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Plant Pathology

AERIAL DISSEMINATION OF GRAIN SMUT OF SORGHUM [*SPHACELOTHECA SORGHI* (LINK) CLINT.]

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Five stages in the morphology of smut sori were recognized. Stages 3, 4 and 5 denoted sori with increasing degree of broken tips. The relative preponderance of these stages were found to be important in the air dissemination of grain smut chlamydospores. A four grade scale was developed for recording the intensity of various soral stages in the field. Hirst spore trap (Burkard model) was found to be quite efficient in estimating the concentration of air-borne chlamydospores. The trap catches spores both as single units and clumps. Nearly 20% of air-borne chlamydospores occurred in clumps with spore numbers 2–65. The spores occurred in air over a period of 35–50 days in each crop period showing peaks at the time of ripening of the grains, and when the earheads were showing infection grades 3 and 4. The circadian periodicity of chlamydospores differed significantly in its pattern in the two crop seasons. Importance of air-borne chlamydospores in contamination of plots around the infected field, surface contamination of healthy seeds and in causing allergic reactions in human beings, is suggested.

INTRODUCTION

The occurrence of smut chlamydospores in air has been demonstrated by several aerobiologists (Pady & Kramer, 1960). However, the aerial dissemination of a very few smut diseases only had been investigated. The aerobiological studies on barley loose smut by Sreeramulu (1962), oat loose smut by Mills (1967) and sugarcane whip smut by Sreeramulu & Vittal (1972) have revealed the influence of crop growth, dispersal stages of smut sori and wind velocity on the aerial dissemination of smut spores.

Sorghum is one of the chief food crops of Karnataka and is grown over a vast area. It suffers heavily from grain smut disease caused by *Sphacelotheca sorghi* (Link) Clint. Losses up to 30% were reported (Butler, 1918; Ciccarone & Malaguti, 1950; Mercer, 1969). Mathur, Jain & Bajpai (1965) estimated the loss in yield for 1% infection increase, on the area basis, as 0.9–1.0%. The disease has been considered as a covered smut (Ramakrishnan, 1963; Tarr, 1962) and most of the investigations conducted were about seed-borne infection, survival of smut spores, optimum conditions for infection etc. With the aim of investigating the aerobiology of air-borne diseases of sorghum, spore trapping was conducted for a period of two years, viz., 1971 and 1972, in a sorghum field at Mysore. Spores of *Sphacelotheca sorghi* were encountered in very large numbers in three of the four crop periods. A specific study was undertaken to determine the

dispersal stages of sori, aerial dissemination, periodicity patterns of air-borne smut spores, effect of weather.

Materials and Methods

Continuous air sampling was conducted with the help of a 'Burkard' model of Hirst Spore trap kept in the centre of a sorghum field with its orifice 1.22 m above ground level. Methods of spore trapping and recording of weather conditions were described earlier (Shenoi & Ramalingam, 1976). During 1972, leaf wetness was recorded by an improvised clock-work mechanism using an ink pencil. Rotorod samplers, Vertical cylinders and Gravity slides were used for studying the vertical and horizontal diffusion of spores in and away from the field.

Four crops were grown in the experimental field during the period of survey; two crops in each year, viz., 1971 and 1972, in the growing season, May to December (see Figs. 2 and 3). The seeds of a local variety 'Bili Jola' were used for raising the crop. The land used was fallowed for the past 10 years. While healthy seeds were used for raising the first crop, for the subsequent three crops seeds mixed with grain smut spores were used for sowing. The growth phases of sorghum were recorded at 5-day intervals and presented according to the scale given by Vanderlip & Reeves (1972). The local variety took 112 days for maturation and produced 14–16 leaves.

For collecting the data on grain smut incidence in the field, a minimum of 50 plants, selected in randomly placed quadrats were examined. Data on the number of plants infected, nature of sori, percentage of infected grains per earhead, and percentage of ruptured sori in each infected head was gathered at 5-day intervals.

Results

Stages of grain smut sori and grades of infection

The sori of grain smut were first covered with a white silky membrane which turned pale brown with age, becoming dark brown from the tip. With age the membrane developed ruptures at the tip exposing spore mass. The rupture increased leading to the shedding of portions of the membrane exposing a portion of columella. Basing on these field observations, five stages (Fig. 1) were recognized in the morphology of the sori (Table I). The percentage of grains infected and the stages of sori on randomly selected earheads is estimated. It was found that the infected sori in stage 3 and 4 were never greater than 10%. On the basis of the field data a four grade scale (Table II) is proposed for presenting information on the dispersal stages of smut sori in the field. Data collected in different crop periods are presented on the basis of this scale, in the panels of Figs. 2 and 3.

Table I

Stages of development of grain smut sori

Stage	Characteristics
1	Sori with white silky membrane, unbroken and soft
2	Membrane turning brown at the tip and unbroken
3	Membrane brown, tough and ruptured at the tip
4	Rupture extended back exposing spores
5	Ruptured sori with the columella partly exposed

TABLE II

Infection grades for grain smut of sorghum caused by Sphacelotheca sorghi

Grade	Characteristics
1	Most sori in infection stages 1 and 2; less than 5% with broken tips
2	5% or more sori in stage 3, with ruptured tips
3	5% or more sori in stage 4, with extended ruptures exposing spores-mass
4	1% or more ruptured sori in stage 5, with exposed columella

Seasonal variations in air-borne grain smut spores

Data on the daily mean concentrations of *Sphacelotheca sorghi* spores in the air are presented in Figs. 2 and 3 and are related to weather, growth stages of sorghum crop and infection. *S. sorghi* chlamydospores were not encountered in the air during first crop of 1971. The sorghum crop was also free from smut infection in this season. It is possible that some spores of grain smut coming from distant sources might have been counted under "other smut spores group". During the other three crop periods, chlamydospores of grain smut were encountered in very high concentrations exceeding 1,000/m^3 in more than one occasion. In general, three peaks were observed during each of the crop periods. The first peak coincided with the sowing time, the second with the ripening stages of the crop and the third with the harvest. Apart from these, high catches were also encountered on certain days in March as well as in the months of September and October. The grain smut infection was noticed in the field 55 to 75 days after sowing and peak catches were recorded 15 to 30 days after the detection of the disease in the field. These high catches were noticed when the crop was in ripening stages (7–9) and when 20% or more of the infected plants were showing infection grades, 3 and 4.

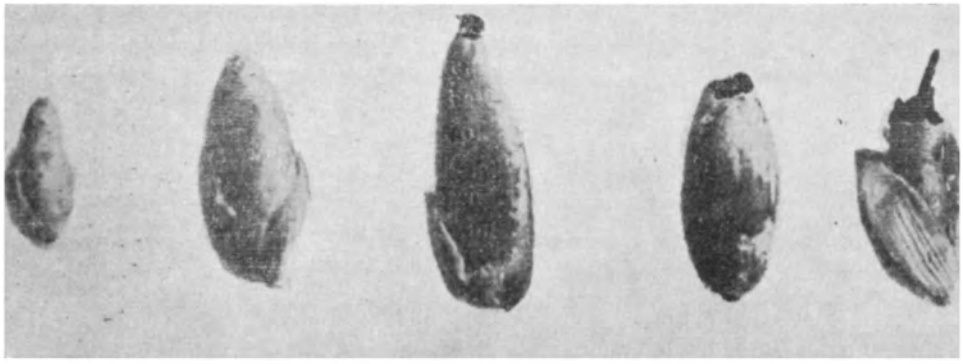

FIG. 1. Stages of grain smut sori on sorghum caused by *Sphaceiotheca sorghi*.

Circadian periodicities

The circadian periodicity curves given separately for the first and second crop periods of 1972 in Fig. 4, show great differences with each other. While a single

afternoon peak at 14 hr was noticed in the first crop period, two peaks, a major one in the forenoon at 04.00-08.00 hr and a minor one at 16.00–18.00 hr, were noticed in the second crop period. While spores were caught in negligible concentrations in the non-peak hours in first crop period, the concentrations recorded at all hours of the day were significantly higher in the second crop period. High catches were recorded on the traces when temperature (16–24°C) and relative humidity (51–100%) were in a wide range.

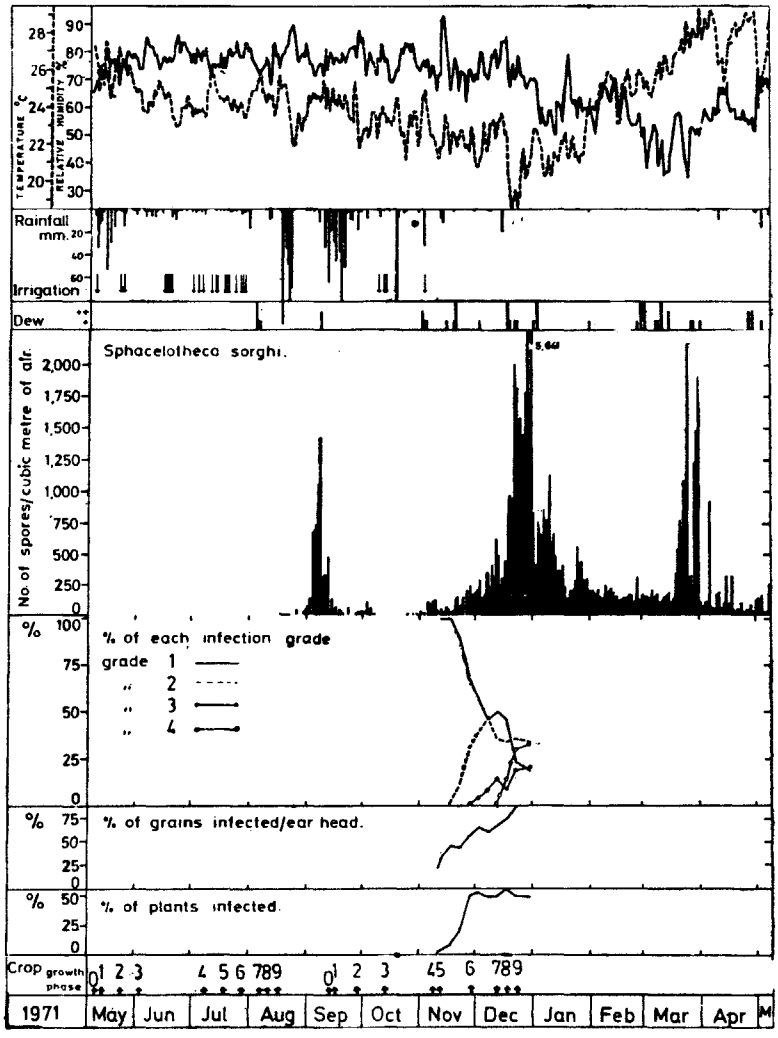

FIG. 2 Daily mean concentrations of the chlamydospores of *Sphacelotheca sorghi* sorghi in air over sorghum field in 1971, related to weather, infection and crop growth.

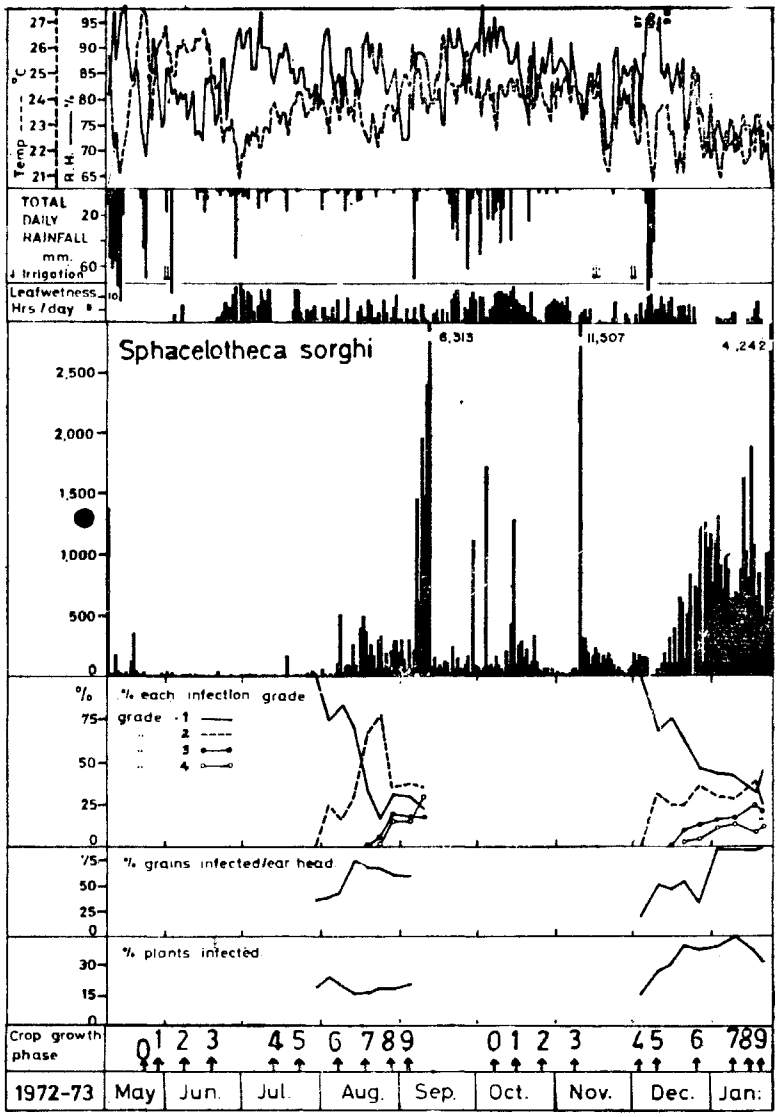

FIG. 3 Daily mean concentrations of chlamydospores of *Sphacelotheca sorghi* in the air over sorghum field in 1972, related to weather, infection and crop growth.

Clumping of air-borne smut spores

Grain smut spores (80.8%) were caught as single units and the rest as clumps having up to 65 spores (Table III). Their percentage of occurrence was found to be inversely proportional to the number of spores in the unit.

TABLE III

Percentage frequency of air-borne dispersion units of chlamydospores of Sphacelotheca sorghi

No of spores/unit	Percentage	No. of spores/unit	Percentage
1	80.84	19	0.01
2	11.11	20	0.05
3	3.58	21	0.02
4	1.40	22	0.00
5	0.69	23	0.03
6	0.41	24	0.01
7	0.26	25	0.00
8	0.17	26	0.01
9	0.23	27	0.00
10	0.09	28	0.02
11	0.05	29	0.01
12	0.16	30	0.00
13	0.07	31	0.00
14	0.02	32	0.01
15	0.03	53	0.01
16	0.02	59	0.01
17	0.01	60	0.01
18	0.01		

Horizontal and vertical diffusion

The concentrations of smut spores at different distances from the sorghum field in the leeward direction of the wind, during growing season and harvest time, are studied with the help of Rotorod samplers. Samples were taken at 0.5 m above the ground level for a period of 30 min. The data presented in Table IV, indicate that the concentrations of smut spores diffusing away from the field were enormously great at the time of harvest. Smut spores were carried away from the field to distances of 100–200 min measurable concentrations.

TABLE IV

Horizontal diffusion of Sphacelotheca sorghi *chlamydospores from the sorghum field to various distances in the leeward direction*

Date	No. of chlamydospores/m^3 of air at various distances											
	0m	5m	10m	20m	30m	40m	60m	80m	100m	120m	160m	200m
	During growing season											
1- 9-72	94	51	35	66	22	20	37	22	37	—	—	—
	During harvest											
31-12-71	—	—	75,374	10,582	—	7,254	—	5,044	—	—	—	—
12-9-72	75,218	—	9,256	5,226	—	1,690	1,040	1,222	—	468	52	52

The concentrations of grain smut spores at various heights up to 5 m above ground level, in and 30 m away from the sorghum field were studied with the help of Rotorod

samplers. The tests were carried out during the first crop period of 1972 when the crop was in the post-flowering stages. The data (Table V) indicate that the smut spores were present up to a height of 5 m (nearly 3½ m above the height of the crop) and the concentrations were greatest at 0.5 m above ground level, both inside and away from the field.

TABLE V

Vertical profiles of Sphacelotheca sorghi *chlamydospores inside and 30m away from the sorghum field on 4th and 5th August,* 1972

Time I. .S. T.	Number of chlamydospores per cubic metre of air Height above the ground level (in metres)								
	0.25	0.50	0.75	1.00	1.50	2.00	3.00	4.00	5.00
				Inside the field					
14.00	96	720	0	48	0	288	288	288	0
20.00	48	0	0	96	48	192	0	48	0
02.00	0	0	0	0	0	0	0	0	0
06.00	0	0	48	0	0	0	0	0	0
08.00	0	48	0	0	0	48	0	0	0
10.00	144	0	0	0	96	144	48	96	48
12.00	0	0	0	0	48	48	0	96	48
				Outside the field					
14.00	288	432	144	192	240	144	0	0	0
20.00	96	0	0	96	144	0	0	0	0
02.00	0	0	0	0	0	0	0	0	0
06.00	0	0	0	0	0	0	0	0	0
08.00	0	144	240	96	192	48	48	0	0
10.00	144	96	96	48	144	144	48	96	192
12.00	96	0	0	0	48	0	48	0	0

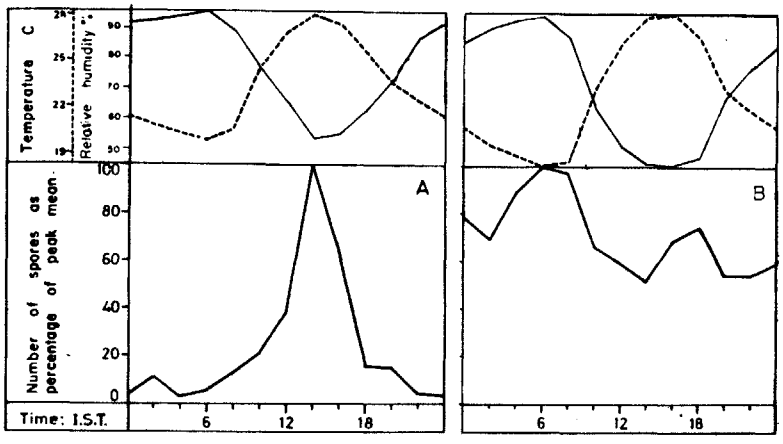

FIG. 4 Mean circadian periodicities in the air-borne chlamydospores of *Sphacelotheca sorghi* in the Ist A and IInd B crop. seasons in 1972 related toweather.

On 12 September 1972, when the sorghum crop in the experimental field was being harvested, smut spore samples were taken at various heights using Vertical cylinders at a distance of 150 m away from the sorghum field in the leeward direction. The spore catches at 1, 2, 3, 4, 5, 6, 7 metres above ground level were 1,218; 273; 546; 987; 252; 42; and 21 per cm^2 respectively.

The data on spore deposition on gravity slides exposed at various measured distances from the sorghum field in the leeward direction are tabulated for three tests in Table VI. In all the experiments the spore deposits were greater near the field and decreased with distance. The deposits at the time of harvest were not only greater in number but also were observed at greater distances (180 m) from the field.

TABLE VI

Deposition of Sphacelotheca sorghi *chlamydospores at various distances from the sorghum field in the leeward direction on horizontal sticky slides exposed for* 12 *hr*

Distance (in m)	Number of chlamydospores deposited/cm^2 of the slide surface		
	Growing season	Harvest period	
	1-9-1972	31-12-1971	12-9-1972
0	22	300	112
5	1	487	31
10	14	44	35
20	2	97	13
30	1	8	7
40	2	3	2
50	1	2	1
60	4	2	1
70	6	7	—
80	1	17	2
90	1	0	—
100	4	2	0
120	4	—	1
140	—	—	1
160	—	—	1
180	—	—	1
200	—	—	0

— indicates that the horizontal slides were not exposed.

DISCUSSION

Disease grades

Sreeramulu (1962) recognized seven dispersal stages in the case of barley loose smut. Following this pattern, Sreeramulu & Vittal (1972) recognized 8 disseminating stages for the whip smut of sugarcane. They found these scales are very helpful in interpreting the data on air-borne smut spores. The grain smut of sorghum has all along been considered as covered smut and only its externally seed-borne nature is emphasized.

During our aerobiological studies very high numbers of grain smut spores were trapped and close field observations were made on the developmental stages of smut sori. Five stages were recognized in the grain smut sori, of which stages III, IV and V with partially ruptured spore sacs were found to be important in the aerial dissemination of the smut spores. A four grade scale was proposed to estimate intensity of dispersal stages in the field and it was found to be useful in correlating the data on the air-borne smut spores. This observation that considerable number of sori are ruptured while still on the ear-head and dispersed the spores into the air necessitates the recognition of aerial dissemination in addition to the externally seed-borne nature.

Spore dispersal

The air-borne nature of smut spores has been recognized by many workers. However, there seems to be no report on the aerial dissemination of *Sphacelotheca sorghi*. Ramalingam (1971) who reported the higher incidence of smut spores in the air at Mysore, indicated that grain smut spores are probably a chief constituent of the group. The results of this survey clearly show that the smut spores of *S. sorghi* were caught on most of the days in the year and made up to 2.65% of the total air-spora. When combined with other smut spores, the group made up to 8.3% of the total air-spora and in the order of numerical abundance was next only to *Cladosporium* and basidiospores (Shenoi & Ramalingam, 1976).

The grain smut spores were identified and counted from the exposures of 136 and 347 days in 1971 and 1972 respectively. However, peak catches were reported only in certain periods during the year, which coincided with ripening phase of crop, harvest and threshing operations. The high catches that were encountered in the month of October and November 1972, are due to the threshing operations of the sorghum crop staked after the harvest in August and September, and that encountered in March 1972, are due to the smut spores coming from the infected earheads of ratoon tillers. The existence of high concentrations of grain smut spores in the air over long periods, 35 to 55 days, is probably due to the occurrence of heading of sorghum plants on different days. As compared with the reports on barley (Sreeramulu, 1962) the grain smut spores were caught for longer periods of time.

In most of the reports a noon or afternoon peak with a daytime pattern has been recorded for smut spores (Sreeramulu, 1962; Sreeramulu & Vittal, 1972). However, air-borne chalmydospores of *S. sorghi* exhibited two types of circadian periodicities in the two different crop seasons. In the first crop period raised in rainy season, a single peak was observed at 14.00 hr. Whereas in the second crop period raised in the later part of the rainy season and early part of winter, a double peak pattern was recorded. Pady & Kramer (1960) have also reported a double peak pattern for 'smut spores'. It is possible that two sorts of conditions might be playing an active role in the liberation of spores from smut sori. The early morning peak is probably brought about by the liberation of spores due to swelling of sori by the absorption of dew most prevalent in winter months and the afternoon or evening peak is brought about by the liberation of spores under dry and windy conditions. Sreeramulu & Vittal (1972) have found that the maximum dispersal in *Ustilago scitaminea* takes place at 22–24°C temperature and 50–60% relative humidity. However, maximum dispersal, in the present study was

noticed over a greater range of temperature and relative humidity (temperature 16–24°C and relative humidity 51–100%). The optimum conditions reported by Sreeramulu & Vittal (1972) coincide well with those observed at the afternoon peak hours of *S. sorghi* at Mysore. The exposure of sori to the varying temperatures, relative humidity, sunshine and rain probably will lead to the rupture of the peridium and consequent liberation of spores into the wind currents. The mechanical agitation of the plants caused by wind currents and the swelling and shrinking of the sori due to the absorption of moisture might play a very important role in the liberation of the spores and the circadian periodicity patterns observed. Experimental data has to be gathered to substantiate the above proposals. Sreeramulu (1962) and Sreeramulu & Vittal (1972) have clearly indicated the influence of wind velocities on smut spore dissemination. Similar data could not be gathered in the study for the lack of instrumentation. However, the effect of mechanical agitation leading to peak dispersal of *S. sorghi* has been noticed on more than one occasion. The data tabulated in Table VII clearly show that mechanical agitation as it happens during harvest, threshing etc., is responsible for the peaks recorded on certain days during the period of survey.

TABLE VII

Concentration of Sphacelotheca sorghi *chlamydospores in air during selected periods to demonstrate the effect of various operations leading to agitation*

Nature of operation	Date	Time I.S.T.	No. of air spores/m^3
Sowing	8- 9-1971	06.45h	19,107
Harvest	31-12-1971	08.15h	73,337
Harvest of tillers	25- 3-1972	09.30h	29,172
Ploughing	9- 5-1972	06.00h	17,886
Harvest	12- 9-1972	09.00h	82,071
Threshing	4-10-1972	10.30h	22,242
Harvest	24-1-1973	08.30h	55,143

Nearly 80% of *S. sorghi* conidia were released in the form of single units and a fifth of the spores in the form of clumps. The spores were carried to more than 200 m away from the field and even vertically to a height of 5 m. Thus, the aerial dissemination which is taking place might lead to the contamination of soil around, as well as the healthy grains on the earheads around the infected plants. While the single spores might be killed quickly, those which are deposited in clumps might live for a longer time and effectively carry infection to the subsequent crops.

The enormous number of smut spores released into the air during ripening, harvest and threshing operations may cause allergic reactions in human beings and animals exposed to such heavy doses.

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