed around the world, some regions are more vulnerable than others [124]. One such region is Africa which is warming at a faster rate than the rest of the globe with records of drought/flood disaster events, which already constitute 25% of disasters on the continent. By 2025, many parts of Africa are expected to face increased water stress and scarcity [125]. A report from the Global Climate Risk Index 2021 revealed that from 2000 to 2019, 70% of countries affected by climate change were in Africa. Over 80% of Africa's population depends on rain-fed agriculture for their livelihoods, which makes them particularly vulnerable to climate change.

Elevated CO_2 concentration, altered precipitation patterns, and increased temperature are all expected to have both negative and positive effects on insect pest infestations on cereals globally. Among these factors, temperature has the most dominant effect on insects by affecting their biology in an inverse relationship; increasing global temperature is expected to shorten herbivorous insect lifecycle but proportionately increase pest population as well as the feeding rate of insect pests. Global simulation studies have predicted median yield losses of 46%, 19%, and 31% for wheat, rice, and maize, respectively, due to pest infestations, when there's a 2 °C rise in global mean surface temperatures [126]. Many multivoltine migratory insect pests will be expanding their geographic range and at the same time becoming invasive in new areas. This is the same case for the fall armyworm *Spodoptera frugiperda* which invaded Africa from America and has turned into one of the most veracious pests of maize within the continent [127]. A study showed that the development of *S. frugiperda* was faster and each life cycle stage was shorter at higher temperatures which could pose a greater risk to annual production across maize-growing areas of Africa [128]. A simulation study, using the CLIMEX model, has predicted a greater risk of fall armyworm being established in a large part of east, west and central Africa. Yet, projections have also noted that the distribution of FAW will shrink in both the northern and southern ranges in Africa owing to a sharp increase in heat shocks and dry conditions [59]. Increased warming will likely affect the spatial distribution and population density of stem borers such as *Busseola fusca* which is usually found in higher altitudes with wetter and colder conditions; however, on the contrary, another native stem borer *Chilo partellus* will thrive with massive infestations in lower altitudes with a drier and hotter environment [129]. At the same time, native natural enemies of these stem borers which include larval parasitoids, *Cotesia sesamiae*, might become affected by changing weather patterns leading to increased stem borer densities in monocropping systems of cultivated cereals [129].

Climate change indices such as elevated atmospheric CO_2, alternating environmental temperature and changing rainfall patterns are known to notably impact weed population biology, ecological distribution and competitive balance [130]. There are sufficient documented reports of how these climate change indices affect weed invasiveness and abundance. Studies on the potential impact of climate change on *Striga* infestations in Southern Africa have also revealed futuristic risks. Dormancy in witchweeds is easily broken by alternating wet and hot conditions—a phenomenon which is predicted to become a norm in climate change events. Hence, future climate scenarios, characterised by elevated CO_2 levels and increased temperatures, will favour increased germination of *Striga.* In addition, expected strong winds will encourage the rapid spread of *Striga* and other cereal-limiting grass weeds, whose seeds are very light, across geographical boundaries across the African landscape [131]. All grassy weeds which were highlighted in this review—*Imperata cylindrica*, *Cynodon dactylon*, *Cyperus rotundus*, *Echinochloa crus-galli* (L.) and *Echinochloa colona*—are C4 plants and are not expected to respond to elevated CO_2 because they possess internal machinery to maintain CO_2 concentration at the site of CO_2 carboxylation; however, each weed species might be affected differently by alternating temperature conditions. From the perspective of rainfall variation, C4 weeds and parasitic weeds such as *S. hermonthica* will begin to thrive better under prolonged drought spells in mono-cropping systems primarily cultivating C3 cereal crops, such as rice. This will pose a great threat to the rice production in Sub-Saharan Africa. In contrast, the parasitic weed *Rhamphicarpa fistulosa* is expected to be favoured by excess water conditions caused by high precipitation, hence posing a threat to rice production once again in Africa [130]. Weed species such as *Echinochloa crus-galli* (L.) are known to exhibit herbicide resistance and reports have revealed that climate change indices such as temperature increase up to 30 °C and high CO_2 levels increase resistance to cyhalofop-butyl and glyphosate—a widely used herbicide by many local farmers in Sub-Saharan Africa [104, 132]. This comes as no surprise as it has already been postulated that there will be an increasing rate of herbicide inefficacy on weed with global warming. However, due to the unavailability of proper technical structures as well as robust research setups in many agricultural systems of Sub-Saharan Africa, such challenges can aggravate very significant losses as well as cause the indiscriminate use of herbicides; hence further damaging the local ecosystem.

Recent reports by the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services predicted that Africa will lose more than half of its bird and mammal species by 2100, primarily as a consequence of the effects of global climate change and habitat loss [133]. Therefore, attacks from birds such as *Ploceus cucullatus*, and *Quelea quelea* on cereals might drastically reduce with drier climates in some parts of Africa; nevertheless, they will be extremely dangerous in regions with more favourable humid climates. Global projections predict that warmer but humid weather conditions will prompt a drastic increase in rodent pest abundance and geographical distribution; however, extreme warming will certainly reduce their abundance [134]. Interestingly, a few research have been carried out to make futuristic predictions on the potential impact of climate change on cereal pests in Africa, with a prominent focus on stem-borers and the fall armyworm (Fig. 3) [59, 129].

Conclusions

Africa is considered one of the most vulnerable continents to climate change primarily because there is a lack of support services for small-scale farmers in tackling its consequences and impact on the dynamics of various noxious weeds of major cereals, such as maize and rice. In the wake of increased precipitation and alternating temperatures, certain weeds and rodent pests might become highly threatening in regions where they were not originally widespread. Unfortunately, not so much research has been done to predict the potential impact of many weeds, including *Striga*, and rodent pests on cereals within the Sub-Saharan belt. Given the invasive nature

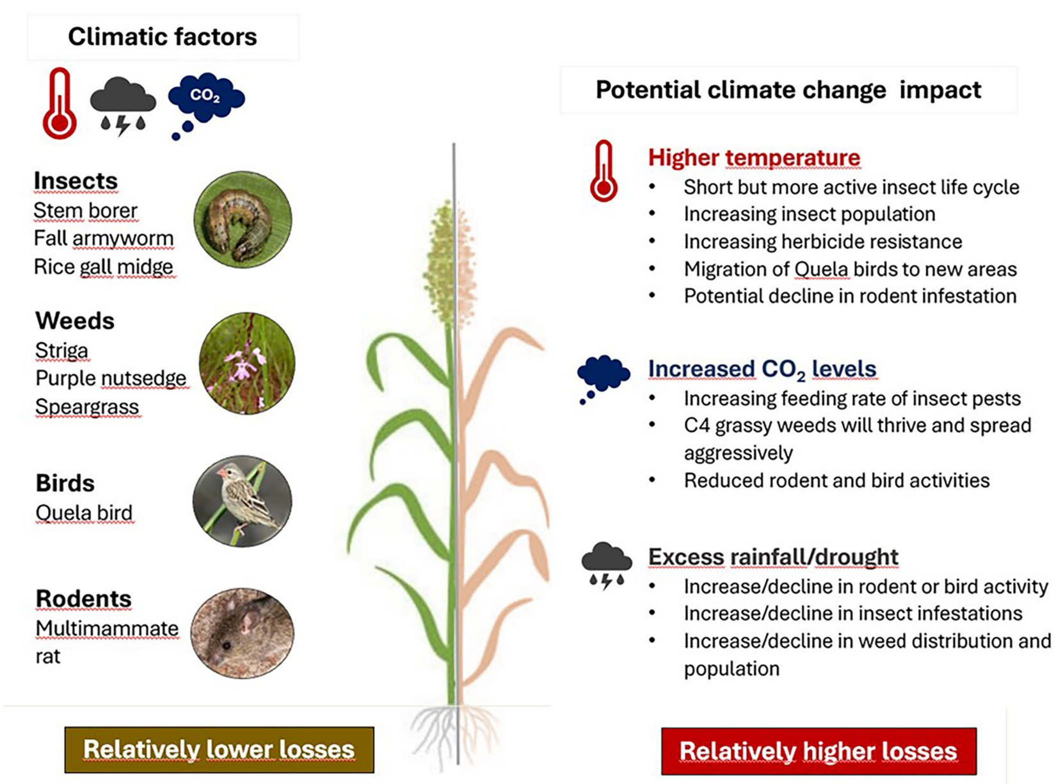

Fig. 3 Potential impact of climate change on insect pests, weeds, birds and rodents possibly affecting crop yield

of many weed species, it is imperative to carry out studies to understand the trends of climatic change events in major cereal-producing regions of Africa and their corresponding influence on the cereal pests considered in this review. Findings from these predictive studies will provide insights into the best-integrated pest management approach (especially preventive) to uniquely adopt against the impact of these pests on cereal production within the African landscape.

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