

Maize Head Smut: Pathogenesis, Epidemiology, and Management Options

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Abstract

Maize (*Zea mays*) head smut caused by *Sphacelotheca reiliana*, a basidiomycete with worldwide distribution, can cause devastating crop losses that pose a food security threat. While Kenya has experienced high incidences of the disease in the recent years, the seed certification regulation has a zero tolerance on *S. reiliana*. The spores of *S. reiliana* remain viable in soil for many years and serve as the main inoculum source as they germinate when the conditions are favourable and infect the host in the early stages of growth after germination. After penetration, the fungus grows systemically as the plant matures eventually transforming part or all of the inflorescence (ears and tassels) tissues into smut galls. The symptoms develop because the inflorescences have increased levels of reactive oxygen species, auxin, and misregulation of floral regulatory transcription factors. The most practical control strategy for maize head smut encompasses the use of resistant/tolerant cultivars, fungicide treatment (of seed or drenching of rows immediately after seeding), and field hygiene/ sanitation. Crop rotation may help when host crops are not planted for between 2-3 years or even more. Resistance genes, including ZmWAK, found in the major quantitative trait locus qHSR1/qHS2.09 regulate resistance of maize to head smut. The objective of this review paper is to provide an understanding of the head smut disease pathogenesis, epidemiology, and effective management options.

Key words: *Sphacelotheca reiliana*, basidiomycete, seed certification, smut galls, resistance gene

Introduction

Being the most important cereal crop in sub-Saharan Africa, Maize (*Zea mays*) is Kenya's staple crop with annual production steadily increasing over the last ten years, despite the area under production not changing significantly (FAOSTAT, 2018). Pest and diseases remain the main challenge to maize production and yield. Maize is affected by two types of smut diseases: head smut caused by *Sphacelotheca reiliana* (J. G. Kühn) G. P. Clinton [syn. *Sporisorium reilianum*], and common smut caused by *Ustilago maydis* (DC.) Corda. The head smut pathogen, *S. reiliana*, is a destructive soil borne basidiomycete of the ustilaginaceae family and has a worldwide distribution. *S. reiliana* is biotrophic (Martinez *et al.*, 2002; Mohan *et al.*, 2013) with systemic infection occurring in the very early stages of growth while the plant is in the seedling phase (Kosiada, 2011). *S. reiliana* has two formae speciales which are host specific, one infecting maize only while the other infecting sorghum (Martinez *et al.*, 1999; Poloni & Schirawski, 2016). Distinct mechanisms

in maize and sorghum determine specificity of host (Poloni & Schirawski, 2016; Zuther *et al.*, 2012). *S. reiliana* reproduces sexually. One study (Schirawski *et al.*, 2005) described two mating type loci of *S. reiliana* as triallelic 'a' and multiallelic 'b'. Each of the 'a' loci is composed of two pheromone genes where only one mating partner specifically recognizes each pheromone.

In severe cases, maize head smut can cause up to 80% yield loss (Frederiksen, 1977). The severity depends on the incidence since no viable kernels are produced by maize plants that are infected (Jackson-Ziems, 2014). This is why maize head smut needs to be urgently and effectively managed.

The Kenyan Seed and Plant Varieties Act (Cap 326) lists *S. reiliana* as a significant pathogen in seed production systems and places a zero tolerance on it during the final inspection of a maize seed crop that is due for seed certification. In August 2016, four counties of Kenya (Nandi, Elgeyo

Marakwet, Trans Nzoia, and Uasin Gishu) reported high incidences of head smut in maize. According to a surveillance (report unpublished) carried out by the Nakuru County Early Warning and Rapid Response Team, led by KEPHIS, in September 2019, Nakuru County reported increased cases of the disease, especially in Njoro sub-county.

Most of the affected counties have the favourable climatic conditions (average soil temperatures of 28 °C and moderate to low soil moisture) for seedling infection. Figure 1 represents the situation of infection in one of the visited farmers' fields during the surveillance.

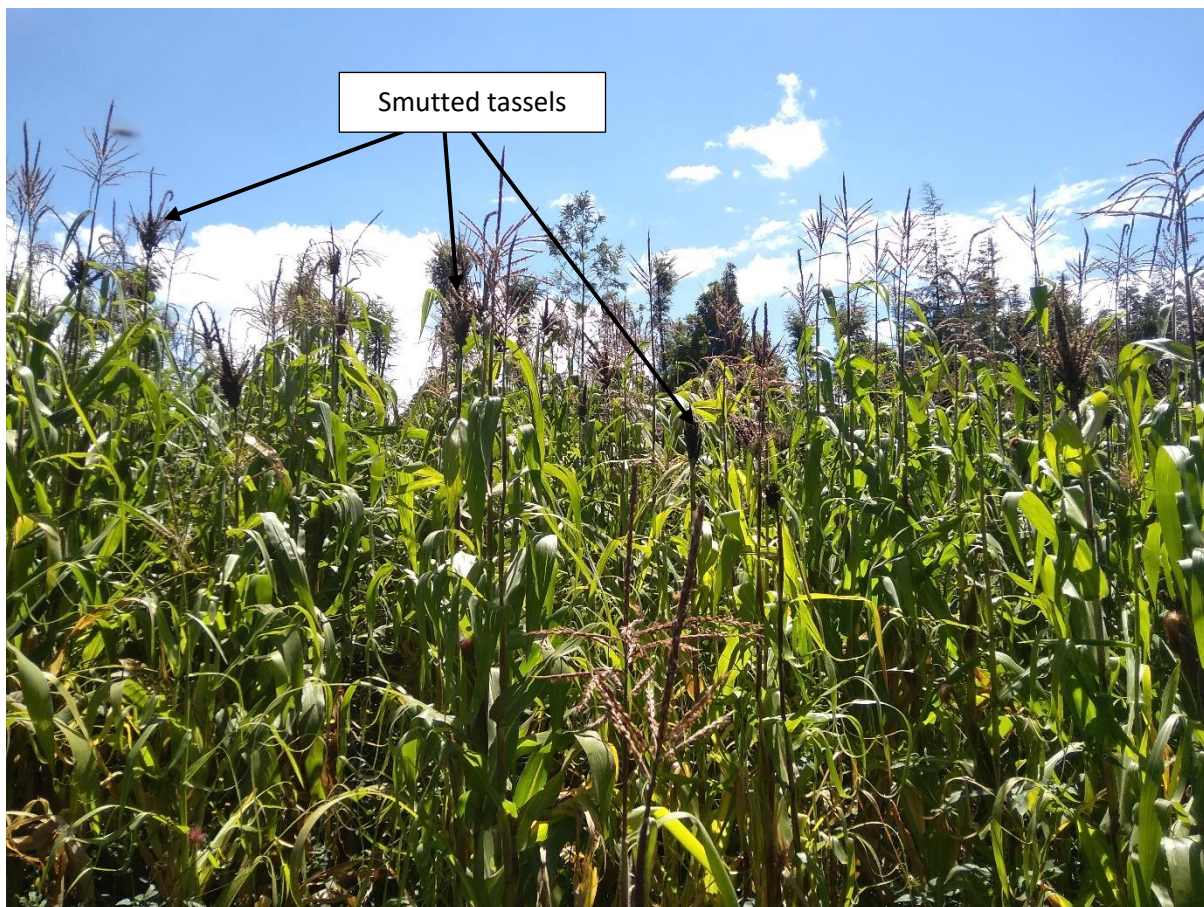


Figure 1: - High incidences of head smut in a maize field in Njoro, Nakuru County (September 10, 2019). All the infected plants are unproductive.

One of the findings of the surveillance was that in the previous cropping seasons, most farmers had fed infected maize debris to cows and the resulting

farmyard manure were used in the following season. Such practices may have contributed to the increased disease epidemics in the following

seasons. With maize being Kenya's staple food crop, outbreaks of head smut can spell a food security crisis hence the need to understand the pathogen and disease dynamics. The

Disease cycle and symptoms

Spores from smutted inflorescence are easily dispersed by wind and rain and can remain viable in soil for up to four years (Mohan *et al.*, 2013) hence serving as the main source of inoculum. The germination of the *S. reiliana* spores in soil tend to be high in acidic soils. Under favourable conditions (acidic soils, moderate to low soil moisture, and warm temperatures of between 23-30°C), the spores germinate into infective hyphae which penetrate the roots of seedlings before they reach the six-leaf growth stage (Jackson-Ziems, 2014; Martinez *et al.*, 2002; Mohan *et al.*, 2013). The initial contact between the infective hyphae

objective of this review paper is, therefore, to provide a concise outline of head smut pathogenesis, epidemiology, and management options.

and the maize root entails the formation of a fungal sheath around the root tissue (Martinez *et al.*, 2000) which facilitates penetration whereas the initial infection of seedling is promoted by delayed rains (Jackson-Ziems, 2014). Following an infection of a maize seedling, the fungus passes through the host cell wall by lysis and mechanical pressure (Martinez *et al.*, 1999). The infective hyphae mainly grow intracellularly and systemically advances through the plant tissues, eventually transforming part or all of the inflorescence tissues into smut galls. Head smut then portrays on maize ears and tassels as galls, which later mature and sporulate to restart another disease cycle.

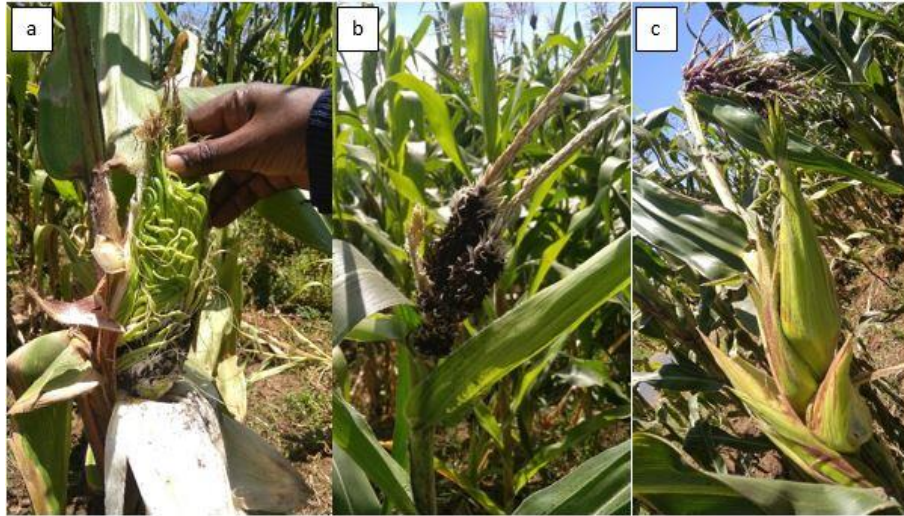


Figure 2. Symptoms of head smut disease on maize; (a) sori with teliospores and finger or wire-like proliferations on maize ear, (b) black mass of fungal teliospores on tassel, (c) malformation of the tassel and ear lacking silks.

Infected ears have rounded or pear-shaped smuts and lack silks whereas infected tassels turn into leafy structures with smutted spikelets (Jackson-Ziems, 2014; Mohan *et al.*, 2013). In the early stages of ear development, these galls have a thin membrane that ruptures to expose dry, powdery, dark brown to black masses of teliospores (Mohan *et al.*, 2013). The presence of fine, thread-like strands within the galls are remnants of the infected and damaged vascular tissue of the plant (Mohan *et al.*, 2013). The symptoms develop because maize inflorescences (ears and tassels) that are infected by *S. reiliana* have increased levels of ROS (reactive oxygen species) and auxin, and misregulation of floral regulatory transcription factors (Ghareeb *et al.*, 2011). It is important to note that even

though infected, the vegetative tissues of maize do not show any symptoms and may appear healthy (Martinez *et al.*, 1999) and thus mycelia in crop residue can serve as inoculum source in the following crop season (Anderson *et al.*, 2016).

Disease Management

The increase in maize head smut occurrence and incidences over the years can be attributed to the continuous mono-cropping, use of susceptible varieties, misuse of seed coating agents and change in weather patterns (Li *et al.*, 2015). These factors have contributed to the availability of favourable conditions (acidic soils, moderate to low soil moisture, and warm temperatures of between 23-30°C) for infection and disease proliferation. It is important to point out

that there are no curative measures for maize head smut and thus the only available options are preventive as described in the following paragraphs.

The use of resistant varieties - The resistance of maize to *S. reiliana* has received some remarkable attention through studies in the recent years and has been found to be quantitative and mostly additive (Anderson *et al.*, 2016). Two quantitative trait loci, qHSR1/qHS2.09/q2.09HR (Konlasuk *et al.*, 2015; Li *et al.*, 2015; Weng *et al.*, 2012) and q5.03HR (Li *et al.*, 2015), have been described as responsible for head smut resistance and is useful in marker assisted resistance for breeding programs. The resistance is conferred by the *ZmWAK* gene which is found in the qHSR1 locus (Konlasuk *et al.*, 2015; Zhao *et al.*, 2012; Zuo *et al.*, 2015). The genome-wide association study (GWAS) by Wang *et al.*, (2012) illustrated that resistance to head smut entails complex molecular interactions. In Kenya, two maize varieties, KH500-21A and PAN3M05, have been listed as resistant to head smut whereas WH699 is recorded as tolerant to smut, although the causative agent of the referred smut is not specified. Farmers must use certified seed in order to utilize the variety resistance. Whenever there are high head smut disease incidences in Kenya, farmers always blame the seed they used. This could be true because the cultivar they planted is susceptible to *S. reiliana* but

may not have a direct connection with the quality of the seed, as long as the seed is certified.

Fungicide treatment – This is achieved by either seed dressing or by soil drenching, before or after seeding. Because *S. reiliana* is biotrophic in behaviour, systemic fungicide treatment will be effective if their mode of action will inhibit mycelial growth and/or sporogenesis, at least until floral induction occurs (Martinez *et al.*, 1999). Some of the active ingredients that are effective in reducing *S. reiliana* infection, even at low application rates, are tebuconazole, fludioxonil, sedaxane (Anderson *et al.*, 2015), propiconazole, and fiutriafol combined with imazalil sulphate (Wright *et al.*, 2006). Most of these molecules belong to the azole group to which resistance development by fungi is rare and whose mode of action is inhibition of the synthesis of ergosterol hence loss of cell membrane integrity.

Cultural methods – This is best achieved by deep ploughing and rotation with non-host crops to reduce *S. reiliana* inoculum in soil and consequently lower disease incidences. For effective application, the rotation cycle should be at least 2-3 years (Mohan *et al.*, 2013) without maize, sorghum, and any other grasses that serve as alternative sources of inoculum. Additionally, rogueing of infected plants and ensuring field

sanitation to rid the field of crop residue will reduce inoculum load and thus a good management strategy.

Conclusion

The maize head smut disease has a worldwide distribution. Disease incidences occur sporadically especially in high altitude areas and is associated with soils with nitrogen deficiency (Mohan *et al.*, 2013), which means that it is difficult to predict its occurrence during a cropping season. Whereas head smut disease incidence (percentage of infected plants in a crop field) can reach 80%, disease severity in terms of yield loss is 100% because infected plants are not productive. Infections are favoured by acidic soils, moderate to low soil moisture, and warm temperatures. The most practical management strategy for maize head smut, therefore, integrates the use of resistant/tolerant cultivars, seed treatment and/or drenching of sown rows and observing field hygiene/sanitation. It is important to note that while cultural methods such as crop rotation are useful, they cannot limit disease incidence because spores remain viable for long periods.

Recommendation

Even though maize head smut can cause massive crop losses, there are practical options for its management. Phytosanitary challenges associated with maize head smut can be reduced

by ensuring a clear understanding of the disease pathogenesis (biology, infection mechanisms, and symptoms) and epidemiology (spread in time and space).

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