

**STUDIES ON FLAG SMUT OF WHEAT CAUSED BY
Urocystis agropyri (Preuss) Schroet. AND ITS
EFFECT ON PHYSIOLOGICAL PARAMETERS**

By

DHARMVEER

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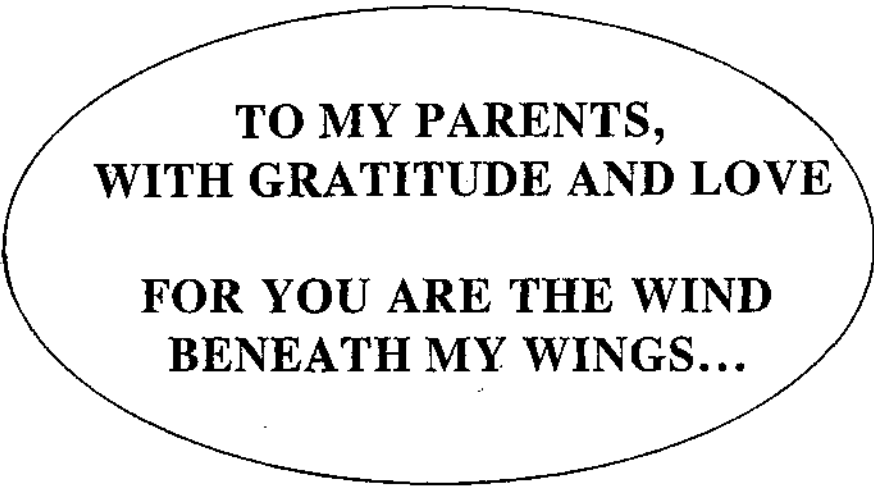
*Dissertation submitted to the CCS Haryana Agricultural University in
partial fulfillment of the requirements for the degree of:*

**DOCTOR OF PHILOSOPHY
IN
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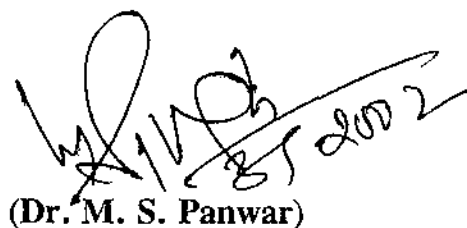
**TO MY PARENTS,
WITH GRATITUDE AND LOVE**

**FOR YOU ARE THE WIND
BENEATH MY WINGS...**

CERTIFICATE - I

This is to certify that this thesis entitled " **Studies on flag smut of wheat caused by *Urocystis agropyri* (Preuss) Schroet. and its effect on physiological parameters**", submitted for the degree of **Doctor of Philosophy**, in the subject of **Plant Pathology** to the Chaudhary Charan Singh Haryana Agricultural University is a bonafide research work carried out by **Dharmveer(98A66D)** under my supervision and that no part of this thesis has been submitted for any other degree.

The assistance and help received during the course of investigation have been fully acknowledged.



(Dr. M. S. Panwar)

Professor

Deptt. of Plant Pathology

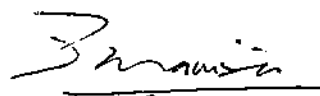
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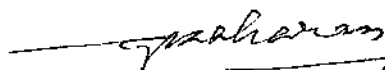
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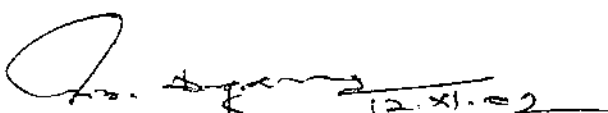
CERTIFICATE - II

This is to certify that this thesis entitled " Studies on flag smut of wheat caused by *Urocystis agropyri* (Preuss) Schroet. and its effect on physiological parameters" submitted by **Dharmveer (98A66D)**, to the Chaudhary Charan Singh Haryana Agricultural University, Hisar in partial fulfillment of the requirement for the degree of **Doctor of Philosophy**, in the subject of **Plant Pathology**, has been approved by the student's advisory committee after oral examination on the same, in collaboration with an External Examiner.


MAJOR ADVISOR


2-11-02
EXTERNAL EXAMINER


HEAD OF THE DEPARTMENT 8/11/02


DEAN, POST GRADUATE STUDIES

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Hisar

Dharmveer
Dharmveer

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CHAPTER-1

INTRODUCTION

Bread wheat (*Triticum aestivum* L. em. Thell.) is a source of staple food for about a billion people in the world and provides about 20 per cent food calories to the human race. Wheat grain provides carbohydrates, proteins, vitamins and minerals for growth and maintenance. Although wheat is grown primarily as a food crop, the plant and seed also find use in industrial products and as feed for livestock. It is one of most important food crops of India covering an area of more than 26 million hectares. With the introduction and large scale adoption of dwarf Maxican varieties, total wheat production in India has increased from 12 million tonnes during 1965-66 to 78.3 million tonnes and productivity from 820kg/hectare in 1965-66 to 2800 kg/hectare during 2000-2001 (Anonymous, 2001).

In Haryana, wheat is the premier food grain crop in the *Rabi* season and occupies the largest area 2.3 million hectare with production of 9.9 million tonnes and productivity 4160 kg/hectare in (Anonymous, 2000). Every year about 20 per cent of the wheat,

that otherwise would be available for food and feed world wise, is lost due to diseases either in field or in storage. The magnitude of damage by disease depends on environment and cultivars.

Pal (1951) pointed out that of all factors affecting the wheat yield, none is so important as the diseases and is one of the major constraints in boosting up the production of wheat. He estimated reduction in yield due to diseases to be ten per cent. Among the wheat diseases, as yield reducing agents, smuts and bunts are second only to rusts.

In India very little attention has been paid on flag smut caused by *Urocystis agropyri* (Preuss) Schroet. This disease is widely distributed in many wheat growing parts of the world and is of major importance in some areas. Flag smut leads to considerable reduction in grain yield due to complete loss of productivity in infected plant (Tyagi *et al.*, 1966).

Since, its initial description from Australia in 1868 and from United States in 1918, flag smut (*Urocystis agropyri*) has been observed in all the wheat growing continents (Fisher and Holton, 1957). The potential danger of flag smut on wheat production is indicated by reports of losses in field as high as 100 per cent (Purdy, 1965). In Indian sub-continent, the disease was first reported in 1906 (Butler, 1918).

In India the incidence of this disease has been reported from

Punjab, Haryana, Himachal Pradesh, Madhya Pradesh, Uttar Pradesh, Delhi, Bihar and Rajasthan (Mundkur, 1944, Rao, 1952; Bedi, 1957; Goel *et al.*, 1977). This disease was observed in severe form in some fields near Jobner during 1964-65 and in Chittorgarh (Rajasthan) during 1967-68 (Kothari and Dange, 1968). Where upto 80 per cent disease incidence was observed on a local variety. Majumdar and Bhatnagar (1980), reported 5 to 30 per cent incidence of this disease in Rajasthan.

In Haryana, since 1987-88 the incidence of flag smut ranging between traces to 50 per cent has been observed under natural field conditions at localized places of Bhiwani, Ambala, Mohindergarh and Hisar districts (Beniwal, 1992). Because of the continuous cultivation of susceptible varieties in affected fields, resulting in gradual build up of inoculum in the soil owing to persistence of the pathogen in the soil, gradual build up of inoculum and availability of susceptible cultivar, flag smut may become a serious threat to wheat cultivation particularly in northern India.

Very meagre information is available in the literature regarding the effect of flag smut on seed and seedling vigour, physiological parameters, particularly respiration and leaf area, *in vitro* dry matter digestibility and interaction of insecticides with recommended fungicides for controlling the disease.

Keeping in view the importance of disease and lack of information on

above aspects the present investigation were carried out with following objectives :

1. To investigate the effect of inoculum load on seed and seedling vigour.
2. To study the disease progress in relation to weather parameters.
3. To assess the impact of disease on physiological and qualitative parameters.
4. To find out the interaction of recommended insecticides with fungicides for disease management.

CHAPTER-2

REVIEW OF LITERATURE

This disease was first reported in Australia in 1868 (Mc Alpine, 1910). Earlier flag smut was observed on *Agropyron* sp. in Europe in 1848 and the causal organism described as *Uredo agropyri* Preuss. Thus the presence of flag smut disease on grass in Europe was observed 20 years before it was first observed on wheat in Australia. It is also possible that spores of flag smut occurring on grass might have contaminated the wheat seed imported into Australia where the fungus adopted to wheat and was observed for the first time in 1868 and has also been reported from Japan, China, India, Pakistan, South Africa, Egypt, Italy, Spain and United States (Purdy, 1965).

The first report of the disease in United Kingdom was made by Sansford *et al.*, (1998) in autumn-sown winter wheat. A world wide distribution of flag smut has been established and the disease has been reported from wheat producing countries of all continents. The distribution of flag smut is shown in Map No. 80 of the distribution maps of Plant Diseases (Anonymous, 1945). In the subcontinent of Indo-Pakistan this disease was first reported by

Butler (1918) from Layallpur in Punjab (now in Pakistan) and later on its occurrence was observed from Punjab, U. P., Haryana, H. P., M. P., Delhi, Bihar, Rajasthan, and hills of U. P. (Mundkur, 1944; Rao, 1952; Bedi, 1957; Tyagi *et al.*, 1966; Singh and Sethi, 1975; Joshi *et al.*, 1978; Joshi *et al.*, 1980; Majumdar and Bhatnagar, 1980; Pant *et al.*, 1996). It is believed that this disease has been introduced in Punjab through wheat grain imported from Australia (Bedi, 1957). Although occurrence of flag smut is not wide spread in country, its importance can not be under estimates, as unlike other smuts, it is the long persisting and if sowing methods and environmental conditions are favourable and susceptible varieties are grown, the disease may assume serious form (Singh 1969). Sethi and Singh (1971) observed a heavy attack of flag smut on Kalyansona in Kullu Valley of Himachal Pradesh. Kotheri and Dange (1968) observed it in severe form in 1964-65 in a few fields near Jobner, Rajasthan. Wheat disease surveys conducted by the scientists of Indian Agricultural Research Institute, New Delhi have revealed the presence of this disease in few isolated pockets of Rajasthan and Punjab since 1974-75 (Goel *et al.*, 1977; Joshi *et al.*, 1978; 1979; 1980; 1981; 1984).

Economic Importance

Reduction in yield is directly correlated with the number of infected plants since the disease plants usually resulted in complete

loss of yield. Therefore, the percentage of diseased plants reported in a commercial fields was regarded as a reliable measure of the economic importance of flag smut (Purdy, 1965). Mc Alpime (1910) reported that 10 per cent loss has been common while some times one half of the crop could be lost due to flag smut in Australia. Brittlebank (1920) pointed out that flag smut takes an annual loss of 5 to 70 percent of the crop in Australia. Churchwood (1934) estimated the loss of 4,00,000 dollars annually in Australia. Surveys conducted of thirty seven localities in eight provinces of China indicated that the flag smut incidence ranged from traces to 94 percent (Yu *et al.*, 1936). Jones and EL Nasr (1940) calculated a loss in yield of 20 percent when the flag smut incidence was 50 per cent in the field. Stated another ways a loss in yield of 0.4 per cent can be expected for each one percent infection in the field. Purdy and Holton (1963) found incidence of flag smut in the state of Washington from traces to 30 percent. In a study 10-15 percent losses from this disease has been reported in New South Wales (Anonymous, 1970). In India, Bhatnagar and Majumdar (1978) reported that this disease which was considered to be of minor impotence in the past is now causing 5-20 percent losses. Bhatnagar *et al.*, (1978) and Bhatnagar and Majumdar (1978) reported appreciable reduction in the number of ears per infected plant, 1000 grain weight and height of the infected plants and further reported losses of 60.8, 44.4, and

wheat varieties Arjun, Lal Bahadur and D-134, respectively, as result of flag smut infection. Majumdar and Bhatnagar (1980) reported upto 78.5 percent losses in grain yield due to this disease among 11 wheat varieties tested. Bhatnagar and Majumdar (1983) indicated that in general incidence varies from 0-10 percent but in certain endemic areas the incidence assumes very severe proportion amounting to 100 per cent losses in some cases in Rajasthan.

Wattspadwick (1948) stated that losses due to flag smut causes above five per cent reduction in yield or a loss of 15,000 tonnes of wheat grains in sub mountain region in Punjab. Bedi (1957) pointed out that the damage caused by this disease was either overlooked or under estimated by farmers since the infected plants were killed early in the season. Tyagi *et al.*, (1966) reported considerable reduction in wheat yield in varieties C-306 and C 286 in some districts of Punjab. In Haryana the incidence of flag smut ranging between traces to 50 percent has been observed under natural field conditions at localised places of Bhwani, Mohindergarh, Hisar, Ambala, Jind and Sonapat districts (Beniwal, 1992). He further reported that yield reduction varied from variety to variety depending upon varietal susceptibility and effect of flag smut on yield components. The reduction in tillering, plant height, earhead length and 1000 grain weight differed in different wheat varieties. He recorded yield reduction ranging from 22.93 to 65.41 percent in different wheat

varieties due to flag smut infection. Bansandrai *et al.*, (1993) reported widespread incidence of flag smut of wheat from Himachal Pradesh. Flag smut has been sporadically affecting the wheat in north India. However, in recent past its incidence in isolated fields is on rise. In Rajasthan many districts, such as Jaipur, Dausa, Sikar and Srinagar had flag smut incidence as high as 80 per cent in local wheat varieties. From Haryana, as high as 30 to 35 per cent flag smut incidence has been reported in wheat variety C-306 (Anonymous 1995).

Epidemiological Factors affecting disease development

The disease is soil as well as seed borne. The fungus gains access to seed and straw during harvest and is distributed as seed contaminant or on straw or any other material which has become contaminated.

It belongs to seedling infection group of smut fungi. The fungus infects the seedling and unlike most cereal smut fungi, it persists for many years in infested soil without access to the host (Walkar, 1969). The point of entry during infection is restricted to the young coleoptile less than 4mm long. After infection the fungus grows both inter and intra cellularly until it begins to sporulate, generally first in leaf blades and then in the leaf sheath and other parts of the plant. Takanashi and Ivata (1964) studied the mode of infection of flag smut fungus on wheat varieties differing in resistance.

The infection in the seedling stage of the plant development is necessarily influenced by inoculum load. Goel and Jhoo (1989)

reported that increase in disease incidence was noted when the inoculum load was increased from 0.001 to 0.005 and from 0.005 to 0.01 (spores/seed/w/w). The environmental factors play important role in infection and progress of flag smut of wheat including soil moisture, soil temperature, soil pH, as well as cultural practices such as planting date, sowing depth, host variety and its stages of development. The effect of planting date of wheat on flag smut infection is significant mainly with respect to the temperature prevailing at the time of seed germination. Although reports tends to be contradictory, the cardinal minimum, optimum and maximum soil temperature for infection by flag smut pathogen are in general 5, 20 and 28°C, respectively. Minimum temperature for infection have been reported to be 5°C (Noble, 1924); 6-12°C (Griffiths, 1924); 9°C (Wu, 1949); 10°C (Sattar and Hafiz, 1952) and 18°C (Verwoerd, 1929).

Similarly, optimal temperature for infection have been reported to be 14-21°C (Noble, 1924). 15-20°C Yasu and Yoshino (1963). 15-22°C Sattar and Hafiz (1952), 20°C Wu (1949) and 22-25°C Verwoerd (1929). Whereas, maximum temperature when infection can take place were observed to be 24-26°C (Noble, 1924); 25°C Griffiths (1924), 26°C Wu (1949); 27°C Statter and Hafiz (1952); and 28°C Verwoerd (1929). However, Noble (1924) recorded that one plant was infected at 31°C when germinated spores of flag smut pathogen

were used for inoculation. Hafiz (1948) and Tyagi *et al.*, (1966) recommended early sowing in October in place of 3rd week of November for reducing flag smut incidence in wheat. Goel and Jhooty (1989) and Kumar (1983) observed that the incidence of the flag smut increased as the sowing was delayed from 10th to 30th November but it decreases significantly in the 10th December sowing at Ludhiana. Beniwal *et al.*, (1992) reported that the disease symptoms appeared 4-17 days earlier in late December sown wheat, while the per cent disease incidence was reduced by 43.2 to 73.8 per cent in different varieties compared with normal sown November crop. Goel and Jhooty (1989) found a soil moisture content of 9 per cent to be optimum for infection and attribute the failure of *U. agropyri* to infect wheat at relatively higher moisture contents.

The flag smut was more at soil pH range of 5.5 to 8.7 (Foster and Vasey, 1929; Millar and Millikan, 1934; Millikan, 1939). Deep sowing increases chances of infection than the shallow sowing (Carne, 1924; El-Helaly, 1948). Bedi (1957) also observed the increase in disease incidence with depth. Bhatnagar and Mali (1983) confirmed the earlier results and reported little infection in shallow sowings. Several methods have been used to determine germination rate (Tucker and Wright, 1965; Timson, 1965; Nicholas and Heydecker, 1968). The speed of germination has been shown to be positively correlated with seed vigour in wheat, rye and barley

positively correlated with seed vigour in wheat, rye and barley (Germ, 1960). Germination percentage, root length, shoot length and seed size correlated with dry matter in sorghum (Singh and Makne, 1985).

Host resistance

Host resistance has been used against flag smut in many areas of world. Mc Alpine (1910) started to locate sources of resistance in wheat against flag smut. He reported that out of ten wheat varieties in Australia, all the ten were susceptible at one location and only four at the other location. Many workers (Carne, 1924; Carne and Limbourn, 1927; Limbourn, 1928; Pridham *et al.*, 1929; Millikan and Sims, 1937; Phipps *et al.*, 1943) reported the reaction of many wheat varieties to flag smut in Australia. Pal (1951) reported that resistance to flag smut was inversely related with loose smut. Sources of resistance to flag smut have been reported by several workers in India. Pal and Mundkur (1941) tested 97 wheat varieties against flag smut and found only six varieties to be resistant and two varieties viz., 1P 4 and 1P 111, as highly resistant. Mundkur (1946) reported that out of a total of 129 wheat varieties tested in 1942-43 and 1943-44, 53 were immune, 19 highly resistant and remaining highly susceptible. Goel and Jhooty (1984) screened several commercial varieties and some international elite wheat lines under artificial seed inoculation and reported that all the 14 lines of *T. durum* were

WH 147 and UP 310 were moderately to highly susceptible. Of the 163 commercial Indian and International wheat cultivars evaluated for resistance to flag smut under artificial seed inoculation, 32 lines were found to be immune, 16 highly resistant and 28 moderately resistant (Goel and Gupta, 1990), while all the 13 tetraploid wheat tested were immune. Out of 126 strains of *T. aestivum* and *T. durum* screened for reaction to *U. agropyri*, 19 strains of *T. aestivum* and 2 of *T. durum* were resistant (Bhatnagar *et al.*, 1991). In a study, Beniwal *et al.*, (1992) evaluated 148 entries belonging to bread, macroni and triticale wheat for 3 crop season and reported that all the 23 entries of Macroni and triticale wheat were immune and out of 125 bread wheat lines 23 were immune, 7 highly resistant, 24 moderately resistant, 21 moderately susceptible, 23 susceptible and 27 highly susceptible. Beniwal *et al.*, (1993) evaluated wheat and triticales against flag smut using seed inoculation and observed 46 macroni and 4 triticale entries to be free from flag smut infection and out of 155 bread wheat only 17 were free from the disease. Singh *et al.*, (1997) evaluated 87 wheat and triticale genotypes and wheat x triticale crosses, were evaluated for resistance to flag smut under artificial inoculation conditions at Hisar during 1992-93 and 1993-94. All of the durum wheat and triticale genotypes included in the study (8 and 13, respectively) showed complete freedom from flag smut incidence. Bread wheat genotypes gave variable disease

reactions from complete freedom to high susceptibility. Similarly, wheat x triticale crosses showed differential flag smut incidence ranging from no disease incidence to moderately resistant disease response.

Effect of disease on physiological parameters

Respiration

Increased respiration in tissues generally accompanies a variety of pathological conditions (Allen (1953); Uritani and Akazawa, 1959; Sadasivan, 1964; Rubin and Artsikhoskaya, 1963 and Daly, 1976) except in plants systemically infected with viruses. A study of the altered respiration of infected plants is also of interest to plant physiologists and biochemists investigating the nature of the respiratory rate. Prior to 1953, studies on respiratory stimulation in infected plants were confined mainly to the quantitative aspect of the increase. It was Allen (1953) who first pointed out that the disease was result of disturbances in host metabolism induced by the diffusible metabolites (toxins) of the parasite. He postulated that increased respiration in mildew disease was the result of a toxin produced by the fungus which uncouples phosphorylation from electron transfer in host cells. Attempts have been made by several workers to isolate toxic agents inducing stimulation of respiration (Millerd and Scott, 1955; Daly and Sayre, 1957; Bushnell and Allen, 1962).

The respiration rate of plants is usually increased by infection, sometimes within hours of inoculation, but large increases (upto 50%) typically occur shortly before the symptoms appear. Both facultative and obligate parasite are able to evoke this respiratory increase in host tissue. Millerd and Scott (1955) presented data indicating that an uncoupling factor could be isolated from barley infected with powdery mildew and was responsible for the increase in respiration of barley leaves infected with *Erysiphe graminis* var. *hordei*. The results obtained by Samborski and Shaw (1956) and Shaw and Samborski (1957) were also interpreted as a host mediated respiratory rise in wheat infected by *Puccinia graminis tritici*.

A significant positive correlation between rates of O₂ uptake during imbibition and later stages of germination and seedling growth in corn was observed (Woodstock and Grabe, 1967). They also reported a high correlation between respiration quotients and seedling growth. The relationship of seedling vigour and respiration in wheat was studied by Kittock and Law (1968). The significant positive correlations were found between rate of emergence and vigour, emergence and rate of respiration and between vigour and both tetrazolium chloride reduction rate of respiration for seeds of different ages. The mechanical injury in seeds complicated the interpretation of respiration results, which may increase rather than decrease respiration rates (Woodstock, 1969).

The deteriorated wheat seeds also showed reduced respiration (Anderson and Abdul-Baki, 1971). The spring wheat yield variation among samples was most consistently dependant on standard germination, O_2 uptake and field emergence (Das Gupta and Austenson, 1973b). They reported that the rate of O_2 uptake by seed during the 8th and 9th hour of imbibition was satisfactory indicator of seed vigour.

The field emergence of seed lots of barley was directly related to rate of emergence (Matthews and Collins, 1975). The rates of O_2 uptake were directly related to both rate of emergence and ultimate emergence. Correlation between seed lot, shoot lengths and respiration were not significant. There was a highly significant inverse correlation between respiration and seed lot test weight. To further understand why respiration was negatively correlated with test weight, a water uptake study was performed. The water uptake was found to be positively correlated with test weight and protein content of the planted seed. Because of this, respiration was negatively correlated with water uptake (Delaney, 1980). The respiration quantum (RQ) was reported to be negatively and significantly correlated with field emergence in wheat (Steiner *et al.*, 1989).

A significant positive correlation between seedling vigour and respiration rate in wheat has been reported by (Ram and Wiesner,

1988). Chaudhary *et al.*, (2001) pointed out that significant variation in the respiration rate was recorded when seed of wheat cultivars were treated with three insecticides. Formothion treatment affected mean respiration rate the most in cultivar Sonalika followed by WH 147 and HD 2329. Seed treatment with Chlorpyrifos of cv. Sonalika, Chlorpyrifos and Endosulfan treatment of HD 2329 was comparable with the respiration rate of respective untreated seeds. A significant variation in respiration rate existed, when the insecticide treated seed was imbibed for 24 and 48h in cultivars Sonalika, WH 147 and HD 2329. Loss of seed vigour in formothion treated seeds of cv. Sonalika was also confirmed by the lower respiration rates as compared to the seeds of cv. HD 2329.

Leaf area

Goodman *et al.*, (1986) reported that plants infected with fungi, bacteria or viruses usually exhibit a reduced photosynthesis rate. Abnormalities in form and function of chloroplasts are a common feature of diseased tissues. There is a typical decline in photosynthesis and leaf area (Berghaus and Reisener, 1985; Magyarosy *et al.*, 1976). This change may be partially (Berghaus and Reisener, 1985; Magyarosy *et al.*, 1976 and Mitchell, 1979) or completely (Berghaus and Reisener, 1985; and Wynn, 1963) accounted for by a reduction in chlorophyll content. Zelitch (1982) and Kaur and Deshpande (1980) also observed decreased

photosynthesis in leaves infected by rusts and powdery mildews along with a decrease in chlorophyll content. Acceleration of water loss from infected tissue has been attributed most frequently to epidermal rupture by pathogens (Duniway and Durbin, 1971; Goodman *et al.*, 1986; Spotts and Ferree, 1979; Tissera and Ayres, 1986) and secondarily to enhanced permeability of the tissue as a result of the infection (Yarwood, 1947), inhibition of stomatal closure (Turner and Graniti, 1969) or direct water loss through the fungus (Hewitt and Ayres, 1975).

Decreased respiration is caused by pathogens that cause stomatal closure, hypertrophy of chlorenchyma or spongy mesophyll cells, thereby obliterating intercellular spaces, reduction of air spaces by hyphae, and or obstruction of conducting tissue and stomata (Duniway and Durbin, 1971; Goodman *et al.*, 1986; Spotts and Ferree, 1979). It was demonstrated qualitatively through experiments under controlled environmental conditions that stem rust and leaf rust, independently increased the transpiration rate of wheat plants and that stem rust reduced photosynthetic rate and leaf area of wheat leaves (Berghaus and Reisener, 1985; Mitchell, 1979). Photosynthetic rate of cotyledons of *Raphanus sativus* and *Brassica juncea* reduced under pathogenesis of *Albugo candida* (Black *et al.*, 1968). Garg and Mandhar (1975) observed that net rate of photosynthesis of downy mildew infected pearl millet leaves was

highly reduced and it was 42.1 per cent lower in infected than the healthy ones.

McGrath and PennyPacker (1990) reported that leaf rust (*Puccinia recondita* f. sp. *tritici*) and stem rust (*P. graminis* f. sp. *tritici*) were associated with decreased apparent photosynthetic rate per unit of leaf area, photosynthetic rate per unit of chlorophyll, chlorophyll content and transpiration rate. Rust severity was also associated with increased stomatal resistance.

Akai and Fukutomi (1964) reported that chlorophyll content reduced in downy mildew (*Sclerospora macrospora*) infected rice and graminaceous hosts. Garg and Mandhar (1975) observed that chlorophyll was reduced in infected leaves of pearl millet following infection of *S. graminicola*. Total chlorophyll content was found to decrease with age in the rusted (*Puccinia arachidis*) leaves of groundnut, whereas, the reverse is true in case of healthy leaves (Subrahmanaym *et al.*, 1976). The total chlorophyll content was reduced from 58.3 to 46.8 percent in health leaves of groundnut due to tikka disease (Singh *et al* 1986). Chlorophyll content decreased significantly in downy mildew infected leaves of pearl millet at all the stage of sampling as compares to healthy leaves (Bhatia and Thakur, 1991). Kumar (1994) observed that photosynthesis rate chlorophyll content, stomatal conductance and transpiration rate decreased, where as leaf temperature increased in the downy mildew infected leaves of pearl millet.

Qualitative parameters

In vitro dry matter digestibility (IVDMD)

Regarding human and animal health no indication of harmful effects of any kind on 3 to 4 months old chicks, continuously and exclusively feed for 24 days on a mixture containing bran and finally chopped heavily flag smut infected wheat plants was observed (Verwoerd, 1929). Heitefuss *et al.* (1959) reported that three new protein antigens were produced by the host in susceptible cabbage upon infection by *Fusarium oxysporum* f. sp. *conglutinas*. Farkas and Kiraly (1961) showed that free ammonia content of leaves increased only in wheat leaves infected with a race of stem rust which resulted in susceptible interaction. Shaw (1963) reviewed the physiology of host-parasite relations of rusts and concluded that susceptibility to rust was characterised by the increased amount of protein in host plant. Strobel and Sharp (1965) found the presence of certain host protein in the non-infected host, being associated with infection type of *Puccinia striiformis* on wheat. It has been reported that in attached leaves of bean infected with rust fungus *Uromyces phaseoli*, there is an increased protein synthesis in the tissues of the 'green islands' surrounding the infection centre, while the tissue zones between the 'green islands' become senescent and are characterised by a low protein synthesis capacity (Kiraly *et al.*, 1966).

Goodman *et al.*, (1986) have proposed that infection by pathogen is accompanied by the biosynthesis of new pathogen protein, which

may be few in number in case of simpler viruses and several hundreds in the case of bacteria or fungi. There may be both quantitative and qualitative changes in the pattern of protein biosynthesis or degradation, which may further change the infection progress. Luthra *et al.*, (1988) observed decrease in protein content in infected leaves of susceptible variety of lucerne to downy mildew. The soluble protein content increases in blight infected leaves of all the maize cultivars tested (Sharma *et al.*, 1989). Gupta and Gupta (1991) studied the rapeseed-mustard leaves infected by *Alternaria* blight pathogen and observed decrease in protein content after infection.

In rust, alteration in the carbohydrate metabolism has been reported by several workers (Welch and Martin, 1975; Subrahmanyam *et al.*, 1976; Roberts and Mitchell, 1979). Vidhyasekaran *et al.*, (1975) discussed the possible role of sugars in development of resistance in *Setaria italica* to rust (*Uromyces setariae italica*) and found that it increased in susceptible variety upon inoculation. Saini *et al.*, (1988) observed that resistant cultivar exhibited higher amount of total soluble sugar in both the phases (vegetative and ear emergence) of wheat to loose smut. Similarly, increased amount of total sugar was observed upon infection to *Turcicum* leaf blight in maize and charcol rot (*Macrophomina phaseolina*) infected sorghum (Sharma *et al.*, 1989; Rao *et al.*, 1990) respectively. Total soluble sugars decreased in wheat infected with

A. niger and *A. tamarii* (Dube *et al.*, 1988). On the other hand Subramanyam *et al.*, (1990) found higher values of total sugars in healthy leaves of all the wheat varieties tested, than their leaf blight (*Drechslera harvatiensis*) infected counter parts. There was no significant difference in soluble sugar content in the leaves of susceptible wheat variety to their healthy counter parts, following infection by *Cochliobolus sativus* (Ma and He, 1992). But a severe decline in sugar content was observed during infection of clusterbean by *Alternaria cyamopsidis* than the healthy leaves (Bhatnagar and Kumar, 1995).

Chemical control

Control of flag smut of wheat by seed treatment began in Australia soon after its discovery in 1868 (Mc Alpine, 1910). Wet treatments almost exclusively used in earlier times included immersion of seed in Formaldehyde (Mc Alpine, 1905) or copper sulphate solutions followed by lime water (Darnell Smith, 1914; 1915; Hamblin, 1921). Almost similar recommendations were also made by Humphrey and Johnson (1919). Reed and Dungan (1920), Tisdale and Griffiths (1921). Tisdale *et al.*, (1923), Carneli (1934), Jones (1936) and Jones and El-Nasr (1940). In addition to these treatments, Tisdale *et al.*, (1923) also reported the effectiveness of chlorophol, one of the first organo-mercurial seed treatment chemicals, where as, Ling and Li (1943) found dipping of seed in

chemicals, where as, Ling and Li (1943) found dipping of seed in five per cent of ferrous sulphate solution to be partially effective.

Verwoerd (1929) controlled flag smut of wheat effectively with various dusts like Bayer, Cuprite, Germisan (crrysyl mercuric cyanid), copper carbonate, semesan (hydroxy mercurichloro phenol), semesan bel (hydroxy mercurichlorophenol + hydroxy mercuric nitrophenol). Tillantin R and Tillantin B dust but reported that these chemicals failed to eliminate the disease completely. Similarly, El-Helaly (1948) reported only partial control of this disease with Germisan, Uspulum, Sulphur, Copper carbonate and Agrosan GN. Scaramuzzi (1951) obtained only partial control of this disease with Caffaro powder in tests conducted in Italy. Chu *et al.*, (1955) reported effective control of flag smut with red arsenic powder (mixture of AS_2O_3 and AS_2O_2 in the ratio 10:1).

Several earlier workers (Hamblin, 1921; Tisdale *et al.*, 1923) pointed out that chemicals used for flag smut control were effective only against seed-borne spores and none could control infection originating from soil-borne spores. Cass Smith (1954) and Purdy (1963) also failed to control flag smut under field conditions with hexa-chlorobenzene at the recommended rates of application, although this treatment was shown to be effective against both seed borne and soil borne infections of bunt in the Pacific North West by Purdy (1957). Subsequently, an effective control of this disease

with Pentachloronitro benzene (PCNB) by Yasu and Yoshino (1963) and with tetra-chloronitroanisole (TCNA) by Purdy (1962, 1963).

Edginton *et al.*, (1966) reported the inhibition of mycelial growth of several basidiomycetes with 2,3-dihydro-5-carboxanilido-6-methyl-1, 4-oxathiin (DCMO or Carboxin) at concentrations of less than eight ppm. Hardison (1966) also studied the therapeutic activity of the two systemic fungicides DCMO (carboxin) and DCMOD (oxycarboxin, i.e. 2,3-dihydro-5-carboxanilido-6 Methyl-1, 4-Oxathiin-4, 4-dioxide) against several rusts and smuts of grasses.

In the sub-continent of Indo-Pakistan, Sattar and Hafiz (1952) for the first time attempted chemical control of seed borne as well as soil borne infection of *U. agropyri* with copper carbonate, copper sulphate and sulphur dusts, formalin and copper sulphate solutions and ceresan. Copper carbonate dust regulated in 40 per cent reduction in seed borne and 85 per cent reduction in soil borne infection. While Ceresan reduced both seed borne and soil borne infections by 90-99 per cent. In addition, the efficacy of copper carbonate dust and ceresan treatments enhanced when wheat seed was sown at shallow depths or if the field was irrigated within three days after sowing.

In Punjab, Bedi (1957) recommended seed treatment with ceresan or Agrosan GN @ 1:400 for controlling flag smut in susceptible cultivars of wheat. Tyagi *et al.*, (1970) tested nine fungicides namely Tillex, seed dresser 6335, ceresan dry, ceresan

wet, Agrosan GN, Tapasan 6W, Thiram, Captan and Petachloronitrobenzene (PCNB) as seed treatments for the control of seed borne flag smut infection of wheat. Tafasan 6W among the mercurials and PCNB among the non-mercurials were found to be the most effective.

Several fungicides namely Vitavax, Plantvax, Brassicol, Trameton and Agrosan GN were tried as seed treatment against flag smut in Punjab (Anonymous, 1970). Out of these vitavax, plantvax and trameton were found to be the most effective. Tyagi (1972) and Bedi *et al.* (1975) confirmed the efficacy of vitavax and plantvax for control of seed and soil-borne flag smut of wheat. Among non-systemic organic fungicides tested tetra chloronitroanisole (TCNA) gave maximum protection followed by Brassicol, Thiram and Captan.

Bhatnagar *et al.*, (1975) reported almost complete disease control with Campogram M, Benlate and Vitavax seed dressing in Rajasthan. Later studies (Anonymous, 1979) conducted by All India Co-ordinated wheat improvement project, Durgapura (Rajasthan) also showed that this disease could be effectively controlled with 0.2 per cent of either of the systemic fungicides like benlate, Brassicol, Vitavax and Bavistin.

Out of the several fungicides including Bavistin, Bayer 5072, Bayleton, Benlate, Captan, Ceresan dry, Thiram, Thiram + Bayer 5072 and Vitavax tested as seed dressing for controlling this disease in Punjab (Anonymous, 1980), Vitavax gave best control followed by

Bavistin treatment and Thiram and Bayer 5072 combination treatment Captan, Thiram and ceresan singly were not effective. Similarly, Raina *et al.*, (1988) evaluated eight fungitoxicants, namely, vitavax, Benlate, Bavistin, Aureofungin, Difolatan, Brassicol, Captan and Dithane M-45 for their efficacy in controlling the incidence of flag smut of wheat under conditions of artificial seed and soil inoculations at Gurdaspur (Punjab). Vitavax closely followed by Benlate and bavistin were found to be the most effective whereas Difolatan and Brassicol were moderately effective. Goel and Jhooty (1985) reported that fungitoxicants, Benlate, Bavistin and Vitavax provided a significant control of flag smut. Bhatnagar and Mali (1983) reported 92-100 per cent disease control with seed dressing of Bavistin and Vitavax. Tariq *et al.*, (1992) obtained complete control of the disease with carboxin and tebuconazole in a susceptible wheat variety from Pakistan. Sindhan *et al.*, (1996) evaluated four fungicides for the control of flag smut of wheat Vitavax 75 WP (carboxin), Bavistin 50 WP (carbendazim), G 696 20WP and Raxil 2DS (tebuconazole). All the fungicides significantly reduced flag smut at all dose levels.

Some chemicals not developed as fungicides have fungistatic or fungitoxic effect. BHC, Chlordane, DDT and aldrin have been reported to inhibit the growth of soil fungi (Bollen *et al.*, 1954; Smith and Wenzel, 1947). Richardson (1957) also reported reduction in

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root rot infection in barley caused by *Helminthosporium sativum* with application of aldrin, endrin, chlordane and heptachlor, dieldrin, endrin, aldrin, lindane have been found to be reducing the early blight of tomato caused by *Alternaria solani*, while endrin, aldrin and DDT reduced the vascular wilt of tomato caused by *Fusarium oxysporum* f. sp. *lycopersici* (Richardson, 1959). Pal and Das (1969) reported that *Helminthosporium oryzae* reduced leaf infection in rice plants grown in diazinon and phorate treated plants than in untreated ones. Triazophos, methyl parathion and pizimicarb inhibited the mycelial growth of *Fusarium roseum* f. sp. *secalis*, *Septoria nodorum* and *Helminthosporium sativum* *in vitro* (Eichler *et al.*, 1976).

Mukhopadhyay and Thakur (1977) tried carbaryl + gammaBHC, quinalphos and phorate against *Sclerotium rolfsii* Sacc. causing root rot of sugarbeet and found these soil insecticides to be much effective in inhibiting the fungal growth and reducing sclerotial formation on potato-dextrose medium. Rod (1983) reported inhibition in the growth of *Botrytis* sp. *in vitro* with the use of insecticides (Bromophos and Primiphos). Singh (1987) reported reduction in cowpea seedling rot (*Rhizoctonia solani*) with endosulfan seed treatment. Arya *et al.*, (1997) evaluated isoprothiuron and 2-4, D as foliar sprays which reduced disease incidence in wheat plants inoculated with *U. agropyri*. Of the insecticides tested, phorate controlled *U. agropyri* best in field and greenhouse trials. Other insecticides Aldrin 35 EC, BHC 10WP and Aluminium phosphide also reduced disease incidence.

CHAPTER-3

MATERIALS AND METHODS

Collection of Inoculum

Inoculum of *Urocystis agropyri* was collected from diseased wheat plants of cv. WH 147 from infected field of the Department of Plant Pathology, CCS Haryana Agricultural University, Hisar during 1999-2000 crop season. Dried and chopped diseased wheat plant material was stored at room temperature (25-40°C). After five months of storage the diseased plant material was taken out and ground against an iron wire-mesh so that the smut spores are released. These smut spores were collected and passed through a fine wire mesh so as to obtain the flag smut inoculum powder (FSIP) in form of diseased material containing spores. This powder containing spore mass was used for seed inoculation in various investigations carried out during the course of present studies.

Seed Inoculation

For inoculation of seed, two inoculum levels, ten grams and twenty grams of FSIP was used for Kg⁻¹ of wheat seed. The flasks containing wheat seed and inoculum were thoroughly shaken to

Plate 1



Plate 2



Initial black linear stripes of flag smut of wheat covered with epidermis

ensure a uniform coating of inoculum over the seed surface. Such inoculated seeds were used for various studies except other wise stated.

Field experiments

The experimental sowing in both the crop seasons, during 2000-2001 and 2001-2002, were invariably done in the first week of December, in plots of 5 x 1.5 M at 25 cm apart, except otherwise stated in the specific experiments. The sowing was done at a depth of 4 to 5 cm in sandy loam soil in the experimental area of Plant Pathology Department, CCS Haryana Agricultural University, Hisar. All the recommended package of practices were followed during both the crop seasons.

Recording of Disease incidence

Disease incidence was recorded at near the crop maturity in the first week of April. A plant was considered to be infected even if single tiller showed typical disease symptoms on the stem, culm and leaf. The leaf and leaf sheaths are most commonly affected. The disease manifests itself from the late seedling stage to the time^{when} the crop is mature. Grey and greyish black linear sori appear on the leaf blades and leaf sheaths. Leaves get twisted and begin to droop and then wither. Sori develop under the epidermis in mesophyll tissue. Later, the epidermis rupture exposing a black powdery mass of spores and finally the leaf tissue disintegrated along the linear sori.

Plate 3



Plate 4



Heavily infected plants with flag smut bearing no ear head

Total plants and number of infected plants were counted separately and per cent disease incidence was calculated. The varieties were classified for disease reaction according to scale employed by Singh and Sethi (1975) with slight modifications as under :

Disease incidence (%)	Reaction
No incidence	Highly resistant (HR)
0.1-2.0	Resistant (R)
2.1-5.0	Moderately resistant (MR)
5.1-10.0	Moderately susceptible (MS)
10.1-20.0	Susceptible (S)
> 20.0	Highly susceptible (HS)

Ten plants randomly from each plot were selected for studying the tillering, yield per plant, plant height, ear head length and grain weight in each variety.

Evaluation of wheat varieties/cultivars against *U. agropyri*

Twenty one varieties widely grown in northern parts of country consisting of 20 bread wheat, 1 durum wheat were evaluated for resistance to flag smut of wheat during the year 2000-2001 and 2001-2002 (Table 1). The seed of each variety was artificially inoculated

Plate 5



Plate 6



Advance symptoms of flag smut on flag leaves, rachis, glumes and awns

as per procedure described earlier and sown in paired row of 5 M length. The disease incidence was recorded and the varieties were graded as described earlier.

Studies on the effect of inoculum load on seed and seedling vigour

Seeds of all the twenty one varieties were smeared with two levels of inoculum, that are 10 and 20 gm inoculum powder Kg^{-1} of seed, in flasks till the all inoculum powder adhere to the seed surface. Then 400 seeds from each variety were taken out randomly and then seeds (100x4) were placed on a moist towel paper at equidistantly for germination and then rolled papers were put in a seed germinator at $20 \pm 1^\circ\text{C}$ for 7 days and R.H. was maintained > 90 per cent. On 8th day seed germination was recorded and per cent seed germination was calculated. First count of normal seedlings was recorded on 4th day and final count on 8th day (ISTA, 1985) and normal seedlings were expressed as per cent germination.

Speed of germination

All the twenty one varieties were tested for speed of germination. The inoculum was applied to the seed @ 20gm Kg^{-1} seed. Emergence was recorded starting from 4th day then daily till the final count (i.e 8th day). The index of speed of germination was calculated as described by Maguire (1962).

$$\text{Speed of germination} = \frac{\text{No. of normal seedlings}}{\text{Days of first count}} + \frac{\text{No. of normal seedlings}}{\text{Days of final count}}$$

and their root and shoot length were measured with help of scale in centimeters. Then roots were chopped separately and then chopped roots and shoot of five seedlings of each replicate were put in paper envelope and kept at 80°C for 24 hours and recorded the dry weight.

Weather conditions

In general, the weather conditions during the growing seasons of crop (November to April) was favourable for the development of flag smut of wheat. Monthly Meteorological data on rainfall (mm), relative humidity (%), temperature (°C) and sunshine (hr) during the crop seasons is depicted in Appendix-I and II.

Effect of weather variables on the development of flag smut under field conditions

A field experiment was conducted to study the role of environmental factors on the progress of flag smut. Four cultivars, out of which two were highly susceptible (WH-147 and C-306), two susceptible (WH-542 and HD 2687) were sown during the last week of November, during 2001 and first week of December during 2002 in a randomized block design having a plot size of 5 x 1.5 m². All the agronomic practices were followed for raising the crop.

The temporal progress of the disease was recorded after every 10th day starting from the appearance of the disease on ten randomly selected plants for each of four cultivars using 0-5 scale.

Recording of weather parameters

The relevant data on environmental variables viz., Maximum

and Minimum temperature ($^{\circ}\text{C}$), relative humidity morning, evening (%), sunshine (hrs) and rainfall (mm) corresponding to the disease observation interval, were obtained from observatory, Department of Meteorology, CCS Haryana Agricultural University, Hisar. The average weather data was used for analysis.

Area under disease progress curve (AUDPC)

The area under disease progress curve was calculated using the formula as proposed by Wilcoxson *et al.* (1975).

$$\text{AUDPC (A-Value)} = \sum_{i=1}^k \frac{1}{2} (S_i + S_{i-1}) \times d$$

where, S_i = Disease intensity at the end of the week i ,

k = the number of successive evaluation of disease

d = Interval between two evaluations (i and $i-1$)

Per cent disease index (PDI) was calculated by formula given by Mc Kinney (1923).

$$\text{PDI} = \frac{\text{Sum of all numerical ratings}}{\text{Total number of plant assessed}} \times \frac{100}{\text{Maximum grade}}$$

Effect of disease on respiration

Seed of six cultivars namely WH 147 and C 306 (highly susceptible), WH 542 and HD 2687 (Susceptible), HD 2329 and WH 896 (Resistant) were inoculated with fine powder of flag smut of wheat @ 20gKg^{-1} of seed in a flask. Then respiration of inoculated seeds of all the three categories (Highly susceptible, susceptible and

resistant) along with control (uninoculated) was measured as mentioned below :

First Set

The oxygen uptake was measured by Gilson Differential Respirometer. After soaking seeds for 48h in moist rolled towel paper at 20°C, five seeds were placed in a reaction flask having 2ml of distilled water outside and 0.2 ml KOH (10%) in side the control well. The temperature of the water bath of the respirometer was set at 20°C. The reaction flasks were placed in the water bath and subjected to shaking of 78 oscillations min⁻¹ for 30 min and oxygen uptake was measured. Each sample was repeated three times.

Second Set

Ten days old inoculated as well as healthy seedlings of each variety grown in pots were used for second set. Two seedlings were placed in 2ml distilled water in a reaction flask and replicated three times. The remaining procedure is the same as in case of first set.

Third Set

Diseased as well as healthy plants of each varieties were uprooted from field and placed in polythene bags containing moist soil. One diseased tiller as well as one healthy tiller placed in 2ml distilled water in a reaction flask separately and replicated three times. The remaining procedure is the same as in case of first set.

The respiration rate was reported as microlitres of oxygen absorbed per seed per hour ($\mu\text{O}_2/\text{seed/h}$) as well as microlitres of

oxygen per gram per hour ($\text{m}^3/\text{L}/\text{O}_2/\text{g}/\text{h}$) at Standard temperature and pressure.

$$\text{Respiration rate (RR)} = \frac{\text{O}_2 \text{ consumed}}{\text{Number of seedling}} \times \text{time}$$

Effects of disease on leaf area

Leaf area was measured by leaf area meter. Ten plants, diseased as well as healthy, were tagged in each variety. All the leaves of plants i.e from first to six, were measured by Leaf area meter. The total area of the leaves of the healthy as well as diseased was measured. The per cent loss in the leaf area of the diseased plants was calculated on the basis of leaf area of healthy plants leaves.

Qualitative characters

In vitro dry matter digestibility (IVDMD). In vitro dry matter digestibility was determined by the method of Tilley and Terry (1963).

Reagents:

- 1) Me Dongall's buffer solution.
 - a) Solution No.1 : Prepared by dissolving 3.7 g anhydrous Na_2HPO_4 and 9.8g NaHCO_3 in one litre of distilled water at 39°C .
 - b) Solution No.2: This solution was prepared by dissolving 4.7g NaCl , 5.7g KCl , 0.4g CaCl_2 and 0.6gm MgCl_2 in 100 ml of distilled

water..

The buffer solution was prepared by mixing 10 ml of Solution No.2 to one litre of Solution No.1 and CO₂ was allowed to pass slowly through it till become pH 6.8-6.9

ii) Pepsin (1: 3000 units)

iii) 6 N HCl.

iv) Inoculant: The rumen fluid for inoculation was obtained from the Fistulated young calves maintained on a constant ration. Rumen liquor was removed from the animals with the help of a suction strainer, stored in thermoflask at 39°C and brought to the laboratory for immediate use. After thorough mixing, the rumen fluid was strained through several layers of fine muslin cloth to remove large particles.

Method

To 250 mg dried plant material added 20ml of Me Dougall's buffer solution in a 50 ml tube fitted with a gas release valve. Then 5ml of rumen fluid was added to each tube which served as inoculum. Carbon dioxide was passed over the surface of the tube contents for about 2 min. Tubes were stoppered immediately and incubated at 39°C for 48h. The tubes were swirled gently during incubation period to suspend the substrate. After 48h, 0.1gm of pepsin and 2ml of 6N HCl were added to each tube and mixed thoroughly. The tubes were incubated for an additional 48h and filtered through Whatman

incubated for an additional 48h and filtered through Whatman No.4 filter paper using a funnel. The tubes were rinsed four times with hot distilled water (90-100°C). The residue on the filter paper was dried in an oven at 100°C for over night and its weight was taken again. Suitable blanks with buffer solution and rumen fluid were run simultaneously. *In vitro* dry matter digestibility was calculated by subtracting the weight of the residue from the original weight of the sample.

Interaction of recommended insecticides with fungicides for disease management.

First of all, seeds of highly susceptible cv. WH 147 were inoculated with dose of inoculum, i.e 20gm inoculum Kg⁻¹ seed, in a flask and uninoculated seed served as control. The seeds were then treated with recommended insecticides, Chlorpyrifos @ 1.5ml in 50 ml of water Kg⁻¹ seed and Endosulfan @ 3.5ml in 50 ml of water Kg⁻¹ seed which are recommended for controlling termites by the University in the package of practices. The seeds were then dried in the shade. After drying the seed, they were treated with three recommended fungicides, Vitavax-200WP, Vitavax 75WP and Bavistin 50WP and with a new fungicide i.e Raxil at two different dose (0.1 and 0.2 per cent) only inoculated, only treated with insecticides, only treated with fungicides and their different combination were prepared. Then sowing was done in randomized block design having a plot size of 5X1.5m² during the month of end

of November and first week of December. All the agronomic practices were followed for raising the crop. Percent disease incidence on plant basis and tiller basis was calculated at near the maturity of the crop during both the crop seasons.

Yields and Yield components

Twenty one commercially grown wheat varieties in the northern zone were inoculated with FSIP@ 20g Kg⁻¹ seed and then sown in a randomized block design having a plot size of 5x1.5m² during end of November in both the years (2000-01 on 2001-02). Untreated seed served as a control. All the agronomic practices were followed for raising the crop. Near the maturity of the crop disease incidence on plant and tiller basis was recorded. Number of tillers, plant height, ear head length, 1000 grain weight were also recorded at maturity.

Table 1 : Details of wheat varieties used in present studies

Reaction	Species	Genotypes
HR No incidence	<i>T. aestivum</i>	UP 2425, WH 291, HD 2329, WH 283
	<i>T. durum</i>	WH 896
MR (2.1-5.0%)	<i>T. aestivum</i>	Sonalika
MS (5.1-10.0%)	<i>T. aestivum</i>	WH 533
Susceptible (10.1-20.0%)	<i>T. aestivum</i>	UP 2338, Raj 3777, PBW 435, WH 542, Raj 3765, HD 2687, WH 157
HS (> 20%)	<i>T. aestivum</i>	HD 2009, PBW 343, PBW 373, WH 147, C-306, WH 416, HD 2285

HR = Highly Resistant

MR = Moderately Resistant

MS = Moderately Susceptible

S = Susceptible

HS = Highly Susceptible

CHAPTER-4

RESULTS

Flag smut of wheat is occurring regularly since 1987-88 in Haryana. Due to continuous cultivation of susceptible varieties in affected fields under favourable environment, it has emerged as a serious problem. The information on this disease regarding effect of inoculum load on seed and seedling vigour, physiological parameters, particularly respiration and leaf area, *in vitro* dry matter digestibility and interaction of recommended insecticides with recommended fungicides for controlling the disease is limited. Hence, the present investigation was aimed to obtain information on the above aspects and the results have been presented as under :-

Effect of inoculum load on seed and seedling vigour

A set of twenty one varieties was inoculated with two levels of flag smut inoculum powder (FSIP) that are 10 g and 20 g inoculum Kg⁻¹ seed. Uninoculated seed served as control. Germination test was conducted by rolled paper towel method (ISTA, 1985). The rolled towel papers were put in seed germinator at 20°C ± 1 for 7 days and

on 8th day per cent seed germination was recorded.

The per cent seed germination was not significantly affected by any level of inoculum as compared to control in resistant varieties (Table 2). The per cent germination was 96.00 at 10 g and 20 g inoculum level Kg^{-1} seed in variety UP 2425 as compared to 96.50 in control meaning there by, there was no effect of inoculum on seed germination in resistant varieties whereas, in case of highly susceptible varieties, WH 147 and C 306, the germination percentage was decreased significantly below the ISTA standard that is 85 per cent. The per cent germination was 71.00 and 65.00 at 10 g and 20 g inoculum Kg^{-1} seed respectively in case of WH 147 as compared to 86.50 in control which differ significantly with each other. Almost same results were obtained with C 306, another highly susceptible variety. The results presented in Table 2 clearly showed that inoculum had no adverse effect on resistant varieties whereas, germination is significantly reduced in highly susceptible and susceptible varieties.

Five seedlings from each replication from previous experiment were randomly chosen and their root and shoot length was measured with the help of scale in cm and results are presented in (Table 3). The data revealed that root length of resistant varieties namely UP 2425, WH 291, HD 2329, WH 896 and WH 283 was not affected significantly by any level of inoculum as it was almost same in all

Table 2: Effect of inoculum load on per cent seed germination in different wheat varieties

Variety	Seed germination (%)		
	0 g Kg ⁻¹ seed	10 g Kg ⁻¹ seed	20 g Kg ⁻¹ seed
UP 2425	96.50	96.50	96.00
WH 291	94.29	94.00	93.50
HD 2329	94.25	93.75	93.00
WH 896	97.00	96.50	96.25
WH 283	97.00	97.00	97.00
Sonalika	91.00	88.50	87.50
WH 533	85.50	80.00	78.50
WH 157	89.25	88.29	87.50
PBW 435	90.50	87.00	85.50
Raj 3765	92.50	88.75	85.00
HD 2687	88.75	83.75	81.00
WH 542	88.00	81.00	80.50
UP 2338	85.75	79.50	77.50
Raj 3777	92.50	86.50	84.50
PBW 373	86.75	82.50	80.50
WH 416	92.50	86.50	85.00
HD 2009	87.75	83.00	80.50
PBW 343	88.50	80.25	77.50
C 306	87.75	80.00	79.50
HD 2285	90.50	80.00	78.50
WH 147	86.50	71.00	65.00

C.D. (P=0.05)

Inoculum = 1.42

Variety = 3.78

Inoculum x variety = 6.54

Table 3: Effect of inoculum load on root length of different wheat varieties

Variety	Root length (cm)		
	0 g Kg ⁻¹ seed	10 g Kg ⁻¹ seed	20 g Kg ⁻¹ seed
UP 2425	11.00	10.75	10.75
WH 291	12.00	12.00	12.00
HD 2329	10.50	10.50	10.25
WH 896	12.75	12.50	12.50
WH 283	11.00	11.00	11.00
Sonalika	10.75	10.00	9.75
WH 533	8.50	7.75	7.25
WH 157	10.00	9.25	9.00
PBW 435	10.25	8.75	8.50
Raj 3765	10.00	9.00	9.00
HD 2687	10.00	9.00	8.75
WH 542	8.00	7.25	7.00
UP 2338	9.50	8.25	8.50
Raj 3777	10.50	9.00	8.75
PBW 373	9.00	8.25	8.00
WH 416	8.00	7.00	6.75
HD 2009	9.25	8.00	8.00
PBW 343	9.50	8.00	7.75
C 306	12.00	10.25	10.00
HD 2285	10.50	8.50	8.25
WH 147	9.25	7.00	7.00

C.D.(P=0.05)

Inoculum = 0.28

Variety = 0.74

Inoculum x variety = 1.28

the treatments. It was 11.0, 10.75 and 10.75 cm in case of UP 2425 at 0, 10 and 20 g inoculum load Kg^{-1} seed respectively and root length was 12.0 cm at all the three levels of inoculum in variety WH 291. Whereas, in case of highly susceptible varieties, HD 2285 and WH 147, the root length was decreased significantly. The root length was 8.50 cm and 8.25 cm at 10 g and 20 g inoculum Kg^{-1} seed respectively, in case of HD 2285 as compared to 10.50 cm in control. More or less same results were obtained in WH 147, a highly susceptible variety.

The data presented in (Table 4) indicated that shoot length was not affected significantly by any level of inoculum as compared to control in resistant varieties. The shoot length was 11.00 and 10.75 cm in variety WH 291 at 10 g and 20 g inoculum level Kg^{-1} seed respectively as compared to 11.00 cm in control. So the results indicated that there was no effect of inoculum on shoot length in resistant varieties. Same results were obtained in other resistant varieties namely UP 2425, HD 2329, WH 896 and WH 283. Shoot length in different varieties ranged between 6.50 to 11.00 cm in control. Where as, it ranged between 5.25 to 10.75 and 5.00 to 10.75 cm at 10 g and 20 g inoculum Kg^{-1} seed respectively. In case of highly susceptible varieties WH 147, C 306, PBW 343 and HD 2285 the shoot length was decreased significantly. The shoot length was 7.00 and 6.75 cm at 10 g and 20 g inoculum level Kg^{-1} seed respectively, in case of PBW 343 as compared to 8.75 cm in control.

Table 4: Effect of inoculum load on shoot length of different wheat varieties

Variety	Shoot length (cm)		
	0 g Kg ⁻¹ seed	10 g Kg ⁻¹ seed	20 g Kg ⁻¹ seed
UP 2425	10.00	10.00	9.75
WH 291	11.00	10.75	10.75
HD 2329	9.00	9.00	8.75
WH 896	10.75	10.50	10.50
WH 283	10.25	10.25	10.00
Sonalika	9.75	9.00	8.75
WH 533	7.50	7.00	6.00
WH 157	9.00	8.25	8.00
PBW 435	8.25	7.25	7.00
Raj 3765	9.00	8.00	8.00
HD 2687	8.50	7.50	7.25
WH 542	6.50	5.25	5.25
UP 2338	8.25	7.25	7.50
Raj 3777	8.50	7.50	7.00
PBW 373	7.50	6.25	6.25
WH 416	6.50	5.25	5.00
HD 2009	7.25	6.00	6.00
PBW 343	8.75	7.00	6.75
C 306	10.00	8.25	8.00
HD 2285	9.00	7.50	7.00
WH 147	9.25	7.50	7.25

C.D. (P=0.05)

Inoculum = 0.23

Variety = 0.60

Inoculum x variety = N.S.

More or less same results were obtained with the varieties C 306, WH 147 and HD 2285.

From previous set of experiment five seedlings were selected randomly from each replicate and put in a paper envelope and kept at 80°C for 24 hrs. to record the dry weight. The results of which are presented in (Table 5).

The data revealed that dry weight of seedlings was not affected significantly by any level of inoculum as compared to control. It was more or less same in all the treatments in resistant varieties i.e. UP 2425 (82.62, 82.25, 82.17 mg at 0, 10 and 20 g inoculum Kg⁻¹ seed), WH 291 (87.75, 87.25 and 87.00 mg at 0, 10 and 20 g inoculum Kg⁻¹ seed). Where as, in case of highly susceptible varieties i.e. WH 147 and C 306, the dry weight was decreased significantly. The dry weight was 60.75 and 59.89 mg at 10 and 20 g inoculum level Kg⁻¹ seed respectively in case of WH 147 as compared to 67.55 mg in control. More or less same results were obtained in HD 2285 and C 306.

Speed of germination of different wheat varieties

All the twenty one varieties were tested for speed of germination. The inoculum was applied to the seed @ 20 g Kg⁻¹ seed. Emergence was recorded from the 4th day onward daily till the final count (i.e. 8th day). The index of speed of germination was calculated as described by Maguire (1962).

Table 5: Effect of inoculum load on dry weight of root and shoot in different wheat varieties

Variety	Dry weight (mg)		
	0 g Kg ⁻¹ seed	10 g Kg ⁻¹ seed	20 g Kg ⁻¹ seed
UP 2425	82.62	82.25	82.17
WH 291	87.75	87.25	87.00
HD 2329	95.00	94.52	94.27
WH 896	93.75	93.72	93.00
WH 283	81.62	81.27	81.22
Sonalika	93.37	91.10	90.96
WH 533	72.37	70.00	69.15
WH 157	78.85	74.76	74.25
PBW 435	74.50	71.67	71.25
Raj 3765	94.25	91.25	91.08
HD 2687	73.95	70.52	70.31
WH 542	47.95	43.75	43.37
UP 2338	74.32	71.25	70.77
Raj 3777	71.02	68.75	67.00
PBW 373	66.37	63.75	62.87
WH 416	82.85	76.70	76.17
HD 2009	59.32	55.32	55.17
PBW 343	54.50	50.35	50.30
C 306	98.67	92.32	91.67
HD 2285	65.37	60.35	60.00
WH 147	67.55	60.75	59.87

C.D.(P=0.05)

Inoculum = 1.06

Variety = 2.80

Inoculum x variety = 4.86

The results of which are presented in (Table 6). The data revealed that speed of germination was maximum in resistant varieties as compared to susceptible and highly susceptible varieties. The speed of germination i. e. 18.55 and 18.05 was maximum in varieties WH 291 and WH 896 respectively, followed by 17.86 in variety HD 2329. Lowest speed of germination (13.72) was recorded in highly susceptible variety WH 147. There was no effect of inoculum on seed germination in resistant varieties. Where as, in case of highly susceptible variety (WH 147) the germination per cent was decreased below the ISTA standard i.e. 85 per cent. The germination percentage was 65.00 in inoculated seed as compared to 86.50 per cent in control. So, the results clearly indicated that speed of germination was maximum in resistant varieties as compared to highly susceptible and susceptible varieties. Inoculum level had also no adverse effect on seed germination in resistant varieties, where as it was significantly reduced in highly susceptible and susceptible varieties.

Epidemiological factors affecting disease development

A field experiment was conducted to study the role of environmental factors on the progress of flag smut. Four cultivars, out of which two were highly susceptible (WH 147 and C 306) and two susceptible (WH 542 and HD 2687), were used. ^Seed of these cultivars were smeared with 20 g FSIP Kg⁻¹ and sown during the last

Table 6: Speed of germination of different wheat varieties at 20g Kg⁻¹ inoculum level

Variety	Speed of germination		Decrease in speed of germination (%)	Seed germination (%)	
	H	D		H	D
UP 2425	17.69	17.67	0.11	96.50	96.00
WH 291	18.61	18.55	0.33	94.25	93.50
HD 2329	17.90	17.86	0.22	94.25	93.00
WH 896	18.20	18.05	0.84	97.00	96.25
WH 283	17.99	17.98	0.05	97.00	97.00
Sonalika	17.31	16.90	2.36	91.00	87.50
WH 533	16.52	15.44	6.53	85.50	78.50
WH 157	17.23	16.56	4.29	89.25	87.50
PBW 435	17.53	16.01	8.67	90.50	85.50
Raj 3765	16.88	15.52	8.05	92.50	85.00
HD 2687	16.82	15.54	7.60	88.75	81.00
WH 542	16.54	15.41	8.70	88.00	80.50
UP 2338	17.01	15.36	9.70	85.75	77.50
Raj 3777	16.93	15.50	8.44	92.50	84.50
PBW 373	17.11	15.93	6.89	86.75	80.50
WH 416	16.61	15.03	9.51	92.50	85.00
HD 2009	15.89	14.89	6.29	87.75	80.50
PBW 343	15.71	13.65	13.11	88.50	77.50
C 306	15.79	14.05	11.01	87.75	79.50
HD 2285	16.17	14.62	9.58	90.50	78.50
WH 147	15.27	13.72	10.15	86.50	65.00

C.D. (P=0.05)

H = Uninoculated

D = Inoculated

Inoculum = 0.07

Variety = 0.24

Inoculum x variety = 0.35

week of November during 2000 and first week of December during 2001 in a randomised block design having a plot size of 5 x 1.5 m². The observations on disease incidence were recorded at weekly interval just after the appearance of the disease till the full development of disease. Disease intensity and area under disease progress curve (AUDPC) were calculated and has been given in (Table 7).

Table 7: Disease intensity and area under disease progress curve of different cultivars of wheat during 2000-01

Variety	Disease intensity (%)	AUDPC
WH 147	45	293.50
C 306	43	282.00
WH 542	16	107.00
HD 2687	18	119.50

It is evident from the persual of the data presented in (Table 7) that disease intensity ranged between 16 to 45 per cent. The cultivars WH 542 and HD 2687 showed less disease as compared to WH 147 and C 306. The later two cultivars were from highly susceptible group as they showed 45 and 43 per cent disease intensity, respectively. Whereas, susceptible cultivars namely WH 542 and HD 2687 recorded 16 and 18 per cent disease respectively.

Further area under disease progress curve (AUDPC) was calculated on the basis of weekly observation recorded for disease

development. The AUDPC ranged between 107 to 293.50. The AUDPC was found more in case of highly susceptible cultivars namely WH 147 and C 306 and it was 282 and 293.5 respectively, whereas, AUDPC for susceptible cultivars WH 542 and HD 2687 was 107.0 and 119.5 respectively.

More or less same results were obtained during 2001-2002. The disease intensity ranged between 15-44 per cent. In highly susceptible cultivars, WH 147 and C 306, the disease intensity was 44 and 41 per cent as compared to 17 and 15% in case of susceptible cultivars namely WH 542 and HD 2687 respectively. The AUDPC ranged between 105.0 to 285.0. In highly susceptible cultivars WH 147 and C 306 the AUDPC was 285.0 and 287.0 respectively whereas, for susceptible cultivars WH 542 and HD 2687 it was recorded 105 and 119.50, respectively (Table 8).

Table 8: Disease intensity and area under disease progress curve of different cultivars of wheat during 2001-02

Variety	Disease intensity (%)	AUDPC
WH 147	44	285.00
C 306	41	278.00
WH 542	17	119.50
HD 2687	15	105.00

Progression of flag smut on different cultivars of wheat with weather variables

Under field conditions progress of flag smut disease was affected by crop season, type of host cultivar grown and availability of pathogen's inoculum. The different weather parameters viz., maximum temperature, minimum temperature, mean temperature, relative humidity morning, relative humidity evening, mean relative humidity and sunshine hours affecting development of disease under field conditions were taken into account. Flag smut progression was studied on four cultivars namely WH 147, C 306, WH 542 and HD 2687. Progress of disease was measured at seven days interval during both the crop season.

The results presented in (Table 9) showed that maximum increase in disease was observed in variety WH 147 followed by C 306, HD 2687 and WH 542. The periodic increase in disease intensity i.e. 22.26, 17.93, 7.20 and 7.13 per cent in different cultivars was maximum on 2nd February, 2001 when favourable weather parameters like maximum temperature (20.7-22.7°C), minimum temperature (3.1-3.4°C), relative humidity morning (92.8-97.2%), relative humidity evening (39.4-54.4%) and sunshine hrs. (5.7-7.3) prevailed (Fig. 1).

There was progressive decline in the periodical increase in disease intensity on all the varieties with the increase in temperature and decrease in relative humidity.

Table 9: Cumulative and periodical progression of flag smut of wheat in relation to weather parameters during 2000-2001

Observation	Varieties				Weather parameters						
	WH 147	C 306	WH 542	HD 2687	X ₁	X ₂	X ₃	X ₄	X ₅	X ₆	X ₇
19.01.2001	1.66 (0.0)	1.23 (0.0)	1.13 (0.0)	1.10 (0.0)	19.9	6.1	13.0	96.4	60.0	78.2	6.8
26.01.2001	11.50 (9.84)	12.73 (11.5)	5.50 (4.37)	6.30 (5.00)	22.7	3.1	14.9	97.2	54.4	75.8	5.7
02.02.2001	33.76 (22.26)	30.66 (17.93)	12.63 (7.13)	13.50 (7.20)	20.7	3.4	12.1	92.8	39.4	66.1	7.3
09.02.2001	53.10 (19.34)	50.73 (20.07)	16.76 (4.13)	17.40 (3.90)	22.9	4.1	13.5	87.8	25.6	56.7	9.3
16.02.2001	64.16 (11.06)	65.33 (14.60)	19.66 (2.9)	20.65 (3.25)	21.1	1.0	11.3	92.0	29.1	60.5	9.4
23.02.2001	67.13 (2.97)	67.76 (2.43)	72.16 (2.50)	23.50 (2.85)	23.5	2.0	12.8	87.6	28.6	58.1	9.4
02.03.2001	70.53 (2.47)	70.33 (2.60)	25.33 (1.33)	26.40 (2.1)	25.9	7.2	16.9	90.7	33.0	61.3	8.1
09.03.2001	73.00 (2.47)	72.93 (2.60)	26.66 (1.33)	28.50 (2.1)	28.0	5.3	16.7	86.3	20.4	53.3	9.4
Mean	46.85	46.46	16.22	17.16							

D.O.S. : 27.11.2001

X₁ = °C(Max); X₂ = °C(min); X₃ = °C(Av.); X₄ = R.H.(M); X₅ = R.H.(E); X₆ = R.H.(Av.); X₇ = Sunshine hr.
Values in parenthesis are the periodic progression

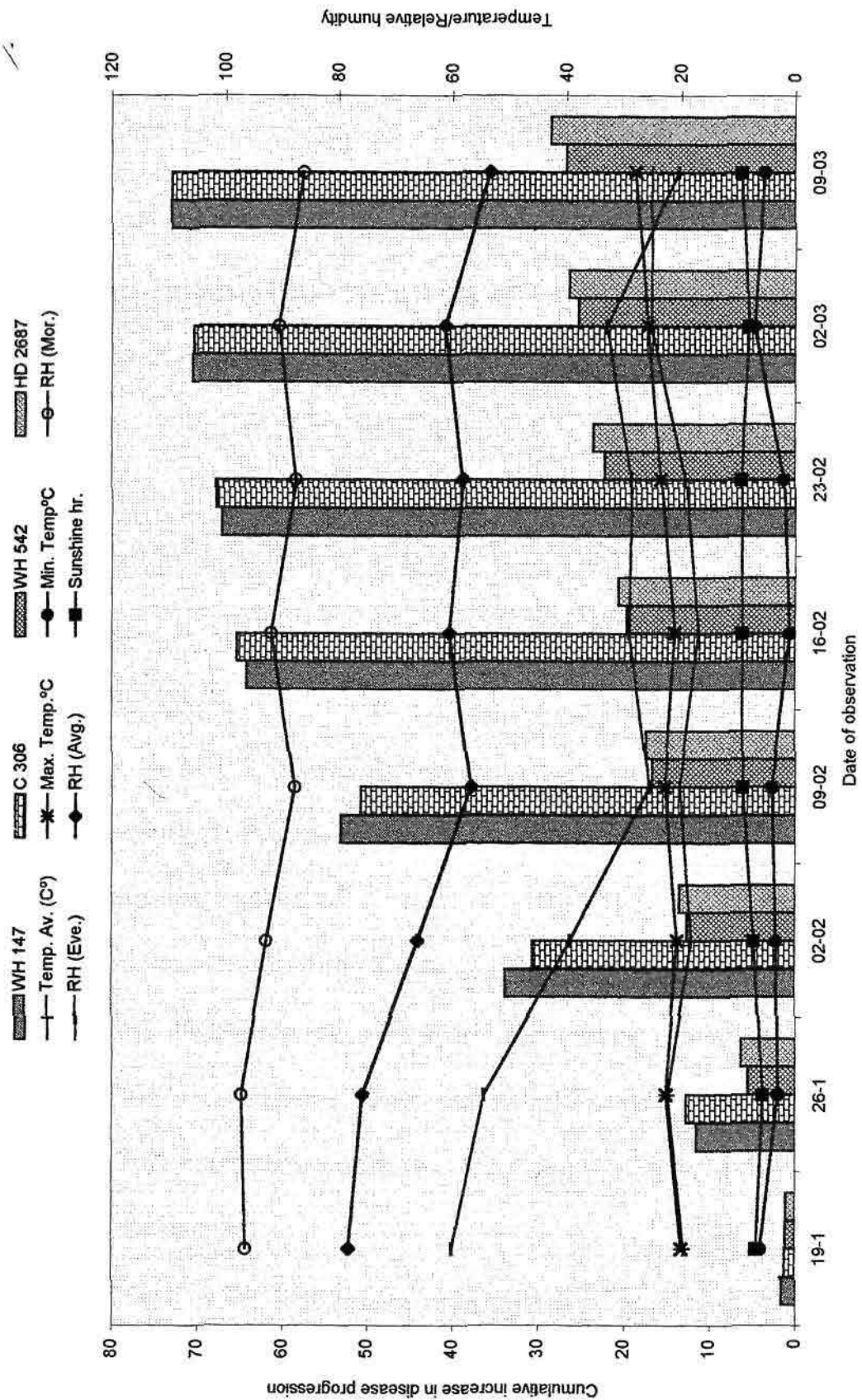


Fig. 1: Cumulative and periodical progression of flag smut of wheat in relation to weather parameters during 2000-2001

The data presented in (Table 10 & Fig. 2) showed that the maximum periodical increase in disease intensity during 2001-2002 in all four varieties viz., WH 147, C 306, WH 542 and HD 2687 was 19.73, 14.37, 5.06 and 5.18 per cent respectively, observed during last week of January, 2002 when favourable weather conditions like maximum temperature (18.85-20.28°C), minimum temperature (2.78 to 2.85°C), relative humidity morning more than 92%, relative humidity evening more than 45% and sunshine hrs. (6.70 to 8.28) prevailed. There was decline in the periodical increase of disease intensity in all varieties with increase in temperature and decrease in relative humidity.

Quantitative relationship

To develop quantitative relationship between progress of disease and weather parameters, stepwise multiple regression analysis was performed.

Results presented in (Table 11) showed that weather factors viz., maximum temperature and sunshine hours were positively and significantly correlated. Whereas relative humidity negatively and significantly correlated with the development of the disease intensity during 2000-2001.

During 2001-2002 crop season maximum temperature was positively and significantly correlated with disease intensity. Morning relative humidity was negatively correlated in all four cultivars.

Table 10: Cumulative and periodical progression of flag smut of wheat in relation to weather parameters during 2001-2002

Observation	Varieties				Weather parameters						
	WH 147	C 306	WH 542	HD 2687	X ₁	X ₂	X ₃	X ₄	X ₅	X ₆	X ₇
17.01.2002	2.76 (0.0)	1.83 (0.0)	1.00 (0.0)	1.20 (0.0)	20.9	8.9	14.9	93.6	62.0	77.8	5.3
24.01.2002	19.43 (16.67)	17.06 (15.23)	5.55 (4.55)	4.53 (3.30)	18.8	2.8	10.8	93.1	59.1	76.1	6.7
31.01.2002	39.16 (19.7)	31.43 (14.4)	10.61 (5.1)	9.32 (4.8)	20.3	2.8	12.9	92.8	45.0	68.9	8.3
07.02.2002	48.23 (9.07)	45.66 (14.23)	16.50 (5.89)	14.50 (5.18)	21.9	3.3	12.6	88.7	44.8	66.8	8.5
14.02.2002	50.83 (2.60)	49.5 (3.84)	19.30 (2.80)	17.61 (3.11)	18.6	3.4	11.0	93.4	69.6	81.4	6.3
21.02.2002	53.76 (2.93)	52.5 (13.00)	22.10 (2.80)	20.51 (2.90)	25.7	9.1	17.4	88.6	41.0	64.8	9.1
28.02.2002	57.66 (3.90)	57.43 (4.93)	23.50 (1.40)	22.75 (2.24)	23.6	10.2	16.3	92.0	58.0	75.0	6.4
06.03.2002	62.60 (4.90)	60.66 (3.23)	25.55 (2.05)	23.45 (0.77)	24.1	8.7	16.4	89.7	47.1	68.4	7.4
Mean	41.80	39.50	15.51	14.23							

D.O.S. : 02-12-2001

X₁=°C(Max); X₂= °C(min); X₃= °C(Av.); X₄= R.H.(M); X₅=R.H.(E); X₆= R.H.(Av.); X₇= Sunshine hr.
Values in parenthesis are the periodic progression

Table 11: Correlation matrix for flag smut progression on wheat cultivar¹/relation to weather parameters

Variety	Weather parameters						
	X ₁	X ₂	X ₃	X ₄	X ₅	X ₆	X ₇
2000-2001							
WH 147	0.668	0.043	0.235	-0.869	-0.912	-0.936	0.869
C 306	0.671	0.055	0.262	-0.853	-0.929	-0.923	0.862
WH 542	0.756	0.052	0.375	-0.854	-0.918	-0.915	0.805
HD 2687	0.764	0.420	0.381	-0.858	-0.918	-0.914	0.798
2001-2002							
WH 147	0.638	0.180	0.349	-0.636	-0.378	-0.431	0.516
C 306	0.665	0.245	0.381	-0.632	-0.326	-0.388	0.460
WH 542	0.631	0.358	0.473	-0.638	-0.307	-0.372	0.408
HD 2687	0.649	0.407	0.507	-0.649	-0.284	-0.348	0.371
Pooled Basis							
WH 147	0.615	0.025	0.285	-0.796	-0.660	-0.711	0.714
C 306	0.636	0.035	0.301	-0.778	-0.659	-0.707	0.699
WH 542	0.682	0.197	0.423	-0.755	-0.555	-0.613	0.596
HD 2687	0.722	0.159	0.428	-0.758	-0.632	-0.679	0.623

Critical value =(1-Tail, 0.05) = + or - 0.63, N = 8 ; Critical value =(1-Tail, 0.05) = + or - 0.43, N = 16

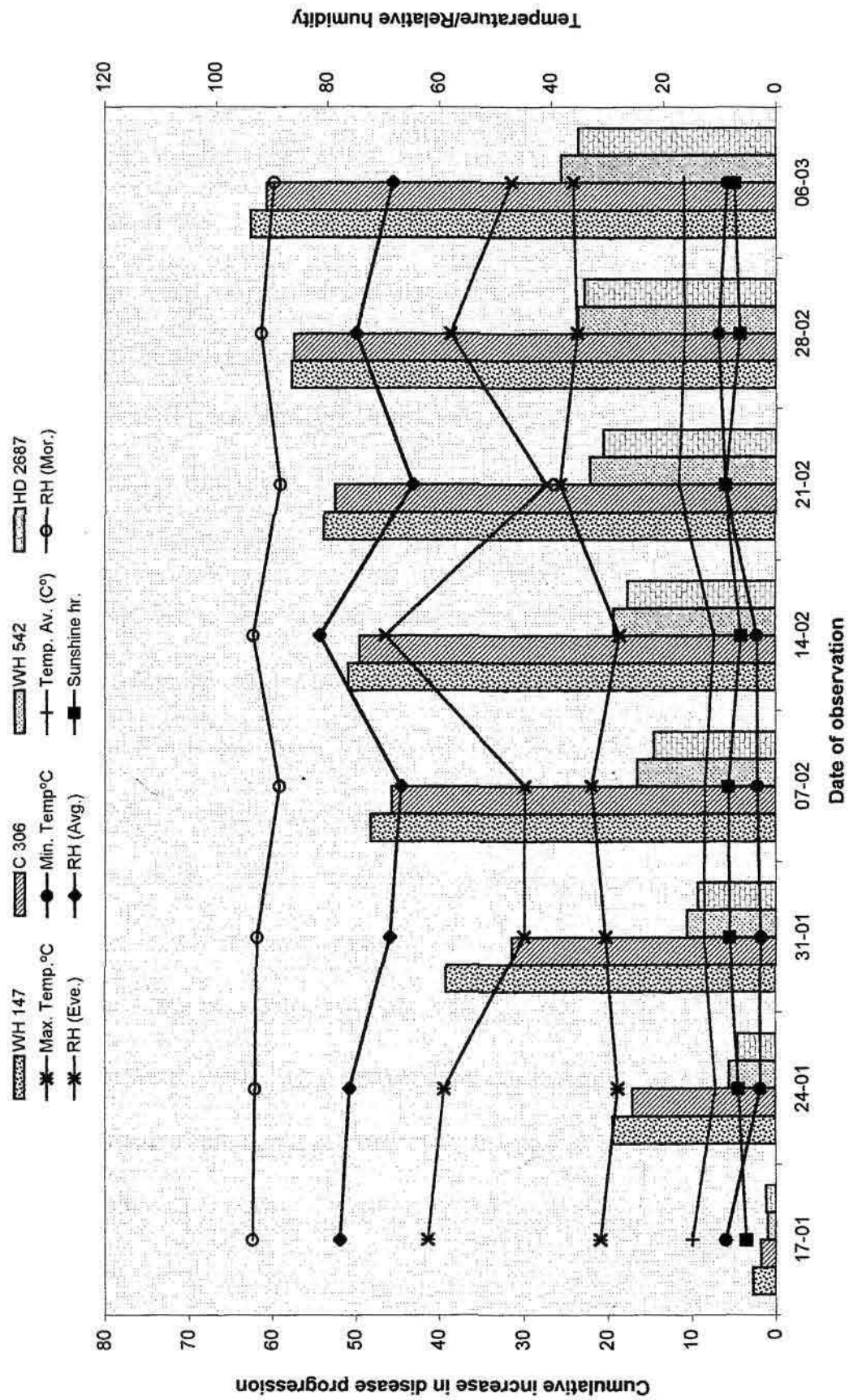


Fig. 2: Cumulative and periodical progression of flag smut of wheat in relation to weather parameters during 2001-2002

A persual of the pooled data of 2000-2001 and 2001-2002 presented in (Table 11) indicated that maximum temperature and sunshine hours were found positively and significantly correlated. Whereas relative humidity was found negatively and significantly correlated with disease intensity in all the cultivars.

It is obvious from regression analysis (Table 12) that mean relative humidity, sunshine hours and maximum temperature explained the variability in disease development upto 81-84 per cent in different cultivars tested during 2000-2001 crop season. Whereas during 2001-2002 maximum relative humidity, maximum temperature and sunshine hours explained variability in disease progression up to 60-65 per cent in all the cultivars.

Analysis of pooled data of the both the years, revealed that maximum relative humidity, maximum temperature and sunshine hours explained the variability in disease development upto 72-76 per cent in all the cultivars.

The observed and predicted values with respect to disease development with their regression equations depicted in (Fig. 3 & 4). It was observed that predicted values were in the agreement with the observed values. Similar trend was observed on the basis of pooled data (Fig. 5).

Effect of disease on respiration

Seeds of two resistant, two susceptible and two highly

Table 12: Prediction equation for flag smut progression on different cultivars of wheat varieties

Cultivar	Prediction equation	r ²
2000-2001		
WH 147	$y = 4.508 - 1.191X_5 + 4.566 X_7 + 2.089 X_1$	0.84
C 306	$y = -20.120 - 1.025X_5 + 5.730 X_7 + 2.464 X_1$	0.81
WH 542	$y = 0.746 - 0.414X_5 + 0.576 X_7 + 1.118 X_1$	0.83
HD 2687	$y = 2.369 - 0.449X_5 + 0.412 X_7 + 1.201 X_1$	0.84
2001-2002		
WH 147	$y = 302.666 - 3.382X_4 + 1.402X_1 + 2.547X_7$	0.60
C 306	$y = 401.558 - 4.344X_4 + 0.419X_1 + 1.508X_7$	0.61
WH 542	$y = 151.887 - 1.718X_4 + 1.106X_1 + 0.417X_7$	0.65
HD 2687	$y = 117.911 - 1.396X_4 + 1.305X_1 + 0.576X_7$	0.65
Pooled Basis		
WH 147	$y = 294.496 - 3.501X_4 + 1.621X_1 + 4.385X_7$	0.76
C 306	$y = 258.196 - 3.237X_4 + 2.122X_1 + 4.320X_7$	0.75
WH 542	$y = 118.750 - 1.408X_4 + 1.075X_1 + 0.235X_7$	0.72
HD 2687	$y = 83.244 - 1.127X_4 + 1.341X_1 + 0.75X_7$	0.76

$X_1 = ^\circ\text{C}(\text{Max})$; $X_2 = ^\circ\text{C}(\text{min})$; $X_3 = ^\circ\text{C}(\text{Av.})$; $X_4 = \text{R.H.}(\text{M})$; $X_5 = \text{R.H.}(\text{E})$; $X_6 = \text{R.H.}(\text{Av.})$; $X_7 = \text{Sunshine hr.}$

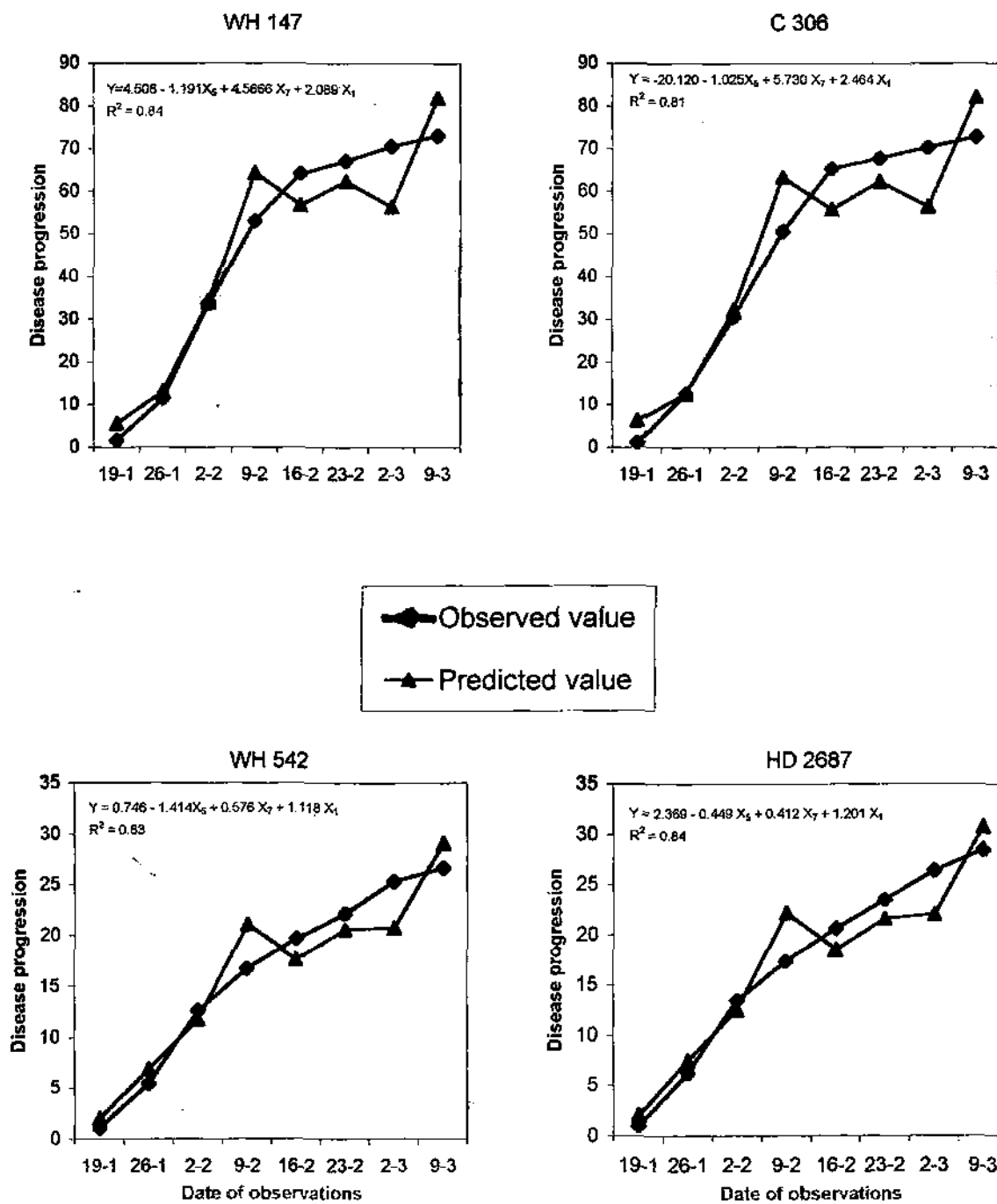


Fig. 3: Effect of weather variables on the progress of flag smut on different cultivars of wheat 2001

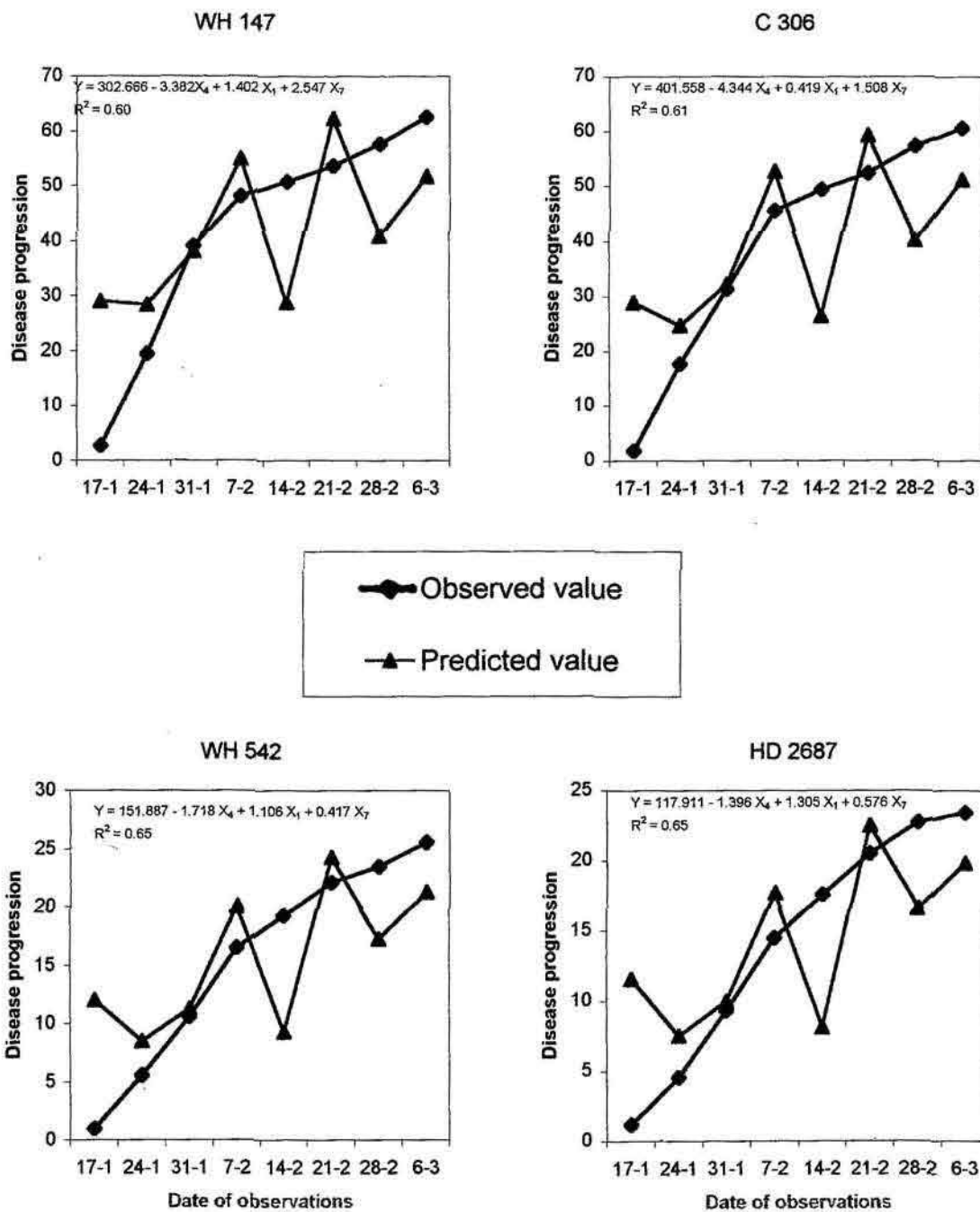


Fig. 4: Effect of weather variables on the progress of flag smut on different cultivars of wheat 2002

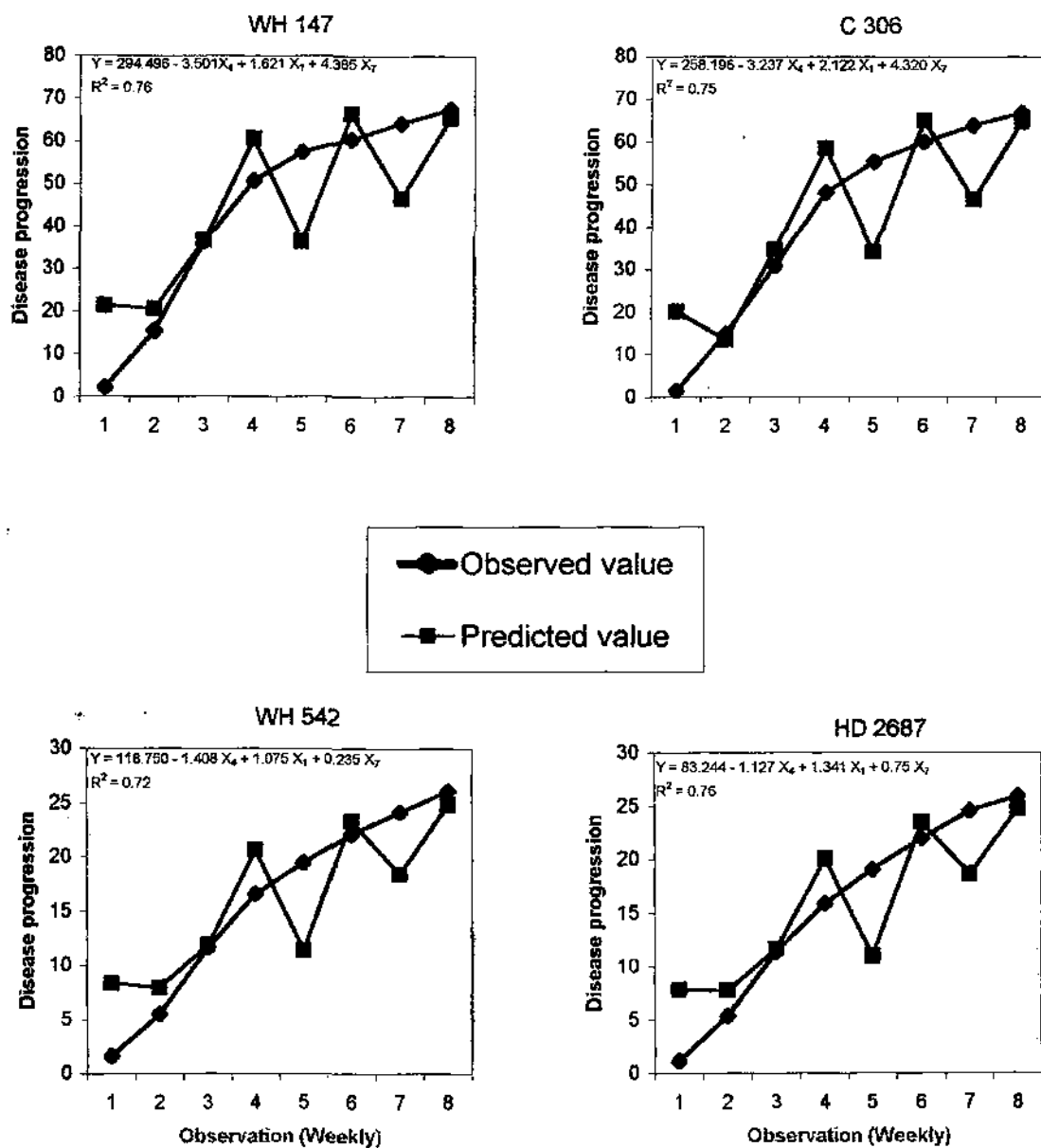


Fig. 5: Effect of weather variables on the progress of flag smut on different cultivars of wheat on pooled basis 2001-2002

susceptible varieties were smeared with FSIP @ 20 g Kg⁻¹ and then imbibed in water for 48 hours. Untreated seeds served as control. After that respiration was measured by Gilson Differential Respirometer. The results obtained are presented in (Table 13).

The data pertaining to seed respiration revealed that in highly susceptible cultivars, WH 147 and C 306, the respiration rate increased. It was 117.66 and 108.66 $\mu\text{L}/\text{O}_2/\text{h}$ as compared to 115.55 and 106.88 $\mu\text{L}/\text{O}_2/\text{h}$ in control respectively. The per cent increase in respiration was 1.70 and 1.78 in WH 147 and C 306 respectively, whereas it was increased 1.02 and 1.01 per cent in susceptible varieties (WH 542 and HD 2687) as compared to 0.73 and 0.83 per cent in resistant varieties (WH 896 and HD 2329).

Table 13 : Effect of inoculum on seed respiration in different wheat varieties

Variety	Respiration rate $\mu\text{L}/\text{O}_2/\text{h}$		Increase in respiration(%)
	Inoculated	Uninoculated	
WH 147	117.66	115.55	1.70
C 306	108.66	106.88	1.78
WH 542	103.00	101.21	1.02
HD 2687	98.44	97.44	1.01
WH 896	121.77	120.88	0.73
HD 2329	99.33	98.44	0.86
C.D. (P=0.05)	1.77	0.69	

The respiration rate of inoculated and uninoculated seed varied from variety to variety. In inoculated seed it ranges between 99.33 $\mu\text{L}/\text{O}_2/\text{h}$ (HD 2329) to 121.77 $\mu\text{L}/\text{O}_2/\text{h}$ (WH 896), whereas it was 97.44-120.88 $\mu\text{L}/\text{O}_2/\text{h}$ in control. The percent increase in respiration ranged between 0.73 in resistant variety to 1.78 in susceptible variety.

Seeds of all the six varieties were inoculated with FSIP @ 20 g Kg^{-1} seed and sown in two rows of 5 m in field. Untreated seed served as control. Ten days old seedlings were taken out from inoculated and uninoculated set of each variety and their respiration rate was measured by Gilson Differential Respirometer. The results are presented in (Table 14).

Table 14 : Effect of inoculum on respiration in 10 days old seedlings of different wheat varieties

Variety	Respiration rate $\mu\text{L}/\text{O}_2/\text{h}$		Increase in respiration(%)
	Inoculated	Uninoculated	
WH 147	83.53	77.80	6.05
C 306	77.96	71.23	6.46
WH 542	66.03	64.23	1.84
HD 2687	51.43	48.93	2.19
WH 896	79.30	79.23	0.79
HD 2329	60.96	60.03	0.89
C.D. (P=0.05)	0.99	1.06	

The data revealed that the respiration rate of the seedling obtained from highly susceptible varieties, WH 147 and C 306, was increased by 6.05 and 6.46 per cent as compared to control. It was $83.53 \mu\text{L}/\text{O}_2/\text{h}$ in WH 147 (inoculated) as compared to $77.80 \mu\text{L}/\text{O}_2/\text{h}$ in control. The respiration rate was also increased in another highly susceptible variety i.e. C 306 from 71.23 to $77.96 \mu\text{L}/\text{O}_2/\text{h}$, whereas, this increase was only 1.84 and 2.19 per cent in susceptible variety (WH 542 and HD 2687). Less than one per cent increase in respiration was recorded in resistant variety. It was $0.79 \mu\text{L}/\text{O}_2/\text{h}$ in WH 896 and $0.89 \mu\text{L}/\text{O}_2/\text{h}$ in HD 2329 (Fig. 6).

From the last set of experiment diseased as well as healthy tillers were collected at flowering stage from the field from each susceptible (WH 542, HD 2687) and highly susceptible (WH 147 and C 306) whereas tillers were also collected from resistant varieties (WH 896 and HD 2329) where inoculum was also added with seed of both the varieties but disease did not appear. Therefore, samples were collected from each set of variety. Then the respiration rate of diseased and as well as healthy tillers was measured with Gilson Differential Respirometer and results are presented in (Table 15).

The data pertaining to effect of respiration on diseased and healthy tillers revealed that respiration was increased by 25.11 and 30.58 per cent in WH 147 and C 306 respectively. The respiration rate in diseased tillers of WH 147 and C 306 was 394.20 and 330.20.

Table 15 : Effect of diseased and healthy tillers on respiration in different wheat varieties

Variety	Respiration rate $\mu\text{L}/\text{O}_2/\text{h}$		Increase in respiration(%)
	Inoculated	Uninoculated	
WH 147	394.20	295.00	25.11
C 306	330.20	229.00	30.58
WH 542	361.60	283.60	21.57
HD 2687	373.20	318.80	14.47
WH 896	256.00	235.00	0.39
HD 2329	266.60	265.20	0.37
C.D. (P=0.05)	6.81	5.95	

$\mu\text{L}/\text{O}_2/\text{h}$ respectively as compared to 295.0 and 229.0 $\mu\text{L}/\text{O}_2/\text{h}$ in control. In susceptible cultivars, WH 542 and HD 2687, the respiration rate was 361.60 and 373.20 $\mu\text{L}/\text{O}_2/\text{h}$ respectively as compared to 283.60 and 318.80 $\mu\text{L}/\text{O}_2/\text{h}$ in control and per cent respiration increase was 21.57 and 14.47 whereas in resistant varieties, WH 896 and HD 2329, the respiration rate was not affected as per cent increase in these varieties was 0.39 and 0.37 (Fig. 7).

Effect of flag smut on leaf area in different wheat varieties

Seeds of all the six varieties namely WH 147 and C 306 (highly susceptible), WH 542 and HD 2687 (susceptible) and WH 896 and HD 2329 (resistant) were smeared with FSIP @ 20 g Kg⁻¹ seed before

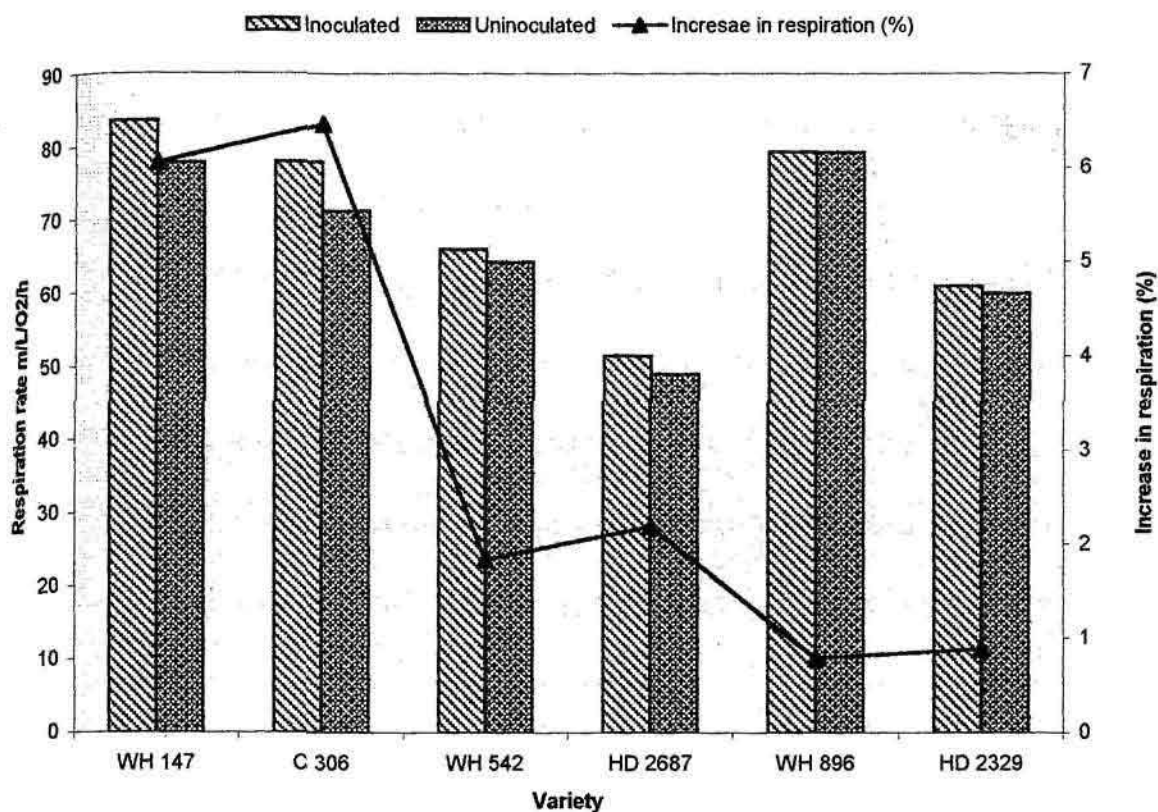


Fig. 6: Effect of inoculum on respiration in 10 days old seedlings of different wheat varieties

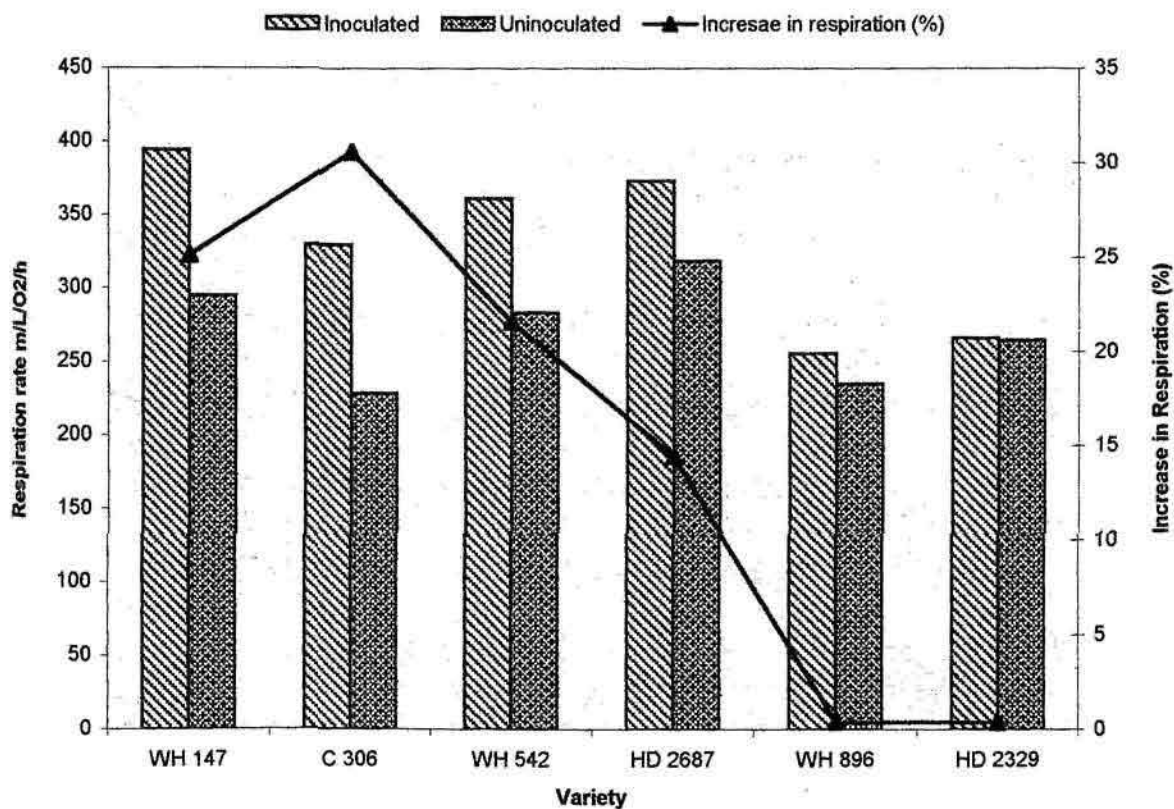


Fig. 7: Effect of diseased and healthy tillers on respiration in different wheat varieties

sowing. The inoculated seeds were sown in four rows of 5 M each and untreated seed served as control. All the agronomic practices were followed to raise the crop.

After the appearance of the disease in susceptible/highly susceptible varieties ten plants in each replicate were randomly tagged which includes diseased as well as healthy plants. Before the drying of the leaves, all the leaves from diseased and healthy plants were detached and their area was measured by leaf area meter under laboratory conditions. The results are presented in (Table 16).

The data revealed that leaf area was reduced significantly in highly susceptible and susceptible varieties (WH 147, C 306, WH 542 and HD 2687) whereas it did not differ significantly in resistant varieties i.e. WH 896 and HD 2329. The leaf area of diseased leaves of WH 147 was 7.22 cm as compared to 26.94 cm in control. The per cent reduction in leaf area in diseased leaves of WH 147 was 70.55 followed by 55.78, 46.05, 50.50 per cent in C 306, WH 542 and HD 2687, respectively. Whereas, it was less than one per cent in resistant varieties WH 896 and HD 2329.

The total leaf area of diseased leaves of C 306, WH 542 and HD 2687 was 9.41, 12.30 and 12.14 cm as compared to 23.32, 23.42 and 25.72 cm in control, respectively. Whereas it was 28.77 and 25.61 cm in resistant varieties WH 896 and HD 2329 respectively and it was not affected by inoculum because no disease symptom appeared in these varieties.

Table 16 : Effect of flag smut on leaf area in different wheat varieties

Variety	Leaf area (cm)*		Reduction in leaf area (%)
	Inoculated	Uninoculated	
WH 147	7.22	26.94	70.55
C 306	9.41	23.32	55.78
WH 542	12.30	23.42	46.95
HD 2687	12.14	25.72	50.56
WH 896	28.77	28.93	0.55
HD 2329	25.61	25.75	0.54
C.D. (p=0.05)	0.59	1.66	

* Mean of sixty leaves
(10 plants X 6 leaves of each plant)

***In vitro* dry matter digestibility (IVDMD)**

For determination of *in vitro* dry matter digestibility (IVDMD) samples of diseased as well as healthy plants of variety WH 147 were collected from the field after the maturity of the crop. Samples were dried, chopped and ground with the help of grinder. The grinded plant material (wheat straw) passed through a fine wire mesh. The different ratios i.e. 9:1, 3:1, 1:1, 1:3 and 1:9, were prepared by mixing straw obtained from healthy as well as diseased plants. Alone diseased and healthy straw served as control. IVDMD was determined by method of Tilley and Terry (1963). The results are presented in Table 17.

The data revealed that dry matter digestibility was maximum i.e. 48.03 per cent when straw was obtained from 100 per cent diseased plants followed by 46.82 and 44.51 per cent when diseased and healthy straw were used in ratio of 9:1 and 3:1, respectively, intermediate dry matter digestibility 40.30 and 35.02 per cent was found when diseased and healthy straw was used in a ratio of 1:1 and 1:3 respectively. Whereas least digestibility i.e. 26.32 per cent was observed when only healthy straw was used. Dry matter digestibility differed significantly with each other. So the (Table 17) clearly indicated that digestibility of wheat straw increased with the increase of disease.

Chemical composition (%) of straw obtained from diseased and healthy plants on dry matter basis

Straw from heavily diseased and healthy plants were taken and subjected to biochemical analysis. Results are presented in (Table 18).

The data revealed that crude protein of straw obtained from healthy plants was 3.84 as compared to 2.97 per cent of straw of diseased plants. Similarly ether extract was 2.25 per cent of healthy straw as compared to 1.64 per cent of straw obtained from diseased plants. Ash was also increased from 11.35 to 18.50 per cent, whereas crude fiber decreased from 33.46 per cent to 14.17 per cent (Fig. 8).

Table 17 : *In vitro* dry matter digestibility (IVDMD) of diseased and healthy straw

Sr. No.	Ratio	IVDMD (%)
1.	90% healthy straw (9:1) 10% diseased straw	28.83
2.	75% healthy straw (3:1) 25% diseased straw	35.02
3.	50% healthy straw (1:1) 50% diseased straw	40.30
4.	25% healthy straw (1:3) 75% diseased straw	44.51
5.	10% healthy straw (1:9) 90% diseased straw	46.82
6.	100% diseased straw (--)	48.03
7.	100% healthy straw (--)	26.32
C.D. (P=0.05)		0.74

Interaction of recommended fungicides with insecticides for controlling flag smut of wheat

Two recommended insecticides in the package of practices of CCS HAU, namely chlorpyrifos and endosulfan for controlling termites were evaluated in combination with different fungicides for controlling flag smut under field conditions during 2000-2001 and 2001-2002. Two doses of fungicides (1g and 2g Kg⁻¹ seed) and

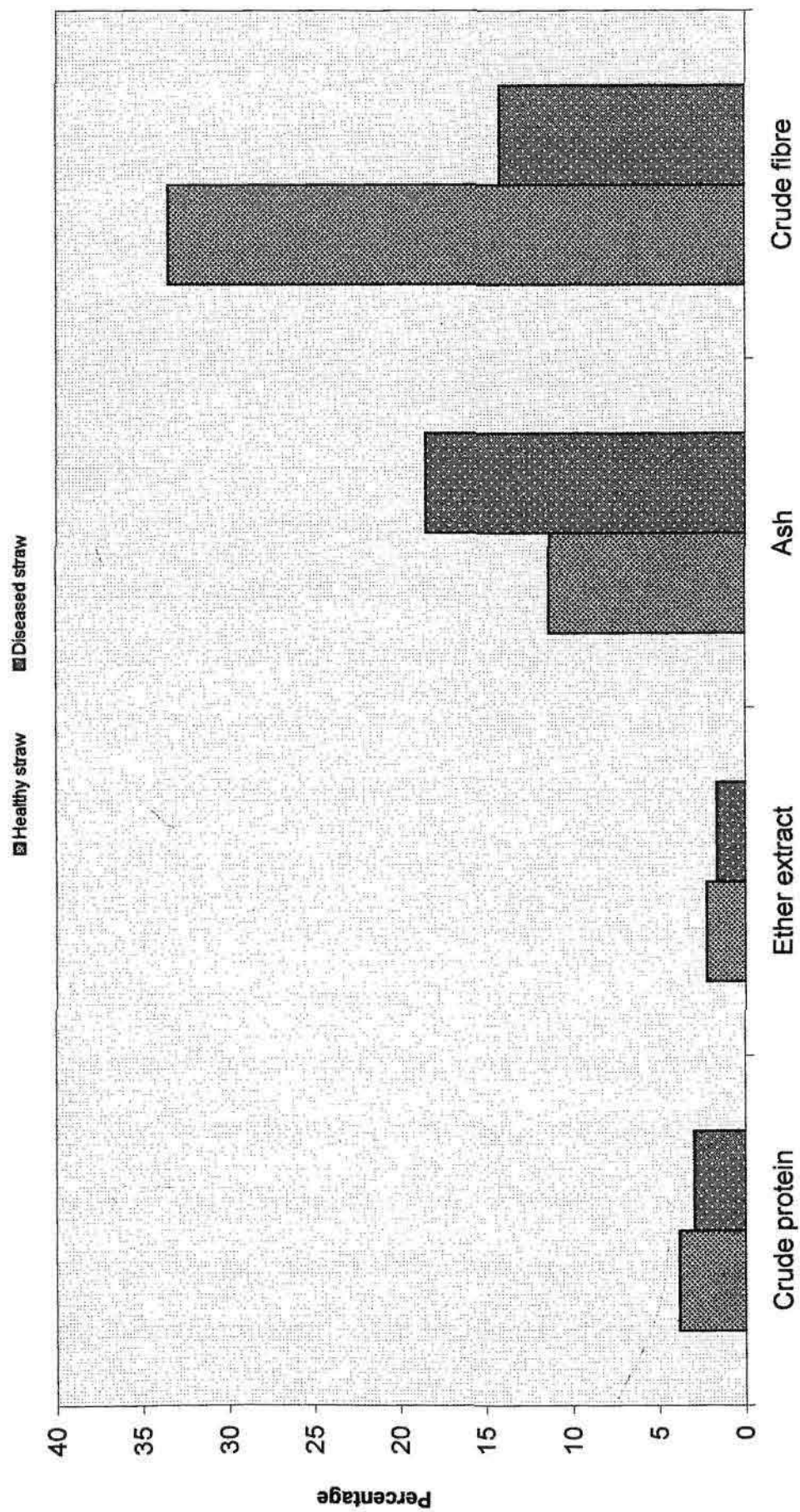


Fig. 8: Chemical composition (%) of straw obtained from diseased and healthy plants on dry matter basis

Table 18 : Chemical composition (%) of straw obtained from diseased and healthy plants on dry matter basis

Sr. No.	Healthy straw	Diseased straw
Crude protein	3.84	2.97
Ether extract	2.25	1.64
Ash	11.35	18.50
Crude fiber	33.46	14.17

recommended doses of insecticides (Chlorpyrifos @ 1.5 ml Kg⁻¹ seed and Endosulfan @ 3.5 ml Kg⁻¹ seed) were tested. Seeds of highly susceptible variety WH 147 were smeared with inoculum @ 20g FSIP Kg⁻¹ seed followed by insecticidal treatment and followed by different fungicidal treatment. Different combinations were prepared and sown in a randomised block design having a plot size of 5 x 1.5 M. All the agronomic practices were followed for raising the crop. The results are presented in Table 19.

The data presented in Table 19 revealed that all the fungicides alone and in combination with both the insecticides significantly controlled the disease. Bavistin, Vitavax 75 W.P. and Vitavax 200 W.P. (@ 2g Kg⁻¹ seed) and Raxil at both the doses completely controlled the disease. The incidence of the disease was 0.00 per cent on plant as well as on tiller basis as compared to 45.31 per cent in control. Lower doses of all the fungicides (0.1 per cent) also

Table 19 : Interaction of recommended insecticides with fungicide for disease management 2000-2001

Fungicide/ insecticide	Dose g/ml kg ⁻¹ seed	Disease incidence (%)		Seed germination (%)
		Plant basis	Tiller basis	
Bavistin 50 WP	0.1	2.98 (11.51)	1.14 (8.43)	86.66
Bavistin 50 WP	0.2	0.00 (5.74)	0.00 (5.74)	90.00
Vitavax 75 WP	0.1	2.41 (10.37)	0.80 (7.71)	85.33
Vitavax 75 WP	0.2	0.00 (5.74)	0.00 (5.74)	86.33
Vitavax 200 WP	0.1	2.00 (9.99)	0.63 (7.34)	85.00
Vitavax 200 WP	0.2	0.00 (5.74)	0.00 (5.74)	87.00
Raxil 2D	0.1	0.00 (5.74)	0.00 (5.74)	89.00
Raxil 2D	0.2	0.00 (5.74)	0.00 (5.74)	89.33
Control	20g	45.31 (42.89)	24.86 (30.57)	75.00

**Insecticide + Fungicide
Endosulfan @ 3.5ml Kg⁻¹ seed**

Endosulfan + Bavistin 50WP	0.1	2.35 (10.56)	0.88 (7.88)	80.33
Endosulfan + Bavistin 50WP	0.2	0.00 (5.74)	0.00 (5.74)	82.66
Endosulfan + Vitavax 75WP	0.1	1.86 (9.78)	0.65 (7.39)	80.33
Endosulfan + Vitavax 75WP	0.2	0.00 (5.74)	0.00 (5.74)	85.00
Endosulfan + Vitavax 200 WP	0.1	1.83 (5.76)	0.34 (6.63)	81.00
Endosulfan + Vitavax 200 WP	0.2	0.00 (5.74)	0.00 (5.74)	84.00
Endosulfan + Raxil 2D	0.1	0.00 (5.74)	0.00 (5.74)	86.66

Endosulfan +	0.2	0.00	0.00	89.66
Raxil 2D		(5.74)	(5.74)	
Control (Endosulfan)	3.5	21.03	11.42	80.00
		(28.00)	(20.63)	

Chlorpyrifos @ 1.5ml Kg⁻¹ seed

Chlorpyrifos +	0.1	1.98	0.73	80.66
Bavistin 50WP		(9.88)	(7.56)	
Chlorpyrifos +	0.2	0.00	0.00	81.66
Bavistin 50WP		(5.74)	(5.74)	
Chlorpyrifos +	0.1	1.46	0.46	80.00
Vitavax 75WP		(9.03)	(6.95)	
Chlorpyrifos +	0.2	0.00	0.00	82.33
Vitavax 75WP		(5.74)	(5.74)	
Chlorpyrifos +	0.1	1.31	0.42	83.00
Vitavax 200WP		(8.61)	(6.84)	
Chlorpyrifos +	0.2	0.00	0.00	84.00
Vitavax 200WP		(5.74)	(5.74)	
Chlorpyrifos +	0.1	0.00	0.00	83.33
Raxil 2D		(5.74)	(5.74)	
Chlorpyrifos +	0.2	0.00	0.00	85.66
Raxil 2D		(5.74)	(5.74)	
Control	1.5	17.49	8.62	80.33
(Chlorpyrifos)		(25.47)	(18.06)	

C.D.(P=0.05)	0.77	0.20
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Values in parentheses are the angular transformed values

controlled the disease significantly as the incidence ranged between 0.00-2.41 and 0.1-0.80 per cent on plant and tiller basis respectively as compared to 45.31 and 24.80 per cent in control. Endosulfan and Chlorpyrifos seed treatment also reduced the disease incidence. Its incidence was 21.03 and 17.49 per cent on plant basis and 11.42 and 8.67 per cent on tiller basis respectively, as compared to 45.89 and 30.57 per cent in control respectively.

The seed germination was ranged between 85.33 to 90.00 per cent as compared to 75.00 per cent in control. Seed germination was slightly decreased in all the combinations with fungicides and insecticides treated seeds.

More or less same results were obtained during 2001-2002 crop season. All the fungicides alone and in combination with insecticides significantly controlled the disease. All the fungicides @ 2 g Kg⁻¹ seed and Raxil at both the doses completely controlled the disease. The incidence of the disease was 0.00 per cent on plant as well as tiller basis as compared to 36.87 per cent in control. Lower doses of all the fungicides i.e. 0.1 per cent also controlled the disease significantly as the incidence ranged between 0.00-2.13 and 0.00-0.71 per cent on plant and tiller basis, respectively as compared to 36.87 and 20.65 per cent in control respectively. Endosulfan and Chlorpyrifos seed treatment also controlled the disease. Its incidence was recorded 18.87 and 16.14 on plant basis and 8.70 and

7.93 on tiller basis respectively as compared to 36.87 and 20.65 per cent in control respectively.

The seed germination was ranged between 85.66 to 89.16 per cent as compared to 76.00 per cent in control. Seed germination was slightly decreased in all the combination of fungicides and insecticides and insecticides alone treated seeds (Table 20).

Effect of flag smut on yield of different wheat varieties

To study the effect of flag smut on grain yield and other yield components, twenty one commercially grown wheat varieties were inoculated with FSIP @ 20 g Kg⁻¹ seed. Uninoculated seed served as control and then sown during 2000-2001 and 2001-2002 crop seasons in RBD having a plot size 5 x 1.5 m² with three replications.

Maximum flag smut i.e. 36.90 and 20.54 per cent on plant and tiller basis respectively was recorded in variety WH 147 during 2000-2001 followed by HD 2285, C 306, PBW 343 and HD 2009. Sonalika showed the minimum disease incidence i.e. 4.83 and 0.89 per cent on plant and tiller basis, respectively. Whereas, no disease was recorded in highly resistant variety namely UP 2425, WH 291, HD 2329, WH 896 and WH 283 (Table 21). Same type of results were obtained during 2001-2002. The disease incidence in different varieties ranged between 0.00 to 34.83 per cent on plant basis and 0.00 to 15.00 per cent on tiller basis.

The effect of flag smut on yield varied from variety to variety.

Table 20 : Interaction of recommended insecticides with fungicide for disease management 2001-2002

Fungicide/ insecticide	Dose g/ml kg ⁻¹ seed	Disease incidence (%)		Seed germination (%)
		Plant basis	Tiller basis	
Bavistin 50 WP	0.1	2.13 (10.30)	0.71 (7.53)	87.33
Bavistin 50 WP	0.2	0.00 (5.74)	0.00 (5.74)	89.66
Vitavax 75 WP	0.1	1.08 (8.37)	0.30 (6.55)	85.66
Vitavax 75 WP	0.2	0.00 (5.74)	0.00 (5.74)	86.66
Vitavax 200 WP	0.1	1.12 (8.36)	0.35 (6.55)	86.00
Vitavax 200 WP	0.2	0.00 (5.74)	0.00 (5.74)	87.33
Raxil 2D	0.1	0.00 (5.74)	0.00 (5.74)	87.00
Raxil 2D	0.2	0.00 (5.74)	0.00 (5.74)	88.66
Control	20g	36.87 (37.81)	20.65 (27.71)	76.00
Insecticide + Fungicide				
Endosulfan @ 3.5ml, Kg⁻¹ seed				
Endosulfan + Bavistin 50WP	0.1	1.12 (8.50)	0.36 (6.70)	80.33
Endosulfan + Bavistin 50WP	0.2	0.00 (5.74)	0.00 (5.74)	83.33
Endosulfan + Vitavax 75WP	0.1	0.98 (8.09)	0.36 (6.46)	81.53
Endosulfan + Vitavax 75WP	0.2	0.00 (5.74)	0.00 (5.74)	86.00
Endosulfan + Vitavax 200 WP	0.1	1.02 (8.14)	0.11 (6.06)	81.33
Endosulfan + Vitavax 200 WP	0.2	0.00 (5.74)	0.00 (5.74)	84.00
Endosulfan + Raxil 2D	0.1	0.00 (5.74)	0.00 (5.74)	79.00

Endosulfan +	0.2	0.00	0.00	85.33
Raxil 2D		(5.74)	(5.74)	
Control (Endosulfan)	3.5	18.87	8.70	80.00
		(20.47)	(17.81)	

Chlorpyrifos @ 1.5ml Kg⁻¹ seed

Chlorpyrifos +	0.1	0.95	0.34	81.66
Bavistin 50WP		(8.02)	(6.64)	
Chlorpyrifos +	0.2	0.00	0.00	82.33
Bavistin 50WP		(5.74)	(5.74)	
Chlorpyrifos +	0.1	0.96	0.33	81.00
Vitavax 75WP		(8.06)	(6.63)	
Chlorpyrifos +	0.2	0.00	0.00	82.53
Vitavax 75WP		(5.74)	(5.74)	
Chlorpyrifos +	0.1	1.02	0.40	84.00
Vitavax 200WP		(8.16)	(6.80)	
Chlorpyrifos +	0.2	0.00	0.00	85.00
Vitavax 200WP		(5.74)	(5.74)	
Chlorpyrifos +	0.1	0.00	0.00	82.33
Raxil 2D		(5.74)	(5.74)	
Chlorpyrifos +	0.2	0.00	0.00	84.66
Raxil 2D		(5.74)	(5.74)	
Control	1.5	16.14	7.93	80.33
(Chlorpyrifos)		(24.47)	(17.46)	

C.D.(P=0.05)	0.33	0.37
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Values in parenthesis are the angular transformed values

Table 21 : Effect of flag smut on yield in different wheat varieties 2000-2001

Variety	Disease incidence(%)		Yield (g) 10 plants		Reduction(%)
	Plant basis	Tiller basis	Uninoculated	Inoculated	
UP 2425	0.0 (5.74)	0.0 (5.74)	243.00	240.99	0.82
WH 291	0.0 (5.74)	0.0 (5.74)	283.66	282.66	0.35
HD 2329	0.0 (5.74)	0.0 (5.74)	230.33	228.66	0.44
WH 896	0.0 (5.74)	0.0 (5.74)	211.00	207.00	1.89
WH 283	0.0 (5.74)	0.0 (5.74)	215.66	213.33	0.92
Sonalika	4.83 (13.97)	0.89 (7.82)	199.33	144.66	27.78
WH 533	8.63 (18.08)	2.13 (10.19)	213.60	148.66	27.14
WH 157	10.73 (18.05)	4.77 (20.11)	207.33	153.33	26.04
PBW 435	11.34 (20.54)	3.67 (12.61)	262.66	190.33	27.53
Raj 3765	11.70 (21.09)	4.93 (14.10)	209.00	143.00	31.49
HD 2687	13.31 (22.22)	5.20 (14.41)	223.00	162.66	27.04

WH 542	15.73 (24.13)	4.50 (13.70)	233.00	162.66	27.04
UP 2338	15.29 (24.33)	5.01 (14.20)	239.66	175.33	26.83
Raj 3777	16.89 (24.83)	5.34 (14.59)	210.33	101.00	52.13
PBW 373	22.05 (28.70)	8.38 (17.84)	259.33	186.33	27.96
WH 416	23.01 (29.11)	10.95 (20.11)	251.33	108.66	56.41
HD 2009	29.24 (33.33)	10.96 (20.24)	236.66	110.00	53.55
PBW 343	31.20 (34.57)	14.03 (22.81)	256.00	121.00	52.33
C 306	32.40 (35.97)	12.00 (21.10)	160.33	84.00	47.59
HD 2285	33.44 (35.93)	13.44 (22.93)	210.00	100.33	52.31
WH 147	36.90 (37.89)	20.54 (27.65)	202.33	71.00	65.02
C.D.(P=0.05)	1.43	0.44	3.62	4.53	

Per cent reduction in yield ranged between 0.35 to 65.02. Maximum losses were recorded in variety WH 147 (65.02 per cent) followed by WH 416 (56.41 per cent). Intermediate losses were recorded in variety WH 157 (26.04 per cent) followed by UP 2338 (26.83 per cent). There was no significant reduction in yield in highly resistant varieties namely UP 2425, WH 291, HD 2329, WH 896 and WH 283.

More or less same results were obtained during 2001-2002 crop season. Losses in different varieties ranged between 0.40 to 64.43 per cent (Table 22). The maximum losses were recorded in variety WH 147 (64.43 per cent) followed by WH 416 (56.18 per cent), intermediate losses were recorded in variety WH 533 (24.72 per cent) followed by WH 157 (25.62 per cent). There was no significant reduction in yield in resistant varieties.

Effect of flag smut on yield components

From previous set of experiments ten plants of diseased as well as healthy were randomly tagged in each replicate. At maturity these plants were taken out and different yield parameters namely tillering per plant, plant height, ear head length and grain weight were recorded and data of which are presented in (Table 23).

The perusal of data (Table 23) revealed that disease significantly affected the number of tillers per plant. The reduction was more significant in susceptible and highly susceptible varieties as

Table 22 : Effect of flag smut on yield in different wheat varieties 2001-2002

Variety	Disease incidence (%)		Yield (g) 10 plants		Reduction(%)
	Plant basis	Tiller basis	Uninoculated	Inoculated	
UP 2425	0.0 (5.74)	0.0 (5.74)	246.33	244.66	0.40
WH 291	0.0 (5.74)	0.0 (5.74)	240.33	238.66	0.41
HD 2329	0.0 (5.74)	0.0 (5.74)	233.00	230.00	1.28
WH 896	0.0 (5.74)	0.0 (5.74)	213.66	210.53	1.40
WH 283	0.0 (5.74)	0.0 (5.74)	231.00	228.66	0.86
Sonalika	3.80 (12.68)	0.96 (6.53)	202.00	106.64	27.39
WH 533	10.26 (19.60)	4.16 (13.10)	213.00	160.33	24.72
WH 157	11.76 (20.93)	3.00 (11.53)	211.00	158.33	25.62
PBW 435	12.43 (26.67)	4.83 (14.00)	263.66	194.66	26.16
Raj 3765	13.16 (21.77)	5.63 (15.05)	210.00	145.66	30.62
HD 2687	12.70 (21.82)	4.66 (13.76)	222.66	165.00	25.78

WH 542	13.46 (22.35)	5.88 (15.14)	233.66	164.66	29.52
UP 2338	14.76 (23.39)	4.20 (13.17)	243.33	180.00	26.02
Raj 3777	13.96 (22.75)	6.00 (15.32)	215.00	101.00	52.56
PBW 373	23.33 (29.55)	7.96 (17.42)	264.66	189.66	28.34
WH 416	24.43 (30.29)	12.83 (21.85)	255.66	122.00	56.18
HD 2009	27.36 (32.18)	11.36 (20.58)	235.66	112.00	52.42
PBW 343	31.30 (34.56)	12.73 (21.69)	261.33	122.00	53.31
C 306	32.83 (35.18)	12.76 (21.69)	163.33	122.00	53.31
HD 2285	33.73 (36.18)	13.93 (22.74)	213.33	101.33	50.50
WH 147	34.83 (36.50)	15.00 (28.45)	208.53	74.66	64.43
C.D.(P=0.05)	0.92	1.08	2.65	1.97	

compared to resistant one. The number of tillers in uninoculated ranged between 8.60 to 10.50 in different varieties as compared to 5.30 to 10.06 in inoculated one. The maximum reduction i.e. 46.08 per cent was recorded in variety WH 147 followed by PBW 343 (42.95%). The per cent reduction in susceptible varieties ranged between 15.23 to 46.08 whereas in resistant variety it was less than one per cent.

The disease adversely affected the plant height. In highly susceptible variety C 306, it was 47.44 cm as compared to 121.33 cm in uninoculated control. The per cent reduction in plant height of C 306 was 60.17 followed by 58.66, 58.01 and 57.71 in HD 2285, WH 416 and WH 542 respectively. The per cent reduction in susceptible variety ranged between 46.21 to 60.17 whereas reduction in plant height was negligible in resistant varieties. Similarly the earhead length was influenced greatly by the disease in susceptible varieties. It ranged between 9.70 to 11.36 cm in different uninoculated variety as compared to 5.20 to 11.28 in inoculated one. The maximum reduction in ear length i.e. 44.88 per cent was recorded in HD 2009 followed by 44.42, 44.37 and 42.54 per cent in WH 147, PBW 343 and HD 2285 respectively. The per cent reduction in earhead length ranged between 26.39-44.80 in susceptible varieties whereas, in resistant varieties the length was not reduced significantly (Table 23).

Table 23: Effect of flag smut on yield components of different wheat varieties 2000-2001

Variety	Tillers/plant*			Plant ht.(cm)			Ear length (cm)			1000 grain wt.(g)		
	H	D	Reduction (%)	H	D	Reduction (%)	H	D	Reduction (%)	H	D	Reduction (%)
UP 2425	9.13	9.03	0.41	99.86	99.00	0.86	11.34	11.28	0.17	44.37	44.10	0.51
WH 291	10.06	10.06	0.00	101.16	100.97	0.18	10.86	10.84	0.18	46.50	46.20	0.64
HD2329	9.16	9.09	0.66	96.70	96.00	0.72	10.46	10.44	0.19	46.83	46.60	0.42
WH 896	10.13	10.08	0.50	96.33	95.97	0.37	9.70	9.69	0.10	41.70	41.50	0.47
WH 283	10.00	10.00	0.00	100.53	100.00	0.52	11.10	11.08	0.18	46.36	46.20	0.34
Sonalika	9.30	7.50	20.73	95.43	49.14	46.21	12.10	7.33	33.12	45.10	36.73	17.74
WH 533	9.03	7.50	16.95	94.63	46.73	49.31	10.80	7.33	26.78	38.26	31.89	15.69
WH 157	8.96	7.60	15.23	98.26	46.73	51.88	11.36	7.90	26.39	37.42	30.33	13.70
PBW 435	9.80	6.80	30.59	94.40	43.93	55.17	11.46	7.30	32.62	45.03	35.00	23.63
Raj 3765	9.00	6.66	25.69	96.56	47.30	50.73	10.73	6.64	37.28	43.96	34.60	18.96
HD 2687	9.10	6.90	26.57	97.46	43.60	57.05	10.63	6.46	38.21	42.16	37.20	17.57
WH 542	9.56	6.50	32.05	96.43	40.30	57.71	10.63	6.23	37.77	36.63	29.86	21.58
UP 2338	9.13	6.26	31.40	97.16	42.46	55.79	10.40	6.34	38.84	42.34	33.30	19.73
Raj 3777	8.66	5.90	33.43	99.53	46.76	52.93	11.30	6.69	35.32	48.34	32.96	22.07
PBW 37310.13	6.83	6.83	32.56	99.70	44.23	54.66	11.30	7.50	29.49	45.56	36.86	18.29
WH 416	10.50	7.80	24.49	84.54	36.33	58.01	10.90	6.40	36.85	38.43	28.64	23.49
HD 2009	9.36	7.00	25.23	93.06	45.70	47.99	11.20	5.20	44.84	48.50	30.83	31.54
PBW 343	9.93	5.66	42.95	98.76	44.53	54.67	11.30	5.80	44.37	44.63	31.33	29.19
C 306	9.60	6.60	31.23	121.33	47.44	60.17	10.63	6.26	37.64	45.83	34.16	24.24
HD 2285	8.60	6.70	22.28	26.43	40.10	58.56	11.33	6.33	42.54	42.50	30.36	33.24
WH 147	9.83	5.30	46.08	91.34	46.21	48.94	10.54	5.56	44.42	45.00	34.13	24.24
C.D.(P=0.05)	2.38	1.94		2.48	2.14		0.25	0.19		1.58	0.72	

* Average of 10 plants H= Uninoculated; D = Inoculated

One thousand grain weight was also greatly influenced by the disease in susceptible varieties. It reduced to a greater extent and ranged between 15.69-33.24 per cent. One thousand grain weight varied from variety to variety i.e. 36.63-48.50 gm in uninoculated check as compared to 28.64-46.60 gm in inoculated set. The maximum reduction (33.74%) was recorded in HD 2285 followed by 31.54, 29.19 and 24.24 per cent in HD 2009, PBW 343 and C 306 respectively.

More or less same type of results were obtained during 2001-2002. The reduction in tillering in susceptible varieties ranged between 17.00 to 43.79 per cent. The maximum reduction recorded in WH 147 followed by PBW 343 (43.63%). Similarly plant height was reduced in susceptible varieties and it ranged between 47.79 to 59.71. The maximum reduction was recorded in C 306 followed by HD 2285.

Ear length was greatly reduced by disease. It ranged between 9.86 to 11.93 cm in uninoculated control as compared to 5.46 to 11.38 per cent in inoculated one. The maximum reduction i.e. 44.54 per cent was recorded in PBW 343 and WH 147 followed by 43.86, 42.42 and 41.78 per cent in Raj 3777, HD 2009 and HD 2285 respectively.

Thousand grain weight varied between 37.00 to 46.70 gm in inoculated one. The maximum reduction in 1000 grain weight (34.45%) was recorded in C 306 followed by HD 2285 (38.13%).

Table 24: Effect of flag smut on yield components of different wheat varieties 2001-2002

Variety	Tillers/plant*			Plant ht. (cm)			Ear length (cm)			1000 grain wt.(g)		
	H	D	Reduction (%)	H	D	Reduction (%)	H	D	Reduction (%)	H	D	Reduction (%)
UP 2425	9.40	9.30	1.06	98.93	97.50	1.01	11.40	11.38	0.17	44.86	44.74	0.35
WH 291	10.06	10.05	0.50	100.36	100.00	0.35	10.56	10.55	0.09	46.10	46.00	0.21
HD2329	9.20	9.20	0.70	96.66	96.32	0.36	10.53	10.51	0.18	45.60	45.40	0.43
WH 896	10.06	10.01	0.54	97.66	97.08	0.67	9.86	9.85	0.10	41.70	41.57	0.31
WH 283	9.93	9.82	1.00	101.23	100.00	0.99	11.16	11.14	0.17	46.50	46.36	0.30
Sonalika	9.16	7.60	17.09	95.26	49.96	47.79	11.93	7.10	36.31	45.50	36.76	18.30
WH 533	9.16	7.53	17.00	91.43	47.06	48.11	10.60	7.00	28.35	38.16	31.79	15.97
WH 157	9.16	7.56	17.45	98.20	46.06	52.61	11.63	7.63	34.38	37.00	30.10	18.80
PBW 435	9.70	6.93	28.15	95.73	43.73	53.96	11.26	7.10	35.32	44.50	34.83	20.22
Raj 3765	9.23	6.63	28.15	96.43	47.06	50.94	10.96	6.23	37.65	43.03	35.13	18.94
HD 2687	8.86	7.00	22.38	97.66	43.26	55.28	10.50	6.16	38.12	45.40	35.70	20.33
WH 542	9.63	6.33	34.25	93.40	40.93	55.67	10.23	6.16	39.09	39.43	30.16	21.95
UP 2338	9.00	6.03	32.96	96.19	41.76	56.48	10.60	6.16	37.41	42.90	34.66	18.56
Raj 3777	9.06	5.83	35.65	98.26	44.93	53.96	11.40	6.33	43.86	42.90	33.46	20.98
PBW 37310.06	6.76	6.76	32.77	100.76	42.60	56.96	10.93	7.14	27.50	45.26	37.76	16.00
WH 416	10.46	7.76	25.79	87.13	38.66	55.08	11.03	6.46	36.97	45.76	34.00	24.79
HD 2009	9.53	7.03	26.21	93.66	45.81	50.53	11.00	5.93	42.42	45.13	31.20	30.28
PBW 343	9.70	5.41	43.63	98.40	43.66	55.55	11.23	5.73	44.54	44.76	31.46	29.84
C 306	9.63	6.53	32.16	123.86	48.83	59.71	10.46	6.03	38.26	45.83	30.00	34.45
HD 2285	8.53	6.53	23.13	98.73	39.90	58.75	10.83	6.13	41.78	46.70	31.00	38.13
WH 147	9.43	5.30	43.79	90.43	96.59	47.79	10.46	5.46	44.54	45.13	34.80	21.43
C.D.(P=0.05)	1.44	1.23		1.16	1.48		0.48	0.20		0.54	0.67	

* Average of 10 plants H=Uninoculated; D = Inoculated

CHAPTER-5

DISCUSSION

Flag smut (*Urocystis agropyri* (Preuss) Schroet) is a widely distributed disease in many wheat growing parts of the world, but is of major importance only in limited areas. In India its occurrence has been reported from Punjab, Haryana, Himachal Pradesh, Madhya Pradesh, Uttar Pradesh, Delhi, Rajasthan and Bihar (Goel, 1992). Although occurrence of flag smut is not wide spread in the country, its importance can not be under estimated unlike other smuts, as it is of long persistence in nature. Under favourable environment if susceptible varieties are grown the disease may assume serious form. In Haryana State since 1987-88 the incidence of flag smut ranging from traces to 50 per cent has been observed under natural conditions. Consequently, it has been envisaged to study the inoculum load on seed and seedling vigour, effect of weather variables on disease progress, physiological parameters, particularly respiration and leaf area, *in vitro* dry matter digestibility and interaction of insecticides with recommended fungicides for disease management. The results of the present studies have been discussed in the subsequent paragraphs.

The per cent seed germination was not affected significantly by any level of inoculum as compared to control in resistant varieties whereas, in case of highly susceptible varieties WH 147 and C 306 the germination percentage decreased significantly and below the ISTA standard that is 85 per cent. These results are in conformity with those of Jain (2000) where he had recorded very poor seed germination in Kado millet inoculated with 3gKg^{-1} inoculum. Similar observations were also reported by Rai and Singh (1978) and Beniwal *et al.*, (1994) in wheat inoculated with Karnal bunt. The root length of resistant varieties was not affected significantly by any level of inoculum as it was almost same in all the treatment. Whereas, in case of highly susceptible varieties HD 2285 and WH 147, the root length was decreased significantly. Shoot length was also not affected significantly by any level of inoculum as compared to control in resistant varieties. In case of highly susceptible the shoot length was decreased significantly. Shoot length was 7.00 and 6.75 cm at 10g and 20g inoculum level Kg^{-1} seed, respectively, in case of PBW 343 as compared to 8.75 cm in control. The dry weight of seedlings was also not affected significantly by any level of inoculum as compared to control. Whereas, in case of highly susceptible varieties the dry weight was decreased significantly. The dry weight was 60.75 and 59.89 mg at 10g and 20g inoculum level Kg^{-1} seed, respectively, in case of WH 147, as compared to 67.55 mg in control.

The speed of germination was maximum in resistant varieties as compared to susceptible and highly susceptible varieties. The speed of germination was maximum (18.55 and 18.05) in varieties WH 291 and WH 896 followed by HD 2329 (17.86). Lowest speed of germination (13.92) was recorded in highly susceptible variety WH 147. These results are in confirmation with those of Rettinababady *et al.*, (2000) where, they have reported around 10 per cent reduction in seed germination in black gram at 10 per cent the inoculum level of *Macrophomina phaseolina*. Samiyappan (1988) also observed that a very low number of progress of *M. phaseolina* were sufficient to cause infection on black gram and there by decreased germination. Whereas, Sheik and Ghaffer (1979) observed that even 1-2 sclerotia/g of soil can cause 12 to 20 per cent infection in urd bean, while Zambolin *et al.*, (1983) reported that 38 sclerotia/g of soil caused 50 per cent infection in soyabean. Shankar (1994) also noticed that 5 per cent *M. phaseolina* inoculum was able to cause 90 per cent root rot incidence coupled with significant reduction in seed germination of sesame. Flag smut belongs to seedling infection group of smut fungi. The fungus infects the seed before the seedling emergence. In susceptible and highly susceptible cultivars deterioration of seed resulted in inhibited the germination of seed. In infected seedlings root and shoot length were also reduced due to point of entry during infection is restricted to the young coleoptile less than 4mm long). After infection the fungus

grows both inter and intra cellularly until it begins to sporulate.

Maximum disease intensity and AUDPC were recorded in highly susceptible cultivar WH 147 followed by C 306 and least in susceptible cultivar WH 542. Similarly AUDPC has been used successfully (Raja and Anil Kumar, 1950; Khangura and Sokhi, 1991; Kumar and Kolte, 2001) to evaluate the progress of disease rate in different crops.

Environmental factors play an important role in the development of the disease. The weather variables viz., temperature, humidity and sunshine are the most important. These variables affect the pathogen, host or host-pathogen interaction during pathogenesis. Maximum periodic increase in disease intensity was observed in the last week of January and first week of February. When the periodic increase was compared with weather variables, it was found that the maximum temperature ($20.7-22.7^{\circ}\text{C}$), minimum temperature ($3.1-3.4^{\circ}\text{C}$) and maximum relative humidity ($>90\%$) and sunshine hrs. (>7) played vit role in disease development.

Present results are contrary to the earlier findings of Noble (1924), Griffiths (1924), Wu (1949), Sattar and Hafiz (1952) and Yerwoerd (1929) who observed 5°C , $6-12^{\circ}\text{C}$, 9°C , 10°C and 18°C respectively, the minimum temperature for infection and are in agreement with those of Wu (1949) and Verwoerd (1929) they had reported optimal temperature 20°C to $22-25^{\circ}\text{C}$ respectively for infection.

Similarly various epidemiological factors such as sowing dates,

relative humidity, temperature, rainfall, sunshine etc., have been also found affecting the white rust in rapeseed and mustard (Dang and Sangwan, 1999; Saharan, 2000).

The quantitative relationship has been developed between parameters and disease development in terms of progress of disease intensity on four cultivars of wheat. Significant differences were observed in the mean cumulative increase in disease intensity on four different cultivars. Maximum periodical increase in disease development was observed on highly susceptible cultivars, WH 147 and C 306 during both the years. Shaner *et al.*, (1978) also reported that slow leaf rusting cultivars Suwan 85 and P 6028 produced less number of uredospores per pustule as compared to fast rusting cultivars. Gupta and Singh (1982) made similar observation on leaf rust of wheat.

The analysis of all the test variables individually and in all the possible combinations revealed that in addition to other unknown factors each known variable played an important role . However, maximum temperature was significantly and positively correlated with disease development and it was negatively associated with relative humidity.

Multiple linear regression models for the prediction of disease development on wheat cultivars based on weather parameters were developed. The data showed that temperature, humidity and sunshine

were important and accounted for 84% variation in disease development. Same results were also observed by Kumar *et al.*, (1986) and Saharan, (2000). They reported that increase in number and size of pustules of white rust was correlated with mean environmental variables. Shaner and Hess (1978) developed various equations with different combinations of slow rusting components which could reduce epidemic significantly.

The respiration rate of inoculated seeds was increased around 2 per cent in highly susceptible cultivars namely WH 147 and C 306 as compared to 0.75 per cent in resistant cultivars. The ten days old inoculated seedlings in case of susceptible cultivars also showed increased respiration. This increase in respiration was around 6 per cent as compared to around 1 per cent in resistant cultivars. The respiration rate in highly susceptible cultivars namely WH 147 and C 306 was increased to 25-30 per cent when diseased tillers at flowering stage were tested. Whereas, respiration rate was not affected significantly in resistant cultivars. These results are in argument with those of Kirely and Farkas (1957) where, they have reported that 35 to 40 per cent inhibition of respiration in rusted and mildew leaves of wheat. Shaw and Samborski (1957), Grimm and Wheeler (1963) and Swamy (1964) reported higher rate of respiration in rusted leaves. Oat plants infected by *Helminthosporium victoriae* and ground nut leaves infected with *Cercospora* as compared to healthy leaves. It

appears that plants invaded by pathogenic organism not only stimulate higher respiration but also activate enzyme system and thus alter respiration pathway. Toxins have also been reported to induces respiration changes. Lakshmanan and Venkata Ram (1957), Andal (1959) and Swamy (1963) observed stimulation in respiration of plant tissue infected with *Cercospora parsonata*.

The leaf area was reduced significantly in highly susceptible cultivars as compared to resistant ones. The leaf area reduced to 70.55, 55.78, 46.05 and 50.50 per cent in WH 147, C 306, WH 542 and HD 2687, respectively. This reduction was less than one per cent in resistant varieties WH 896 and HD 2329. A decreased rate of photosynthesis in the leaves infected by rusts and powdery mildews has also been earlier reported by various workers (Zelitch, 1982, Kaur and Deshpande, 1980). Similar results were obtained by Garg and mandhar (1975), Bhatia and Thakur (1991) and Kumar (1994) where they found high reduction in net photosynthetic rate in downy mildew infected pearl millet leaves. Systemic infection of *U. agropyri* in wheat WH 147 initially caused whitish patches or chlorotic area on the leaf surface. Consequently, reduction in chlorophyll content and was very much evident in infected leaves. Whereas, in disease free leaves chlorophyll content remained normal. Akai and Fukutomi (1964) have observed decreased chlorophyll content in diseased leaf tissue of rice due to *Sclerophthora macrospora*. Garg and Mandhar (1975), Bhatia

and Thakur (1991) and Kumar (1994) also recorded the decreased level of total chlorophyll content in pearl millet leaves infected with *Sclerospora graminicola*, which is in agreement with the present studies. Photosynthesis rate per plant as well as per unit leaf area was reduced under diseased conditions in the highly susceptible and susceptible wheat cultivars because of limited green space due to flag smut expression.

The dry matter digestibility was maximum when straw was obtained from 100 per cent diseased plants. Dry matter digestibility was reduced significantly when the ratio of healthy straw was increased. Whereas least digestibility was observed when only healthy straw was used. The *in vitro* dry matter digestibility (IVDMD), which takes into account all the known and unknown factors being affected by damage, is influenced by the degree of lignification and silicification (Van Soest, 1963; Van Soest and Jones, 1968). Lignin and silica contents have also been found to reduce IVDMD (Arora *et al.*, 1975; Gandhi *et al.*, 1980). On the contrary, Luthra *et al.*, (1988) recorded the decrease in IVDMD (3-4 per cent) in downy mildew infected lucerne leaves. Similar results were also observed by Wilson *et al.*, (1991) that IVDMD decreased significantly in rusted pearl millet leaves.

Obligate parasites/facultative saprophytes subsist mostly on living hosts which may lead to many marked shifts in the metabolic processes of host tissues leading to changes in carbohydrate metabolism. Fungal

infection usually results in drastic changes in biochemical processes of the host (Wood, 1967). In the present study chemical composition of diseased and healthy straw obtained from highly susceptible cultivar WH 147 revealed that Crude protein of straw obtained from healthy plants was 3.84 as compared to 2.97 per cent of straw of diseased plants. Similarly ether extract was 2.25 per cent of healthy straw as compared to 1.64 per cent of straw obtained from diseased plants. Ash content was also increased from 11.35 to 18.50 per cent, whereas, crude fiber decreased from 33.46 per cent to 14.17 per cent. Similar observations had been recorded by Luthra *et al.*, (1988) against downy mildew of lucerne. Quantitative and qualitative changes in proteins occur when a plant cell is penetrated by the pathogen, and the origin of proteins is related to both plant and pathogen (Uritani, 1971).

Total sugar level increased with the increase in age of the plant both under healthy and diseased situations. However, considerable decrease of crude fiber level in the straw was obtained from diseased plants as compared to healthy straw. Vidyashekar *et al.*, (1975) found that total sugars increased in susceptible variety upon inoculation of *Setaria italica* with *Uromyces setariae italicae*. On the other hand Subramanyan *et al.*, (1990) found higher values of total sugar in healthy leaves of all the wheat varieties tested, than their leaf blight (*Drechslera hawaiiensis*) infected counter parts. Bhatnagar and Kumar (1995) recorded severe decline in sugar content of clusterbean leaves upon infection of *Alternaria cyamopsidis*.

Among the various methods available for disease management seed treatment with fungitoxicants has attracted considerable significance. All the fungicides Bavistin 50WP, Vitavax 75WP, Vitavax 200WP and Raxil 2DS alone and in combination with both the insecticides, Endosulfan and Chlorpyrifos used as seed treatment for control of flag smut, revealed that during both the crop seasons, disease was completely checked by all the four systemic fungicides, when applied as dry seed treatment at the rate of 2g Kg^{-1} seed and in combination with insecticides. Lower doses of all the fungicides @ 1g Kg^{-1} seed also controlled the disease significantly and there was not much adverse effect on seed germination.

Similarly carboxin has been reported to be the most effective fungicides for inhibiting growth of several Basidiomycetes and its therapeutic activity against several rusts and smuts of grasses (Edington *et al.*, 1966). Carboxin liquid and dust formulations were found effective against artificial inoculation of flag smut of wheat (Alock, 1978). Tyagi, (1972) and Bedi *et al.*, (1975) evaluated several systemic and non-systemic fungicides against flag smut in the field. Among the systemic ones Vitavax and Plantvax effectively controlled the disease, whereas Thiram among no-systemic fungicides gave good disease control. Vitavax as seed dressing has also been reported to give highly significant to complete control.

Control of flag smut of wheat both under natural as well as

artificial inoculation conditions (Bhatnagar *et al.*, 1975; Anonymous, 1980 and Raina *et al.*, 1980). Of the six non-systemic and seven systemic fungicides including carboxin tested under natural incidence of flag smut, the systemic fungicides except Chloroneb provided complete disease control. Whereas, of the six non-systemic fungicides including Thiram only captafol and Quintazene could provide significant disease control (Goel and Jhooty, 1985). Metcalfe and Brown (1969) obtained high level of flag smut control with Metsulfovax and the present findings are in agreement with the results of above workers. The effectiveness of tebuconazole against *Urocystis agropyri* at very low doses of application is reported for the first time from India, though Tariq *et al.*, (1992) found that Vitavax, Bayton, Vincit and Raxil gave 100 per cent control of flag smut on a susceptible variety in Pakistan. The present findings are also in corroborate with these reports.

In the present investigations, the non-target effect of recommended insecticides was studied. Endosulfan and Chlorpyriphos seeds treatment reduced disease incidence around 50 per cent and 70 per cent respectively as compared to control. The per cent seed germination was recorded slightly reduced in alone insecticides treated seeds. Present investigations are in confirmation with Bollen *et al.*, (1954) who reported decrease in number of *Mucor* spp., *Penicillium* spp. and *Aspergillus* spp. with field application of BHC, DDT and

aldrin. Richardson (1957, 1959) also reported reduction in root rot of barley (*Helminthosporium sativum*) and vascular wilt of tomato (*Fusarium oxysporum* f. sp. *lycopersici*) with application of aldrin. Mukhopadhyay and Thakur (1977) reported inhibition of *Sclerotium rolfsii* causing root rot of sugarbeet with BHC, quinalphos and phorate. Fungicidal activity of many other insecticides has also been reported against various plant pathogens (Hacskeylo and Stewart, 1962; Ram *et al.*, (1971). Singh (1987) observed significant reduction in efficacy of fungicide, tolclotos Mehtyl in presence of Monocrotophos against *Rhizoctonia solani* causing root rot of cowpea. However, low seedling rot was recorded in thiabendazole when used along with endosulfan. Arya *et al.*, (1997) evaluated isoproturon and 2-4,D as foliar sprays which reduced disease incidence in wheat plants inoculated with *U. agropyri*. Of the insecticides tested, phorate controlled *U. agropyri* best in field and greenhouse trials. Other insecticides Aldrin 35EC, BHC 10WP and Almunium phosphate also reduced disease incidence.

The loss in yield due to *U. agropyri* ranged between 0.35 to 65.02 per cent depending upon the host and environment. The maximum losses were recorded in susceptible cultivars namely WH 147 and WH 416 (65.02 and 56.18 per cent) whereas less than one per cent loss in yield was recorded in resistant cultivars namely UP 2425, WH 283 and WH 291. These findings are in confirmation with observation at McAlpine (1910); Brittlebank (1920); Yu *et al.*, (1936), Bhatnagar

et al., (1978). The yield loss as high as 50 per cent have also been reported by Tyagi *et al.*, (1966) and Beniwal (1992) and they further reported that yield reduction varied from variety to variety depending upon varietal susceptibility and effect of flag smut on yield components. These findings are in agreement with present findings where yield losses also varied from variety to variety. The reduction was more significant in susceptible and highly susceptible varieties as compared to resistant one.

Disease also significantly affected the number of tillers per plant particularly in susceptible and highly susceptible varieties as compared to resistant one. The maximum reduction was recorded in WH 147 followed by PBW 343. The per cent reduction ranged between 15.23 to 46.08 in susceptible varieties as compared to less than one per cent in resistant. These findings are in agreement with those of Beniwal (1992) where he has reported reduction in tillering per plant ranging between 15.7 to 45 per cent.

The plant height, earhead length and 1000 grain weight were influenced greatly by the disease. The per cent reduction in plant height, earhead length and 1000 grain weight ranged between 0.18 to 60.17, 0.10 to 44.80 and 0.42 to 38.12 respectively in different wheat varieties. Present findings are in agreement with Bhatnagar *et al.*, (1978) who have reported reduction in earhead length upto 65 per cent, 1000 grain weight upto 20.85 per cent and finally yield upto 60.76 per cent in HD 2009 wheat cultivar Beniwal (1992) have also

reported the per cent reduction in tillering per cent (15.7 to 45 %),
Plant height (37 to 62 %) and earhead length (28-46 %).

CHAPTER-6

SUMMARY

Flag smut of wheat caused by *Urocystis agropyri* (Preuss) Schroet is a disease of major importance in various parts of the country and causing considerable damage in isolated fields in some pockets of the state keeping in view the importance of disease present investigations were carried out.

There was no adverse effect of inoculum load on per cent seed germination in resistant varieties whereas in susceptible and highly susceptible varieties the germination percentage was decreased significantly and below the ISTA standard i.e. 85 per cent. The root and shoot length was also not affected by any level of inoculum significantly as compared to control in resistant varieties. Whereas in case of susceptible and highly susceptible varieties root and shoot length decreased significantly as compared to control. Similarly dry weight of seedlings was not affected significantly by any level of inoculum in resistant varieties. Whereas it decreased significantly in susceptible varieties as compared to control. Speed of germination of inoculated seeds was maximum in resistant cultivars as compared

to susceptible and highly susceptible cultivars. There was no adverse effect of inoculum load on speed of germination in resistant cultivars. Whereas in susceptible and highly susceptible cultivars it decreased significantly as compared to control.

The observations were made on the effect of weather variables on the progress of disease on four cultivars WH 147, C 306, WH 542 and HD 2687. The initiation and development of disease on leaves was found to be greatly influenced by weather factors prevalent under field conditions. Maximum periodical increase in disease intensity (22.26%) was recorded when 18.8-22.0°C maximum and 2.8-3.4°C minimum temperature and more than 90% relative humidity prevailed.

The stepwise multiple regression analysis showed that maximum temperature and relative humidity (morning) has significant role in the development of flag smut of wheat. Prediction equations have been developed using regression analysis on the effect of different environmental interactions on the periodical and cumulative progress of the disease on four cultivars. Variation in cumulative progression of the disease on leaves could be explained up to 81-84, 60-65 and 72-76 per cent during the crop season 2000-2001, 2001-2002 and pooled of both years respectively.

Respiration rate of inoculated seeds of highly susceptible and susceptible varieties increased slightly as compared to control.

Respiration rate of ten days old inoculated seedlings of highly susceptible varieties increased around 6 per cent as compared to control. In resistant varieties less than one per cent respiration rate was increased as compared to control. Respiration rate in diseased plants increased by more than 25 per cent in highly susceptible and 14 per cent in susceptible varieties respectively, whereas less than one per cent increase was noticed in resistant varieties.

Leaf area reduced significantly i.e. more than 55 and 45 per cent in highly susceptible and susceptible varieties respectively, whereas leaf area of resistant varieties did not reduced.

Maximum IVDMD 48.03 per cent was recorded in straw obtained from totally diseased plants as compared to totally healthy control (26.3 per cent). Ether extract, crude protein and crude fiber decreased in straw obtained from diseased plants.

All the systemic fungicides alone and in combination with endosulfan and chlorpyriphos almost provided complete control of the disease. Even the lower concentrations of systemic fungicides alone in combination with insecticides like Bavistin 50WP, Vitavax 75 WP, Vitavax 200WP and Raxil gave highly significant disease control and had no adverse effect on seed germination.

Yield was reduced from 24.7 to 65.02 per cent in different highly susceptible and susceptible varieties. The number of tillers, plant height, earhead length and 1000 grain weight was significantly

reduced in susceptible and highly susceptible varieties. Whereas these characters were not affected by disease in resistant varieties.

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APPENDIX - I

Weather variables prevalent during the preceding week of
observation in the crop season 2000-2001

Standard week	Temperature °C			Relative Humidity (%)			Sunshine(h)
	Max. (X ₁)	Min. (X ₂)	Avg. (X ₃)	Morning (X ₄)	Evening (X ₅)	Avg. (X ₆)	
1.12.2000	24.5	4.7	14.6	85.2	26.1	55.6	7.4
8.12.2000	25.9	2.9	14.4	81.3	21.2	51.2	8.9
15.12.2000	24.6	3.4	14.0	87.1	28.4	57.7	8.1
22.12.2000	24.4	3.3	13.8	89.7	28.2	58.9	8.4
5.01.2001	17.1	7.1	12.1	91.4	76.5	83.9	2.4
12.01.2001	15.7	1.8	8.75	96.1	63.2	79.65	5.1
19.01.2001	19.9	6.1	13.0	96.4	60.0	78.2	6.8
26.01.2001	22.7	3.1	14.9	97.2	54.4	75.8	5.7
2.02.2001	20.7	3.4	12.1	92.8	39.4	66.1	7.3
9.02.2001	22.9	4.1	13.5	87.8	25.6	56.7	9.3
16.02.2001	21.1	1.0	11.3	92.0	29.1	60.5	9.4
23.02.2001	23.5	2.0	12.8	87.6	28.6	58.1	9.4
2.03.2001	25.9	7.2	16.9	90.7	33.0	61.3	8.1
9.03.2001	28.0	5.3	16.7	86.3	20.4	53.3	9.4
16.03.2001	30.6	10.9	20.7	77.1	31.0	54.0	8.6

APPENDIX - II

Weather variables prevalent during the preceding week of observation in the crop season 2001-2002

Standard week	Temperature °C			Relative Humidity (%)			Sunshine(h)
	Max. (X ₁)	Min. (X ₂)	Avg. (X ₃)	Morning (X ₄)	Evening (X ₅)	Avg. (X ₆)	
29.11.2001	26.3	6.5	16.4	92.4	35.2	63.8	8.4
6.12.2001	26.5	6.7	16.6	91.3	34.3	62.8	8.5
13.12.2001	22.2	9.2	16.0	91.5	53.5	72.5	5.8
20.12.2001	21.7	4.0	12.8	94.2	45.7	69.9	7.9
27.12.2001	19.5	5.2	12.3	95.1	65.6	80.3	5.2
3.01.2002	17.4	5.9	11.6	97.0	72.5	84.5	5.4
10.01.2002	20.0	3.1	11.5	97.1	58.4	77.7	5.7
17.01.2002	20.9	8.9	14.9	93.6	62.0	77.8	5.3
24.01.2002	18.8	2.8	10.8	93.1	59.1	76.1	6.7
31.01.2002	20.3	2.8	12.9	92.8	39.0	68.9	8.3
7.02.2002	21.9	3.3	12.6	88.7	44.8	66.8	8.5
14.02.2002	18.6	3.4	11.0	93.4	69.6	81.4	6.3
21.02.2002	25.7	9.1	17.4	88.6	41.0	64.8	9.1
28.02.2002	23.6	10.2	16.3	92.0	58.0	75.0	6.4
7.03.2002	24.1	8.7	16.4	89.7	47.1	68.4	7.4
14.03.2002	27.2	10.78	18.9	82.1	37.2	59.6	9.6

ABSTRACT

Title of thesis : Studies on flag smut of wheat caused by *Urocystis agropyri* (Preuss) Schroet and its effect on physiological parameters.

Full Name of Degree Holder : Dharmveer

Admission No. : 98A66D

Title of Degree : Doctor of Philosophy

Name and Address of Major Advisor : Dr. M. S. Panwar
Professor
Department of Plant Pathology
CCS Haryana Agricultural University
Hisar-125 004

Degree Awarding University/Institute : CCS Haryana Agricultural University
Hisar-125 004

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Flag smut (*Urocystis agropyri* (Preuss) Schroet) of wheat is a widely distributed disease in many wheat grown parts of the world, but is of major importance only in limited areas. The present investigations were undertaken during 2000-2001 and 2001-2002 crop seasons with a view of elicit information on effect of inoculum load on seed and seedling vigour, effect of weather variables on disease progress, physiological parameters, particularly respiration and leaf



area, *in vitro* dry matter digestibility and interaction of insecticides with recommended fungicides for controlling the disease.

Inoculum load had no adverse effect on seed germination, root and shoot length and dry weight in resistant cultivars, whereas, it was significantly reduced in susceptible and highly susceptible cultivars. The disease intensity and AUDPC increase greatly ($>45\%$ and 200 respectively), in susceptible and highly susceptible cultivars. Maximum disease developed when maximum and minimum temperature were 20.7 and 3.1°C respectively and morning R.H. was more than 90% and sunshine hrs. (>7). Respiration in diseased plants increased by more than 25% in all the susceptible cultivars, whereas, no increase was observed in resistant cultivars.

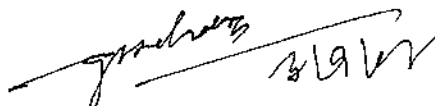
Leaf area reduced significantly i.e. $>55\%$ in highly susceptible and $>45\%$ in susceptible cultivars, whereas it did not reduced in resistant cultivars. Maximum IVDMD was recorded in straw obtained from totally diseased plants as compared to control. Ether extract, crude protein and crude fiber decreased in straw obtained from diseased plants, whereas ash increased. All the systemic fungicides along and in combination of Endosulfan and Chlorpyrifos almost completely controlled the disease and has not much adverse effect on seed germination. Yield was reduced from 24.7 to 65.02% in different highly susceptible and susceptible cultivars. Whereas these characters were not affected by disease in resistant cultivars.



MAJOR ADVISOR



SIGNATURE OF STUDENT



HEAD OF THE DEPARTMENT