"EPIDEMIOLOGY AND CONTROL OF COWPEA RUST

(*Uromyces phaseoli* var *Vignae*)

IN KENYA"

by

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DECLARATION

a) I, A. F. N. Opio, declare that this thesis is my original work and has not been presented for a degree in any other university.

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Date 16/11/1979

b) This thesis has been submitted for examination with our approval as University supervisors.

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Date 16th November, 1979

To

MY HUSBAND, GABRIEL OPIO

and

DAUGHTER, PAMELA NASIRUMBI

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ABSTRACT

Cowpea rust caused by *Uromyces phaseoli* var *Vignae* is a major factor limiting cowpea production in Kenya. Epidemiology and control measure studies were carried out on this disease. Investigations included studies on symptomatology, factors affecting uredospore germination, disease development, histopathology, disease progress in the field, spread and survival of the pathogen, host range of the fungus, varietal reaction of the different cowpea cultivars and chemical control.

Germination of uredospores occurred within a wide range of temperatures, relative humidity, liquid media, and pH. However, the optimum conditions for germination were when the spores were mounted in sterile tap water, dried and incubated at 20°C and 100 percent relative humidity. Plant and leaf age affected disease development. The older the plant and the leaf, the less susceptible it was to cowpea rust. Uredosori developed within six to eight days after inoculation. Uredospores formed on the leaf pustules were spread to higher leaves on the same plant and to other plants through wind and probably by

contact. The pathogen survived only on infected debris. Besides cowpea, the pathogen attacked *Phaseolus aureus*, *Macroptilium atropurpureum* and *Vigna parviflora*. Varieties of cowpea differed significantly in their reaction to this rust and could therefore, be incorporated in breeding for disease resistance. Baycor and bayleton proved to be the best fungicides in controlling cowpea rust in laboratory, glasshouse and in the field.

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INTRODUCTION

Cowpea (Vigna unguiculata L. Walp.) is considered to be one of the most important leguminous crops in Africa (Sellschop, 1962). The crop constitutes the second largest portion of grain legume in Kenya, the first being beans. It is grown in about 66,600 hectares of land, most of which lies in the Eastern Province. The other areas include Coast, Nyanza and Western Provinces (Statistical Abstract, 1977).

The crop is used mainly for the consumption of leaves, green pods and grain. In addition, the green leaves and grains are sometimes sold for cash in the local market. In Machakos alone, the export of green leaves amounted to 189.4 tons in 1968 (Anon, 1969).

Nutritionally, cowpea is very important (Oland and Stabursvik, 1970). It is rich in protein and vitamins. The protein content of leaves is estimated at about 39 percent on dry weight basis while that of the dry grain is 23 percent (Mehta, 1969). The crop contains vitamins such as thiamine, methionine, niacin, pyridoxine, pentothenic acid and folic acid (Ogunmodede and Oyunuga, 1970).

Production of cowpeas in Kenya is, however, affected by many factors among which plant diseases constitute an important factor. These diseases reduce the quality and quantity of the leaves and seeds considerably. More than ten diseases have been recorded on cowpeas in this country (Mukunya, 1978). Cowpea rust caused by Uromyces phaseoli var vignae is among the top five major diseases which are responsible for reducing crop grain yield appreciably. If the disease appears early, it completely defoliates the crop. Unfortunately very little work has been done on the cowpea rust in Kenya and therefore, no indication of the losses caused by the disease can be ascertained.

Although the disease is of economic importance it has attracted little attention in East Africa and many other parts of the world. Therefore, since cowpea rust is one of the major diseases of cowpea in Kenya, work of the basic nature was undertaken to help provide the knowledge needed to control it.

LITERATURE REVIEW

Rusts constitute an important group of plant diseases affecting plant species in both monocotyledons and dicotyledons. They are so called because they produce rusty brown symptoms on the leaf surface of the host. The fungus responsible for inciting cowpea rust is an obligate parasite, belonging to the class *Basidiomycetes* and order *Uredinales*. There are two varieties of the genus *Uromyces*, namely *Uromyces phaseoli* var *phaseoli* which attacks beans and *Uromyces phaseoli* var *vignae* which attacks cowpea. These two are differentiated on the basis of their pores on the uredospores (Fromme, 1924; Doidge, 1948). The uredospore of cowpea rust contains two subequatorial pores while that of bean rust contains two to three equatorial pores.

Geographical distribution

Cowpea rust is cosmopolitan and occurs practically everywhere the crop is grown. Its occurrence has been reported from southern Europe, Asia, Japan, Africa, South America, the West Indies and the United States of America (Fromme, 1924).

In Africa, the disease was first reported by Sweden (1921) on Vigna sinensis in Uganda. Wallace (1945) recorded U. phaseoli on cowpea in Namuhona region of Tanzania and in 1949 it was listed as one of the most economic diseases in the country (Wallace and Wallace, 1949). The disease was also reported from Egypt (Fahmy, 1935), Sierra Leorne (Deighton, 1949), South Africa (Doidge, 1948) and Nigeria (Williams, 1975).

In Asia, the pathogen was reported in China on cowpeas (Teng, 1932), Rhukyu islands on cowpea and on Dolichos lablab (Hiratsuka et al., 1956). It was also recorded in Japan (Hirata, 1953) and India (Rawal et al., 1974).

In southern Europe, the disease was prevalent in Cyprus (Nattrass, 1932) and Portugal (De Sousa et al., 1941).

Rust on cowpeas had also been reported from United States of America especially in the states of Maryland, Virginia, Alabama, Florida, Indiana, Iowa, Missouri, Texas and California (Fromme, 1924). The disease was also reported on cowpeas from Jamaica (Dale, 1956).

Pathogen cycle

Mechanism of release of spores

The mechanism by which spores become free from their stalks is unknown (Hardwick *et al.*, 1975). It has been suggested by Hardwick *et al.* (1975) that spore release may depend on the sudden expansion of the spore during the terminal phase of its growth accompanied by protrusion of spines to the surface and simultaneous dissolution of the primary wall which appears to be the main component binding the spore to the stalks. Final detachment and rupture of the pedicel is probably caused by the pressure of one spore upon another during expansion of the uredospores.

Dissemination and survival of the fungus

Hardwich *et al.* (1975) reported that after detachment, uredospores were dispersed mainly by air currents. He also suggested that loss in weight by dehydration might aid dispersal. Emechebe (1975) reported primary spread of this fungus by air-borne uredospores. Howland *et al.* (1966) reported bean rust uredospores to be disseminated mainly by wind. While Littlefield and Bracke (1975) suggested that spines on uredospores might increase their buoyancy and help long

distance dissemination. Harter (1935) suggested uredospore dissemination by wind, contact, animals and implements.

Harter (1935) reported that U. phaseoli subsisted between crop seasons as uredospores in regions with mild winters and teliospores in cooler climates. Whetzel (1906) working with bean rust reported survival of uredospores on old leaves and vines left in the field.

Infection

Hardwick et al. (1971), Heath (1971), Heath (1974), Littlefield and Bracke (1975), Mendgen (1978) working independently, found that when the rust spore landed on the leaf, stem or pod of the host, a germ tube grew from the spore. After growth for a distance, the germ tube formed an appressorium over a stomatal pore which in most cases resulted in death of the guard cells (Heath, 1971; Heath, 1972). The infection peg developed from the appressorium and penetrated the host through the stomata. Heath (1972) recorded penetration six hours after inoculation. Within twelve to twenty-four hours the hypha enlarged to form a substomatal vesicle. The vesicle later produced mycelium which ramified between host

cells forming haustoria which invaginated the host protoplast.

Heath (1974) found that the formation of the appressorium on cowpea leaves was not always over a stomatal pore. He also pointed out that in such cases formation of appressoria was mostly over the junction between two epidermal cells. The substomatal vesicle and infection hypha then developed on the leaf surface.

Behaviour of U. phaseoli in immune varieties of cowpea and non-hosts

Heath (1971) working with immune and susceptible cowpea cultivars found the mode of germination of uredospores and appressoria formation to be the same in susceptible and immune hosts. He, however, reported differences occurring after substomatal vesicle formation. One immune cultivar, Queen Anne, showed a unique dimorphic reaction to infection by U. phaseoli. In this cultivar haustorial formation induced either rapid host cell necrosis or the formation of calloselike sheath which grew up from the host cell wall to enclose completely the haustorium. This process slowed down haustorial and host cell death. In other immune cultivars resistance was expressed by a hypersensitive reaction of invaded host cells.

Heath (1972) found that the non-host Phaseolus vulgaris responded to each infection hypha by the deposition of electron opaque material on and within surrounding host cell walls. These depositions prevented haustorial formation in about 90 percent of the infection sites. He detected no sign of resistance in immune cowpea cultivars until the formation of the haustorium. The subsequent reaction on other immune cultivars was the same as that reported by Heath (1971).

In his studies of interactions of hosts and non-host plants with cowpea rust, Heath (1974) observed deposition of osmiophilic material on and within cell walls of most non-host plant. In this case they formed too late to prevent haustorium development. In addition there were clusters of rodlike structures in all non-hosts. He further observed that the mode of uredospore germination and appressorium formation was the same on hosts and non-hosts. After haustorium formation, reaction in non-hosts was the same as reported by Heath (1971) and Heath (1972) in immune cultivars.

Symptomatology

Fahmy (1935) described symptoms of cowpea rust as minute, round, bright yellow spots appearing

mostly on the upper surfaces of the leaves and to a less extent on petioles and stems. Soon yellow aecidia appeared in circles mostly on the lower surfaces of the leaves. The darker brown uredosori and the almost black teleuto pustules followed successively occurring on both sides of the leaf.

Gay (1971) reported symptoms of cowpea rust as appearing initially on the upper surface of the leaf. He further observed that infection was first evident as minute, almost slightly raised spots which were developing sori. On very susceptible varieties under favourable conditions in the greenhouse, a ring of secondary sori developed outside the primary sorus, and in some cases even a third ring of sori formed.

Williams (1975) found that on young cowpea plants, leaves became covered with small pustules containing the light brown uredospores. Plants with heavy rust infection appeared to have a brown tinge from a distance and wilted quicker than resistant lines. As the plants aged those leaves not completely destroyed produced a black mass of teliospores.

Sokhi and Sokhi (1976) reported the initial infection of cowpea rust on the upper leaf surface as small raised sori. These were initially

covered with the epidermis which ruptured in due course releasing powdery spore dust. Under favourable conditions, numerous sori appeared subsequently in rings around the first sorus. Similar sori were also encountered on the lower surface of the leaves on the same foci of infection. Both uredospores and teliospores were observed in the same sori. Symptoms were more conspicuous on the leaves even though the disease attacked stems and fruiting banches.

Epidemiology

a) Uredospore germination

Uredespore germination has been reported to take 1 - 2 hours. Gay (1971) reported germination within one hour at 20°C in one percent agar. Sokhi and Sokhi (1976) observed germination of uredospores after two hours when placed in a film of water at room temperature (18 - 20°C) and 100 percent relative humidity. No germination occurred on slides without a film of water.

Yarwood (1939) working with bean rust found that uredospores failed to germinate when seeded onto dry slides in moist chambers. Uredospores on slides atomised with water before incubating them in moist chambers germinated both at 16° and 19°C. Naito (1951) reported germination of uredo-

spores at 10 - 25°C. Germination started one hour after sowing at 10 - 20°C and was completed after four hours. Yarwood (1956) found a decrease in percentage germination with increasing numbers of uredospores while there was an increase in germ-tube length. This dual effect was greater at 25°C than at lower temperatures and increased by acidifying with sulphuric acid.

b) Factors affecting disease development

Fahmy (1935) reported that cowpea rust in Egypt became more severe as the weather cooled down and atmospheric humidity increased. Sokhi and Sokhi (1976) found no effect on disease severity due to variation in relative humidity and temperature. They also reported increase of the disease from 30 percent when rainfall was 40 mm to maximum intensity when rainfall was 205 mm. This led to the conclusion that the main factor in the development of cowpea rust was rainfall. Williams (1975) observed that in Ibadan (Nigeria) rust built up rapidly in irrigated plantings in the dry season and during sporadic rains at the beginning of the rainy season. During the heavy rainfall months

of June and September, the spread of the disease was markedly reduced.

Light has also been found to affect disease development. Sokhi and Sokhi (1976) reported a reduction of infectivity with uredospores kept in the dark as compared to those kept in light and intermitent light respectively. Plants kept in the light showed defoliation of primary leaves nine days after disease appearance whereas no defoliation of leaves occurred on plants kept in shade.

Sempio (1938) observed a retardation of bean rust development due to absence of light during uredospore formation. However, no adverse effect was noted during the first three or four days after inoculation. He further noted that during the first 20 to 24 hours after inoculation, a high degree of relative humidity was necessary for the disease to develop rapidly. Later, especially, seven to eight days after inoculation the disease made rapid progress at a relative humidity of about 70 percent.

Yarwood (1961) reported that bean rust required high humidity during the incubation stage of its life cycle. He also observed greater production of uredospores at high humidity than at low humidity. Ten times as many spores were produced at high humidity compared to low humidity.

Effect of Nitrogen, Phosphorus and Potassium

Nitrogen had significant effect on the cowpea rust severity (Rewal et al., 1974). Rewal et al. (1974) found a decrease in disease incidence at higher doses of nitrogen and maximum incidence was obtained when nitrogen was applied at 15 kg/ hectare. Lowest incidence of the disease was observed when 30 and 45 kg/hectare of nitrogen was applied. Higher doses of nitrogen resulted into vigorous and bushy growth of the plant. Potassium and phosphorus at any level of application showed no effect on disease development.

Host range

Cowpea rust is limited in its host range. It has been known to infect Vigna unguiculata (Hirata, 1935; Savulescu et al., 1930), Vigna sinensis (Sweden, 1921; Fromme, 1924; Nattrass, 1932), Vigna repens, Vigna sesquipedalis, Phaseolus truxillensis (Fromme, 1924) and Dolichos lablab (Fromme, 1924; Hiratsuka et al., 1956).

No infection has been found on french beans (Nattrass, 1932), lima, kidney or any other beans tested (Fromme, 1924).

Control of cowpea rust

Use of resistant varieties has been found to be the most effective means of controlling cowpea rust (Nattrass, 1935). In most cases this is the only method recommended for the control of this disease since chemical control is considered uneconomical for this particualr crop (Emechebe, 1975).

The only work available on chemical control was that of Sokhi and Sokhi (1976). They tried:

benomyl: ((Methyl- 1- (butylcarbamoyl) -2 benzimidazole carbamate)),

captafol: (Cis - N ((1,1,2,2, - Tetrachloroethyl) thio) 4 - cyclohexane - 1, 2 - dicarboximide)),

mancozeb: (Manganese ethylene bisdithiocarbamate), and

mancozeb - dimocarb mixture.

Mancozeb-dimocarp mixture proved superior in controlling the disease and increasing the grain yield. A combination of mancozeb and benomyl also gave good control.

Work on bean rust has shown that several chemicals can be used to control it effectively. Jack et al. (1955) tried lime-sulphur,

Dithane D-14: (Disodium ethylene - 1, 2- bisdithio carbamate),

Thiram: ((tetramethylthiuram disulphide),

Captan: Cis N-(trichloromethyl) thio) 4 cyclohexane -1,2- dicarboximide).

All these fungicides were applied 24 hours before inoculating with a spore suspension of U. phaseoli. They all gave complete protection of the rust in the greenhouse.

Conover (1957) conducted a field experiment on bean rust control in Florida. His results indicated that effective control of U. phaseoli f. typica was obtained when maneb (manganese ethylene bisdithiocarbamate) was added to sulphur.

Howland et al.(1966) reported effective control of bean rust with sulphur dust. In years of severe epidemics only three applications were necessary to control the disease. He, however, noted that this was impractical and uneconomical for beans in East Africa.

Ogle et al (1974) recommended sprays of fungicides such as maneb against bean rust. He also reported that systemic fungicides had shown promise as seed dressings and foliage sprays in the glasshouse. Their effectiveness in the field had not yet been tested.

Bazirake (1975) evaluated different fungicides for their potential fungitoxicity against bean rust.

Sicarol: (2 methyl - 5, 6 - dihydro - 4 - H pyran - 3 carboxylic acid anilide),

Plantvax: (5 - 6 - Didydro - 2 methyl -1, 4 - oxathiin - 3- carboxinilide- 4,4 - dioxide) and

BAS 3172 F: (2 - lodo - N - phenylbenzamide)

gave an excellent control of bean leaf rust. He however, recommended sicarol and plantvax at the rate of 3.50 kg per hectare at very high levels of rust epidemics and 2.50 kg per hectare where rust incidence was low.

MATERIALS AND METHODS

Plants infected by cowpea rust were collected from the University Field Station, Kabete, and Katumani Agricultural Research Station, Machakos, in August 1978. Uredospore suspension from these materials were atomised on 15 - 20 days old seedlings of cowpea cultivar TVX 1836-473 E. This method of inoculation was used to maintain the pathogen in the glasshouse. Inoculated plants were kept at room temperature for 24 hours and then transferred to the glasshouse benches. The minimum and maximum temperatures in the glasshouses varied from 14 $\pm$ 5°C and 35 $\pm$ 5°C respectively.

Uredospore germination

a) Effect of different temperatures

Uredospores harvested from artificially infected cowpea cultivar TVX 1836-473 E were spread in sterile tap water on slides, dried and incubated in moist chambers at 10, 15, 20, 25, 30, 35°C and room temperature (20 $\pm$ 2°C). Data on uredospore germination was taken at two hours interval for the first ten hours and then after 24 hours and 48 hours. Four slides were used at each temperature.

b) Effect of relative humidity

The effect of various relative humidities on uredospore germination was studied using the method of Stevens (1916) and dessicators as humid chambers. Spores were mounted in sterile tap water as mentioned above and incubated in dessicators at 70, 80, 90, 95, 98 and 100 percent relative humidities. The temperature used was 20°C for all humidities.

c) Effect of different liquid media

Uredospores were spread in different liquid media on slides, dried and then incubated in moist chamber at 20°C.

d) Effect of different pH

The following pH were used on uredospore germination: 3.0, 3.5, 4.0, 4.5, 5.5, 6.0, 6.5 and 7.0. Uredospores were spread in a drop of suspension of each pH on slides. They were then dried and incubated in moist chambers.

e) Effect of storage (in a refrigerator) on uredospore germination

Uredospores were stored in a refrigerator (at 2 - 4°C) for different lengths of time. They

were then taken out after 2, 24, 48 and up to 2160 hours, spread on slides in sterile tap water and incubated in a moist chamber at 20°C.

Histopathological observations

Sections of fresh tissues and paraffin embedded material were made. Detection of the mycelium in sections of fresh material was facilitated by staining with lactophenol cotton blue.

For host penetration inoculated leaves of 10 - 15 days seedlings of the susceptible cultivar TVX 1836-473 E were removed after 6, 10, 24 hours of inoculation and then after every 24 hours up to 216 hours. They were then cleared and stained by the method of McBryde (1936). Two other methods of clearing and staining were used, namely, a simplified Giemsa technique as used by Latch and Hanson (1962) and a whole leaf clearing and staining technique of Shipton and Brown (1962).

Before embedding in paraffin wax, leaf sections were fixed in formalin aceto alcohol (FAA), dehydrated in different concentrations of ethyl alcohol (50, 60, 70, 80, 95 and 100 percent), and cleared in chloroform (Sass, 1958). Sections were cut at 10-20 μ thickness and stained in safranin and fast green (Sass, 1958).

Factors affecting disease development

a) Effect of temperature

Nineteen day old seedlings of variety TVX 1836-473 E were inoculated with a uredospore suspension and then kept in incubators at 10, 15, 20, 25, and 30°C for disease development. They were illuminated for 14 hours with six 8w bulbs. Data on disease development was taken for incidence and severity after 18 days. The incubation period of the pathogen was also noted. Three pots, at each temperature, each with five plants, were used.

b) Effect of humidity

Humidity was adjusted by the method of Stevens (1916) using dessicators as humid chambers. Nineteen days old seedlings of variety TVX 1836-473 E were inoculated with uredospore suspension and then placed in humid chambers at room temperature (20 ± 2°C. Humidities used were 70, 80, 90, 95, 98 and 100 percent. Three pots, each with five plants, were used at each humidity.

c) Effect of plant age

Seeds of variety TVX 1836-473 E were planted in pots at seven days interval from 21/5/79 to

2/7/79. Three pots were used at each planting date. Seven days after emergence of youngest seedlings, all the plants were inoculated with a spore suspension. They were then incubated at room temperature (20 ± 2°C) for 24 hours. For the rest of the experimental period they remained in the glasshouse with maximum and minimum temperatures of 35 ± 5°C and 14 ± 5°C respectively.

Progress of cowpea rust in the field

A field trial was conducted at Katumani in November 1978 to February 1979 to find out the progress of cowpea rust on four varieties, namely, Emma B, TVX 1836-473 E, TVX 12-01 E and KCIP 83-SP 28. The experimental layout was a randomized block design with three replicates and each plot was 6 x 6 metres in size. Single superphosphate was applied at the rate of 60 kg/hectare. Planting was done on 2nd November 1978 at a recommended spacing of 60 x 30 cm with two rows of maize between the plots. Two seedlings in the middle of each plot were inoculated with a uredospore suspension using an atomizer. Record on the progress of disease was taken once every week starting from the time the rust pustules first appeared on inoculated plants. Incidence was recorded as the number of plants affected per plot

and number of leaves affected per plant. Severity was recorded by using a scale of 1 - 10 (where 1 = 0 percent and 10 = 86 - 100 percent infection). Data on climatological conditions were taken from the meteorological station at Katumani Research Station. The spread of the disease within plots was noted.

The same experiment was repeated in April to August 1979 using only one variety namely TVX 1836-473 E. Planting was done on 10th April 1979 and inoculation was on 11th May 1979.

Uredospore dissemination

Uredospore dissemination was studied both in the glasshouse and in the field. In the glasshouse eight pots each with five plants were placed next to infected plants so that healthy and diseased plants were in contact. After 14 days the number of plants infected were noted.

In the field vaseline coated slides were exposed in a plot infected with cowpea rust. A total of six slides, one at each corner and two in the middle of the plot were exposed from 9 am. to 3 pm. during the day. The observations covered a total of three times each day for a total of six

days. The slides were kept at 2 - 4°C until needed for microscopic examination.

Mode of survival

Mode of survival was studied using seeds from infected pods, soil from infected cowpea field and infected debris.

a) Seeds

Seeds from severely rust infected plants were collected in February 1979 from Katumani. They were dried and sown in pots with sterilised soil in the glasshouse. Seeds harvested from healthy plants in the same field were planted as a control.

b) Soil

Soil from an infected cowpea field was collected during February 1979 at the University Field Station, Kabete. The soil was kept until June 1979 when it was placed in 12 cm. pots in the glasshouse. Seeds harvested from healthy plants of variety TVX 1836-473 E were sown. Four seeds were sown per pot and six pots were used.

c) Infected debris

Diseased leaves were collected during short rains of 1978 from Katumani. Leaves were powdered in dry form and then used in two ways. (i) Buried below the top of sterilised soil in 12 cm. pots and seeds harvested from healthy plants of variety TVX 1836-473 E planted in them. (ii) Dusted on the first trifoliate leaves of 15 - 20 day old seedlings of variety TVX 1836-473 E.

Host range

Thirty-three different legumes were tested for their susceptibility to the pathogen by inoculating seedlings as well as adult plants with uredospore suspension. Inoculations were repeated twice to confirm the host range.

Varietal reaction

Seventy-six varieties of cowpea were also evaluated for their reactions to cowpea rust. The method of inoculation was the same as mentioned earlier. Data on varietal reaction was taken after fourteen days by using a scale of 1 - 10 (where 1 = 0 percent infection and 10 = 86-100 percent infection).

Chemical control

a) Laboratory evaluation of fungicides

The following ten fungicides were evaluated for their effectiveness on uredospore germination in the laboratory:

common/trade name of fungicide	Active ingredient
Bayleton (25%W.P.)	1 - (4 - chloro-phenoxy) -3,3-dimethyl -1 - (1,2, 4 - Triazol - 1 - yl) - butan - 2 - one.
Baycor (200 E.C.)	B - (1, 1-biphenyl - 4 x loxy - 6 (1 - dimethy- lethyl - 1 H - 1, 2, 4 - Triazol - lethanol.
Blitox (50% W.P.)	copper oxychloride.
Benlate (50% W.P.)	Methyl - 1 - (- butyl- carbamoyl) - 2 - benzi- midazolecarbamate.
Plantvax (75% W.P.)	5 - 6 - Dihydro - 2 methyl - 1, 4 - oxathiin - 3 - carbo- xanilide - 4, 4 - dioxide.

Zineb (80% W.P)	Zinc ethylene bisdi-thiocarbamate.
Captan (65% W.P.)	Cis N- (trichloromethyl thio) 4 cyclohexane - 1, 2 - dicarboximide.
Sulphur (80% W.P.)	Sulphur
Calxin (75% W.P.)	N- Tridecyl 1 - 2, 6, Dimethyl morpholine.
Dithane M45 (80% W.P.)	Ethylene bis (dithiocar-bamate) manganese.

The concentration of the fungicides used was 500 ppm. In case of benlate, baycor and bayleton, concentrations of 50, 200, 350, 500, 650, 800, 950, 1100, 1250, 1400 and 1550 were also tried. Sterile tap water was used as a control. Slides in quadraplicate containing a dried drop of each fungicide and uredospore suspension were incubated at room temperature ($20 \pm 2^{o}C$) for 48 hours. About 10 - 30 uredospores were observed per replication and percentage germination calculated. The percentage inhibition was calculated by the formula given below.

$$100 - \left\{ \frac{\text{Percentage germination in treatment}}{\text{Percentage germination in control}} \times 100 \right\}$$

The layout was a randomised block design with four replications.

b) Glasshouse evaluation of fungicides

A glasshouse trial was conducted to test the efficiency of the above ten fungicides in controlling cowpea rust. Two methods were used. In the first method, 18 day old seedlings were inoculated with a uredospore suspension and incubated at room temperature (20 ± 2°C) for 24 hours before spraying with the fungicides. In the second method, the seedlings were first sprayed with the fungicides and then inoculated with uredospore suspension after 24 hours.

The concentrations of the chemicals used in ppm. were : 600 bayleton, 1200 baycor, 1000 benlate, 1000 blitox, 2400 sulphur, zineb and dithane M45, 2000 captan and 2308 plantvax and calxin.

The layout was a randomized block design with three replicates. Data was taken after 14 days for incidence as number of leaves affected per plant and severity using a scale of 1 - 10.

c) Field evaluation of the fungicides

A spray trial was conducted in November 1978 to March 1979 at the University Field Station, Kabete. It consisted of 5 treatments and 4 replicates. The layout was a simple randomized block and each plot was 3 x 2 metres. Variety TVX 1836-473 E was used at a spacing of 60 x 30 cm. and one metre was left between the plots. The first spray was applied on 24/2/79 when the first sign of rust was noted in the field. A total of four sprays were given at seven days intervals. Data was taken for incidence as number of leaves affected per plot and severity using a scale of 1 - 10 (where 1 = no infection and 10 = 86-100 percent infection). The fungicides, their doses and amount applied per plot, are given below.

Fungicide	Doses/ha	Amount/plot
Dithane M45	2 kg/ha in 600l of water	1.2 gm.
Blitox	2 kg/ha in 600l of water	1.2 gm.
Baycor	0.06L/ha (0.06 percent)	0.04 cc.
Bayleton	0.125 kg/ha (0.0125 percent)	0.08 gm.

A similar trial was set up at Katumani in April to August 1979. The layout was the same as mentioned above but the plot sizes was 4 x 4 metres. Four weeks after emergence, six seedlings in each plot were inoculated with a uredospore suspension. The first spray was applied when rust pustules appeared on the inoculated plants. Data on disease development was taken as above. Grain yield of the middle five rows was recorded. The fungicides, their doses and amount applied per plot are given below.

Fungicide	Doses/ha	Amount/plot
Dithane M45	2 kg/ha in 600 l of water	3.6 gm.
Blitox	2 kg/ha in 600 l of water	3.6 gm.
Baycor	0.06L/ha (0.06 percent)	0.1 cc.
Bayleton	0.125kg/ha (0.0125 percent)	0.45 gm.

RESULTS

Symptomatology

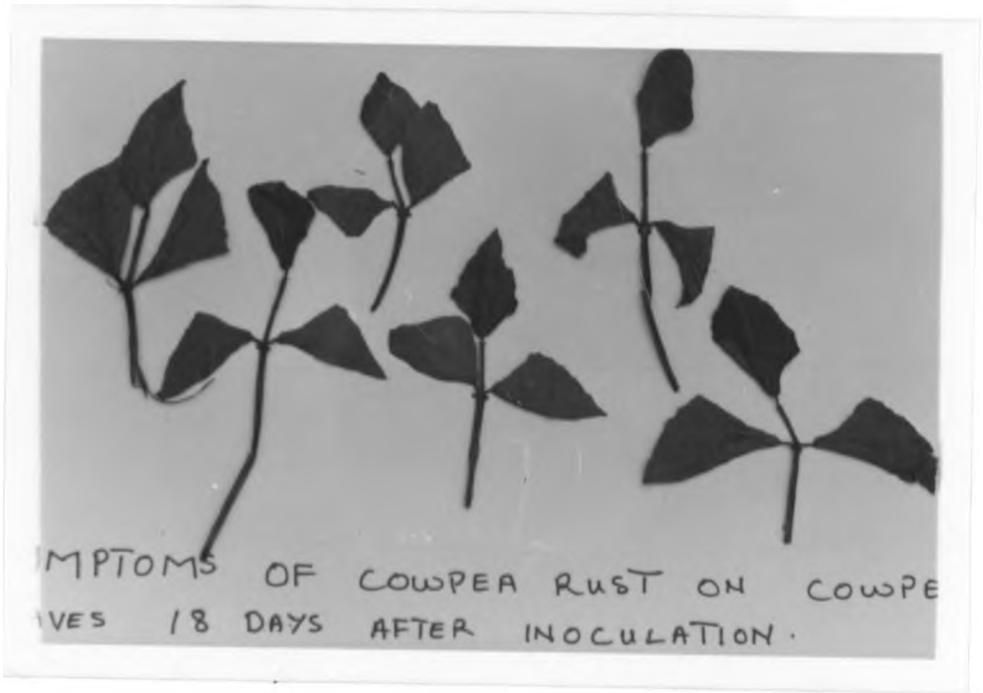
The first sign of rust appeared on the upper leaf surface six to seven days after inoculation as light green flecks. Small whitish raised pustules appeared eight to nine days after inoculation in these flecked areas (Fig. 1A). The pustules increased in size and colour becoming more yellow until completely yellow by the tenth day. This time the pustules had also appeared on the lower surface of the leaf. The pustles were initially covered with an epidermis which ruptured after 18 - 21 days, releasing powdery uredospores (Figs. 1B and 1C). Similar symptoms were observed on stems and pods (Fig. 2).

In the glasshouse, 28 - 30 days after inoculation, dark brown teliospores were observed on the outer edge of the ruptured pustules on the older leaves which were starting to dry. Severely affected leaves dropped off within 29-32 days of inoculation and in some cases severely affected plants wilted. No premature dropping of pods was observed.

Figure 1A

Symptoms of cowpea rust (appearing as light green spots) 9 days after inoculation

Figure 1B



Symptoms of cowpea rust on leaves 18 days after inoculation

Figure 1C

Symptoms of cowpea rust on leaves 20 days after inoculation (ruptured pustules)

Figure 2

Typical symptoms of cowpea rust on leaves, stems and pods

Spore morphology

Uresdospores obtained from ruptured pustules were dark yellow in colour, globoid in shape and measured 17 to 27 μ X 17 to 34 μ in size. Their walls were continuous with two subequatorial pores (Fig. 3A and Fig. 3B).

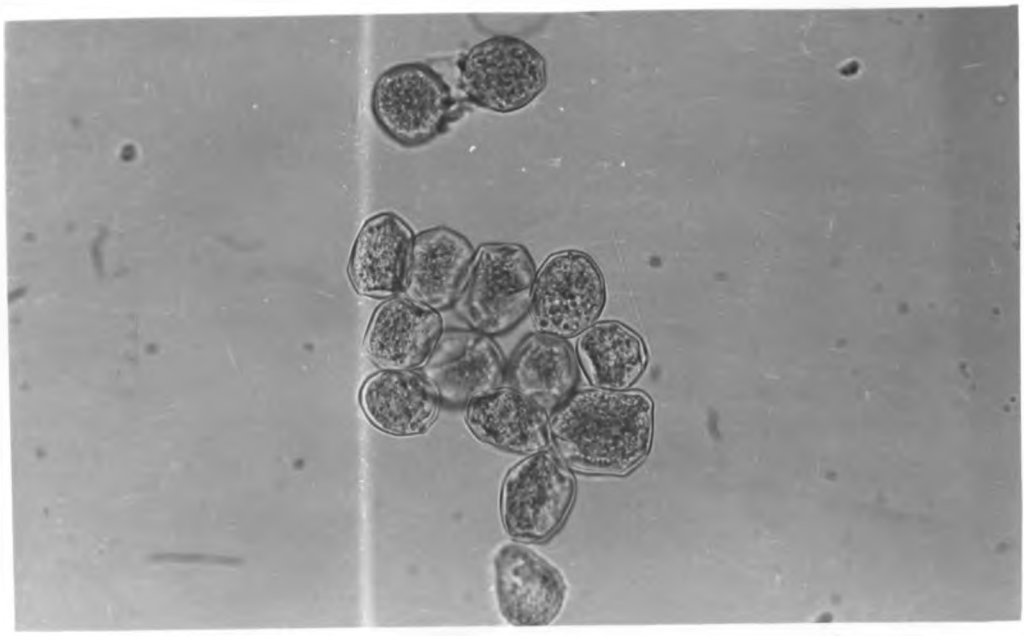
The teliospores were broadly ellipsoid, 20.4 to 23.8 μ X 23.8 to 34 μ in size, ovate at the apex and usually rounded at the base (Figs. 4A, 4B and 5). Their walls were covered with spines and dark chestnut brown in colour.

Factors affecting uredospore germination

a) Temperature

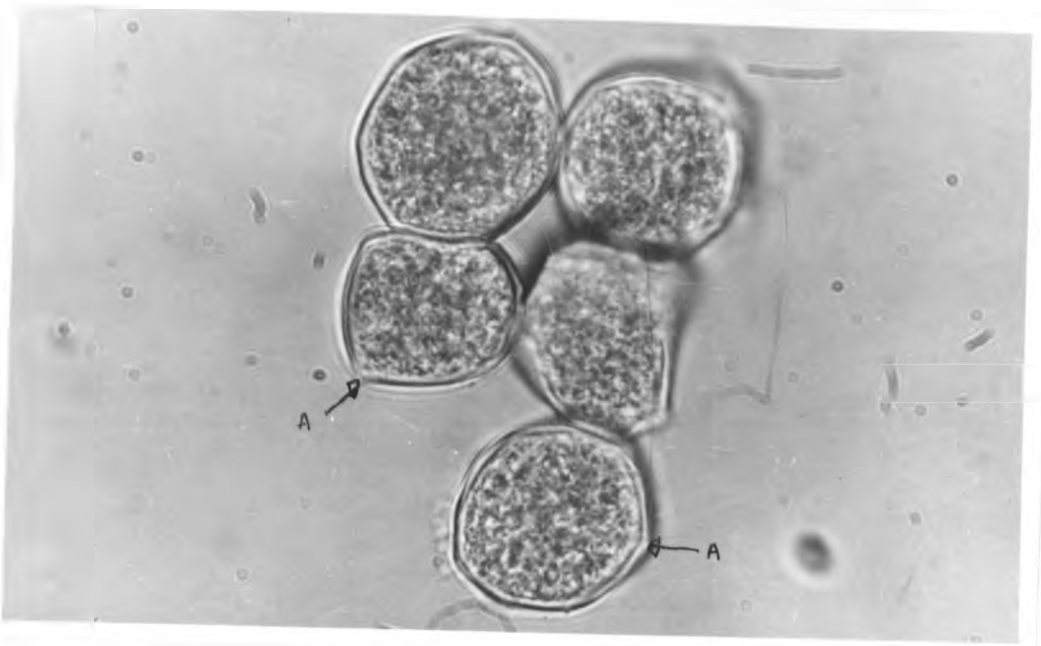
Uredospore germination occured over a wide range of temperature (10 - 30°C) provided enough time was allowed for it to occur. The highest percentage germination was observed at 20°C after 24 hours (83.9%) followed by room temperature (60.3%), 15°C (51.3%), 25°C (13.9%), 30°C (8.3%) and 10°C (3.7%) respectively (Fig. 6). The time at which spores started germinating varied with temperature. It took 4 hours at room temperature and 20°C, 6 hours at 15°C, 8 hours at 25°C and 10 hours at 10 & 30°C. (Appendix IIA). There were significant differences among temperatures (Appendix IIC).

Figure 3A



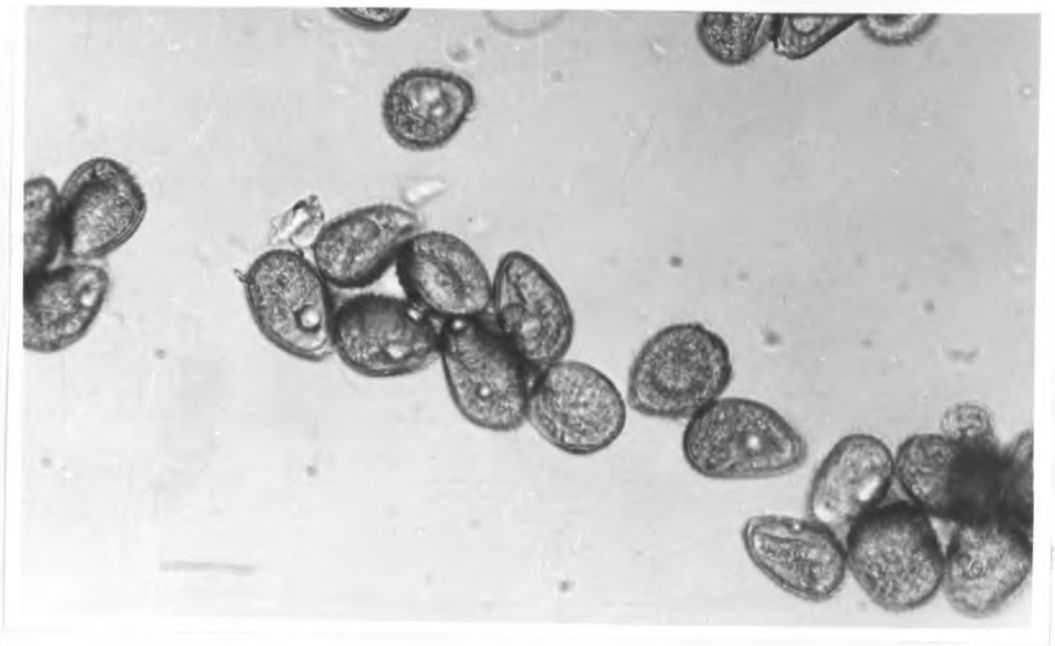
Uredospores of Uromyces phaseoli var Vignae
(40 x 10 magnification)

Figure 3B



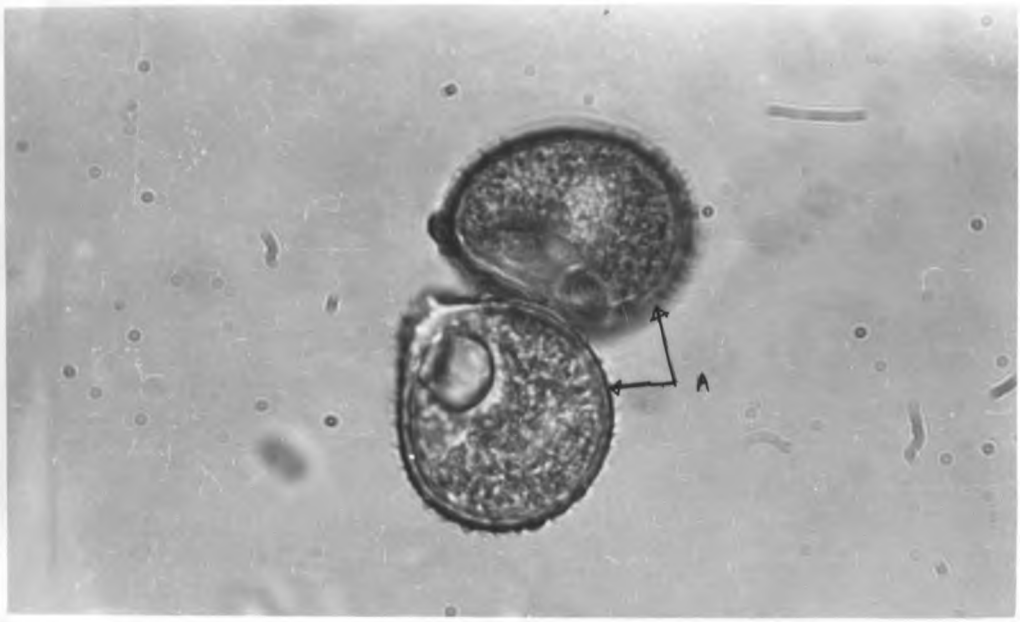
Uredospores of Uromyces phaseoli var Vignae (100 x 10 magnification). A. pores

Figure 4A



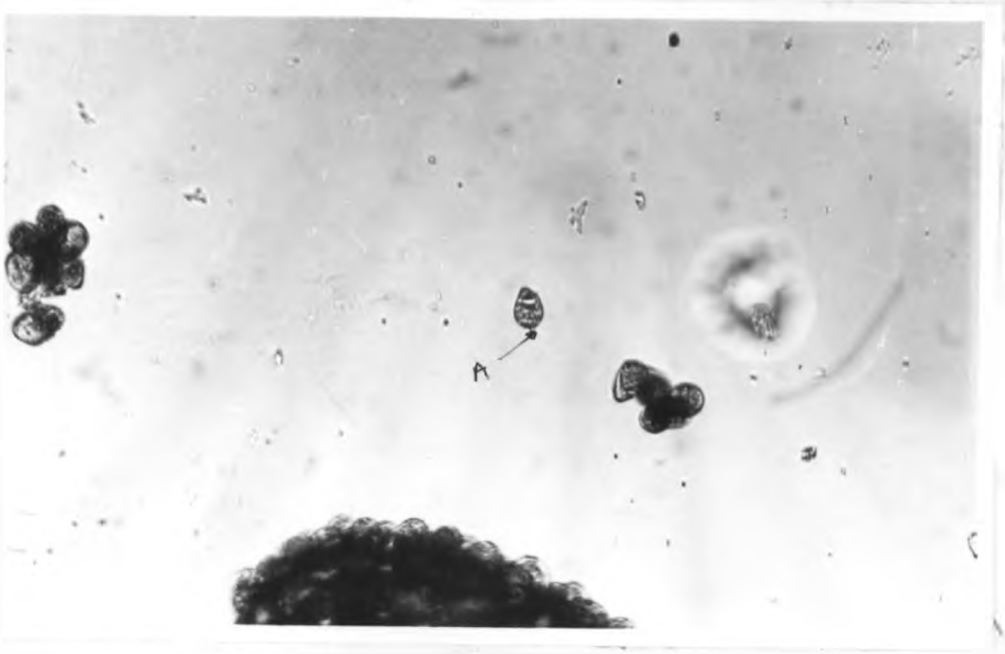
Teliospores of *Uromyces phaseoli* var *vignae* (40 x 10 magnification)

Figure 4B



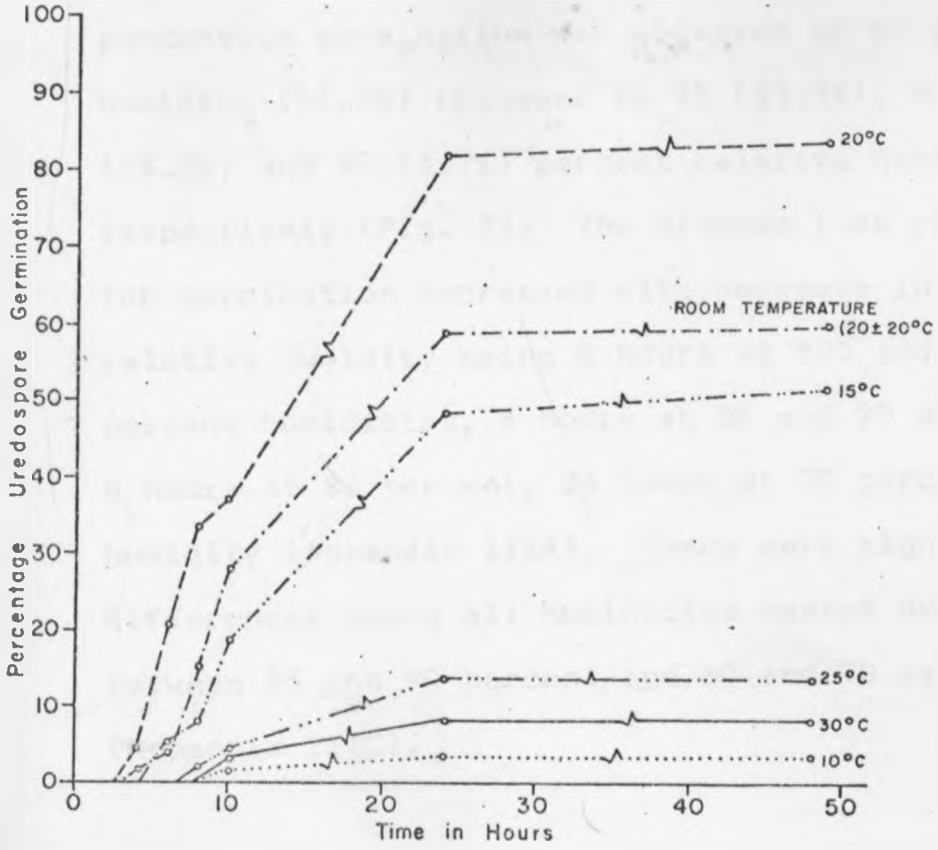
Teliospores of Uromyces phaseoli var Vignae (100 x 10 magnification). A. spines

Figure 5



Teliospores of Uromyces phaseoli var Vignae (10 x 10 magnification). A. Part of the stalk still attached

FIGURE 6 PERCENTAGE UREDOSPORE GERMINATION OF *Uromyces phaseoli* var *vianae* AT DIFFERENT TEMPERATURES FOR DIFFERENT PERIODS OF TIME



b) Relative humidity

Germination occurred in all humidities tested with the highest at 100 percent (73.3%) and the least at 70 percent (2.0%). The second highest percentage germination was observed at 98 percent humidity (56.7%) followed by 95 (33.3%), 90 (25.5%) and 80 (3.7%) percent relative humidities respectively (Fig. 7). The minimum time required for germination increased with decrease in relative humidity being 4 hours at 100 and 98 percent humidities, 6 hours at 95 and 90 percent, 8 hours at 80 percent, 24 hours at 70 percent humidity (Appendix IIIA). There were significant differences among all humidities tested except between 95 and 90 percent and 80 and 70 percent (Appendix IIIC).

c) Liquid media

Germination occurred in all treatments tried but was highest in sterile tap water (83.0%) and lowest in sterile distilled water (22.9%). The second and third highest germination were observed in rain water (80.7%) and host extract (75.0%) respectively. These were followed by sterile stream water (72.3%), dew from cowpea

plant (58.0%) and extract from Whatman filter papers (44.4%) (Fig. 8). No germination occurred in any of the treatments after 2 or 4 hours. The time at which spores started germinating was six hours for all other treatments except sterile distilled water and Whatman filter papers' extract. In these two media, germination was observed after 8 hours (Appendix IVA). Statistically there were significant differences between the treatment means. Sterile tap water, rain water and host extract did not differ significantly from each other but were superior to all other treatments, (Appendix IVC).

d) pH

The highest percentage uredospore germination was observed after 48 hours at pH 5.5 (76.2%) and then decreased with increase or decrease in pH (Fig.9). The second, third and fourth highest germinations were observed at pH 5.0 (73.3%), 4.5 (71.7%) and 4.0 (71.4%) respectively. These were followed by pH 6.0 (67.4%), 3.5 (66.1%), 3.0 (65.2%), 6.5 (64.2%) and the lowest germination was noted at pH 7.0 (62.5%). The minimum time required for germination was 6 hours for all pH except pH 3.5, 5.0 and 7.0. At these three pH uredospores started germinating after 4 hours (Appendix VA).

pH 5.5, 5.0, 6.5, 4.5, 4.0 and 3.5 were significantly different from pH 3 and 7. There was also a significant difference between pH 5.5 and 3.5 (Appendix VC).

e) Storage at 2 - 4°C

Uredospores kept in the refrigerator (at 2 - 4°C) for 24 hours gave the highest germination (76.5%) followed closely by those kept for 2 hours (75.8%). After 24 hours of storage, percentage germination decreased with increase of storage period (Fig. 10). Least percentage germination was observed after 2160 hours storage. The minimum time at which uredospores started germinating also increased with increase in storage period being six hours after 2 and 24 hours, 8 hours after 48 and 96 hours, 10 hours after 168, 336 and 504 hours, and 24 hours after 672, 840, 1440 and 2160 hours storage (Appendix VI A). There were significant differences between treatment means (Appendix VI C).

Histopathological observations

Uredospores germinated on the host within six hours after inoculation (Fig. 12). Appressoria were first observed 48 hours after inoculation

and penetration through the stomata at 72 hours. No direct penetration through the epidermis was observed. Substomatal vesicle formation was observed 96 hours after inoculation. At 120 hours hyphae had grown out from the vesicle and ramified between the epidermal cells (Fig. 13). Mycelia were intercellular in growth and occasionally sending haustoria to the cells which they came into contact with (Figs. 13 and 14). Mature hyphae formed sporogenous tissue under both the upper and lower epidermis 144 hours after inoculation.

No effect on the host cells was noticed up to 120 hours. At 144 hours after inoculation, however, there was a collapse of cells underlying the incipient pustules under both the upper and lower epidermis.

Factors affecting disease development

a) Temperature

More percentage infection was obtained on plants kept at 20°C (Table I). Percentage leaf area covered (severity) was 45.0 percent and percentage number of leaves affected (incidence) was 73.0 percent at this temperature. The second highest incidence (33.3%) and severity (9.0%)

FIGURE 7 PERCENTAGE UREDOSPORE GERMINATION OF *Uromyces phaseoli* var *vignae* AT DIFFERENT HUMIDITIES FOR DIFFERENT PERIODS OF TIME AT 20°C

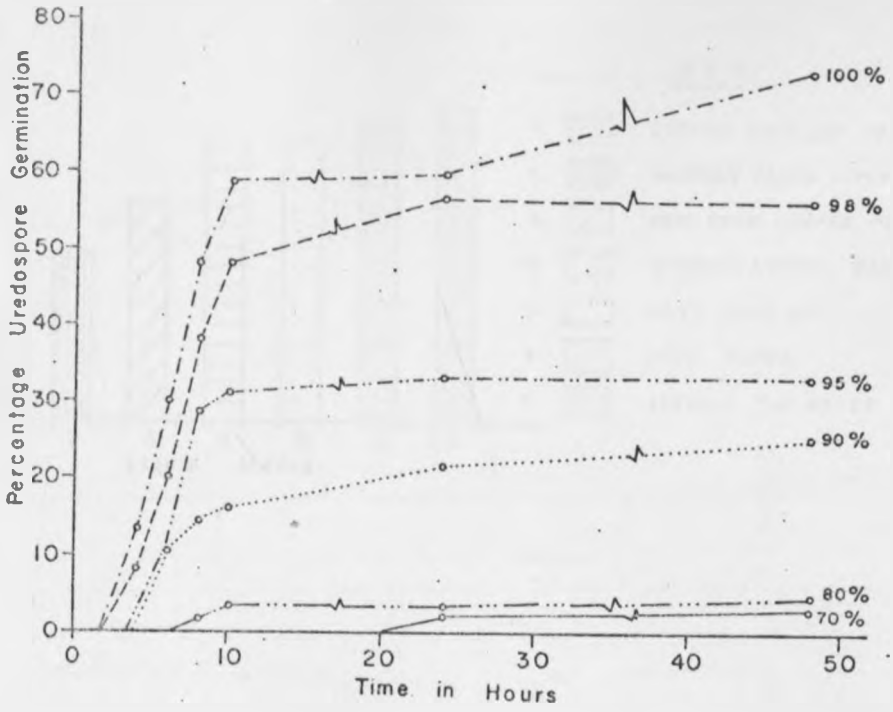


FIGURE 8 EFFECT OF LIQUID MEDIA ON PERCENTAGE UREDOSPORE GERMINATION OF *Uromyces phaseoli* var *vignae* AFTER 48 HOURS

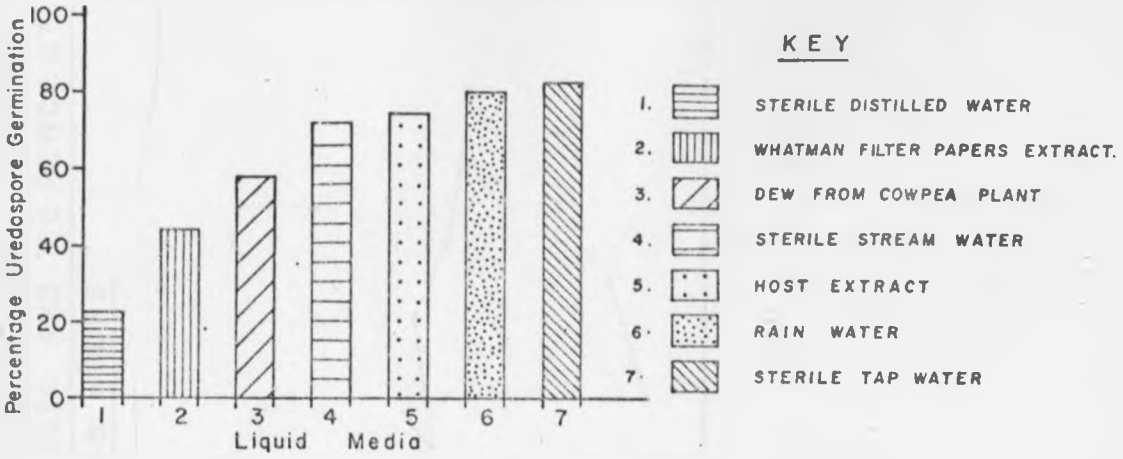


FIGURE 9 EFFECT OF pH ON PERCENTAGE UREDOSPORE GERMINATION OF *Uromyces phaseoli* var *vignae* AT 20°C AND 100 PERCENT RELATIVE HUMIDITY AFTER 48 HOURS

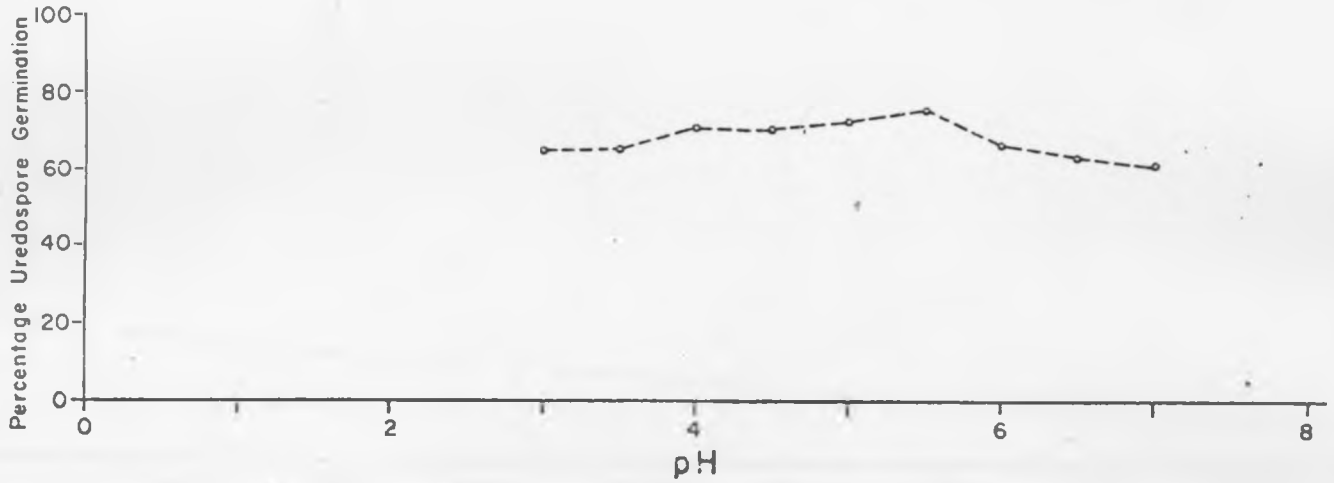


FIGURE 10 THE EFFECT OF STORAGE IN REFRIGERATOR (at 2–4°C) ON PERCENTAGE UREDOSPORE GERMINATION OF *Uromyces phaseoli* var *vignae* AFTER 48 HOURS

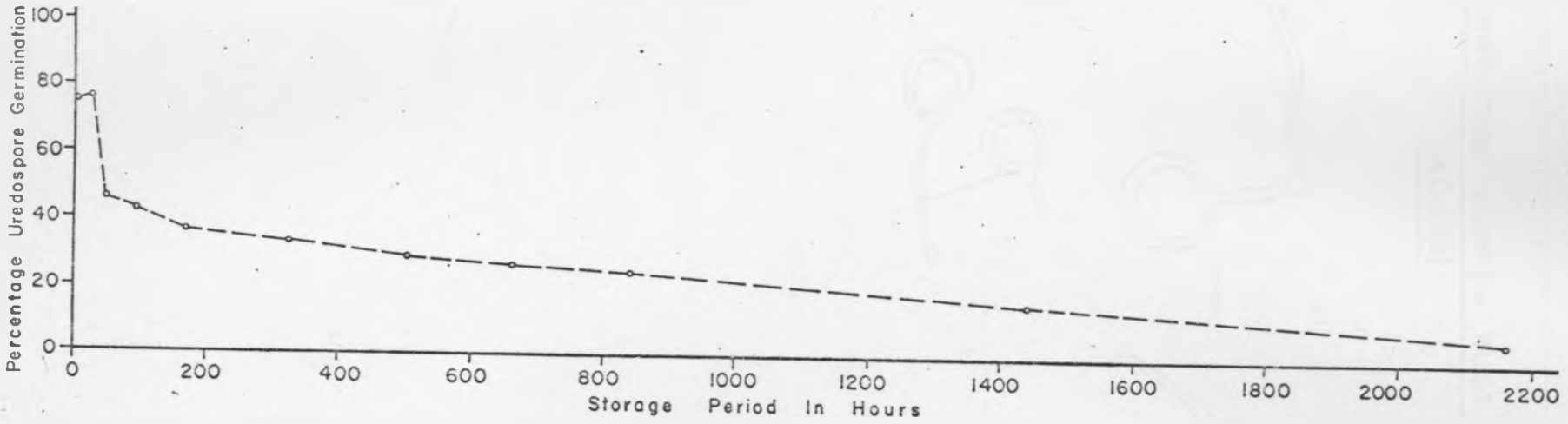


FIGURE II GERMINATING COWPEA RUST UREDOSPORES (40 x 10)

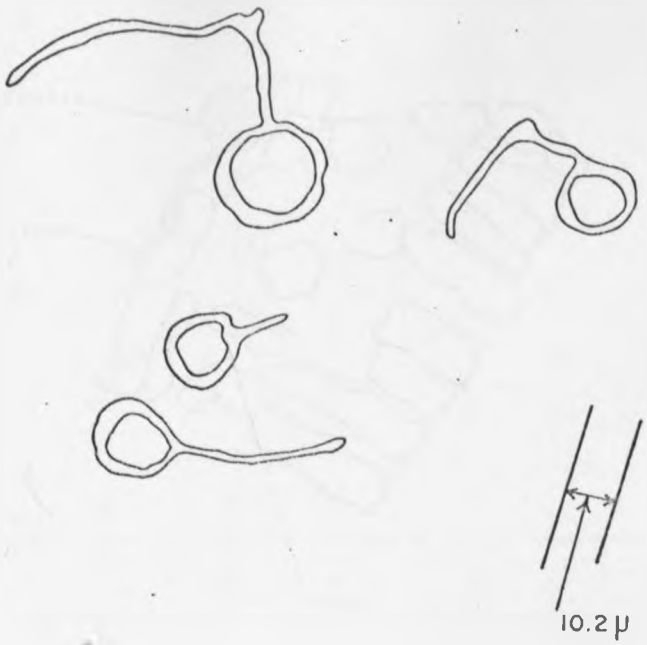


FIGURE 12 UREDOSPORE GERMINATING ON THE LEAF SURFACE (40 x 10)

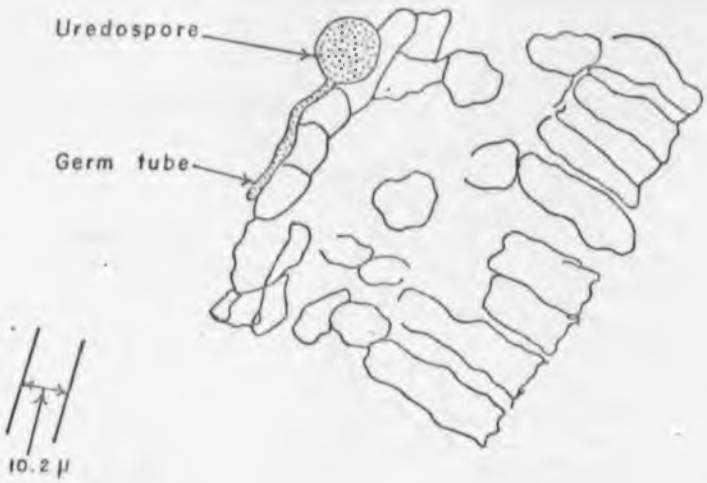


FIGURE 13 APPREOSORIUM WITH INFECTION PEG SUBSTOMATAL VESICLE, INTERCELLULAR MYCELIA AND HAUSTORIUM. (40 x 10)

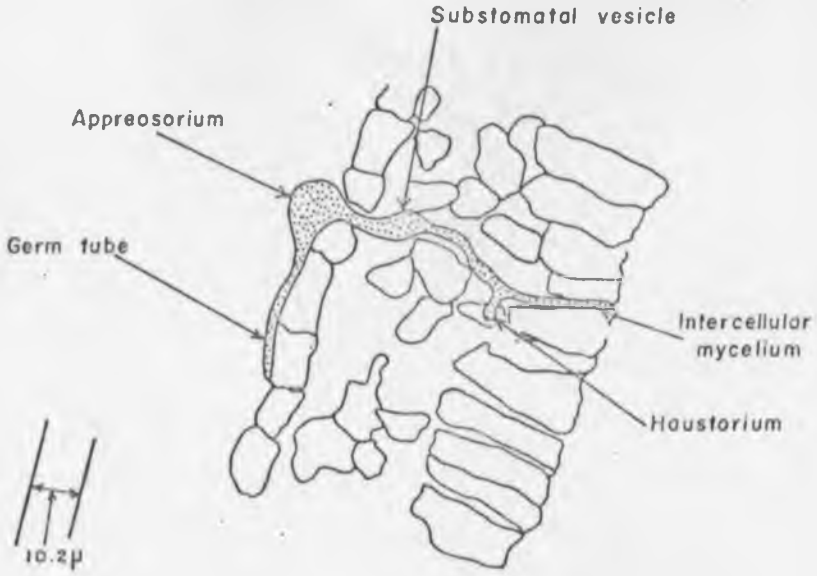


FIGURE 14. MYCELIUM WITHIN INTERCELLULAR SPACE (40 x 10)

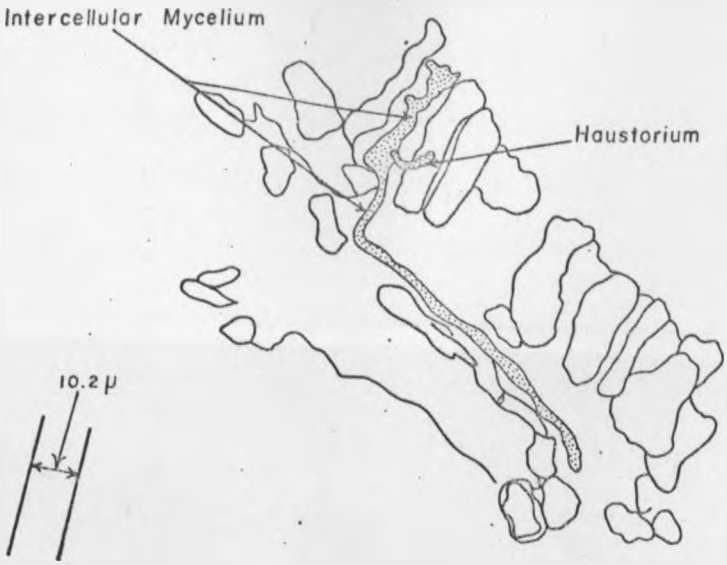
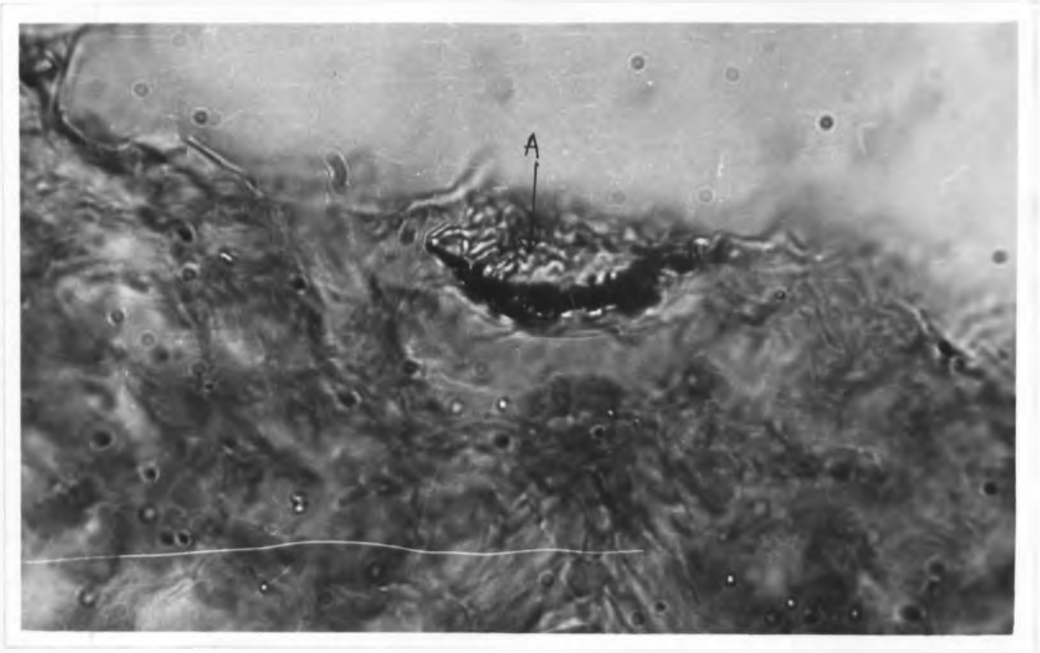


Figure 15



Sporagenous tissue (A) developing into uredosori around the stomata

were recorded at 25°C. This was followed by 15°C with incidence of 24.4 percent and severity of 3.0 percent. Symptoms appeared as necrotic flecks six days after inoculation on plants kept at 20°C while at 15°C and 25°C, they developed after 9 - 10 days. No disease development was observed on plants kept at 10 and 30°C.

b) Relative humidity

Highest severity and incidence were observed on plants kept at 100 and 98 percent humidities (Table 2). Percentage leaf area covered was 35.5 percent at these two humidities. Incidence was 86.7% at 100 percent humidity and 75.6% at 98 percent humidity. They were followed by 95, 90 and 80 percent humidities with severity of 25.0%, 3.0%, 1.0% and incidence of 46.7%, 26.7% and 13.3% respectively. Symptoms appeared as necrotic flecks after 6 - 7 days on plants kept at 100 and 98 percent humidity and after 7 - 9 days with other treatments. No rust development was observed at 70 percent relative humidity.

Table 1: Effect of temperature on the development of Uromyces phaseoli on cowpea cultivar TVX 1836-473E

Temperature in ^{o}C	Percentage leaf area covered*	Percentage number of leaves affected*	Average incubation period
10	-	-	-
15	3.0	24.4	9.5
20	45.0	73.0	6.0
25	9.0	33.3	9.5
30	-	-	-

* Each figure is an average of three replications; 15 plants per replication.

Table 2: Effect of relative humidity on the development of *Uromyces phaseoli* on cowpea cultivar TVX 1836-473 E

Relative humidity	Percentage leaf area covered*	Percentage number of leaves affected*	Average incubation period
100	35.5	87.7	6.5
98	35.5	75.6	6.5
95	25.0	46.7	8.0
90	3.0	26.7	8.0
80	1.0	13.3	8.0
70	-	-	-

*Each figure is an average of three replications; 15 plants per replication.

c) Plant age

The incubation period and susceptibility of cowpea seedlings was largely affected by the age of the plants. Susceptibility of the seedlings increased with age reaching maximum on 18 days old seedlings (Table 3). The highest severity (65.0%) was obtained with 18 days old seedlings while maximum incidence was recorded on 25 days old seedlings. From 18 days, the susceptibility of the plants decreased with increase in age.

The disease symptoms appeared as necrotic flecks on all plants inoculated after six days. However, the incubation period was longer on older leaves than the younger ones. In general, the most susceptible age of the leaves was two to three days. With these leaves maximum severity was obtained regardless of the age of the plant.

Disease progress in the field

Incidence (as number of leaves affected per plant and number of plants affected per plot) and severity (as percentage leaf area covered) were plotted against time (Figs. 16, 17 and 18). No rust development was recorded

Table 3: Susceptibility of cowpea cultivar TVX 1836-473 E to Uromyces phaseoli when plants were of different ages at the time of inoculation

Date of planting	Percentage leaf area covered*	Percentage number of leaves affected*	Average incubation period
21/5/79	8.2	26.0	8.0
28/5/79	12.0	37.5	8.0
4/6/79	19.3	57.1	7.5
11/6/79	34.0	63.8	7.0
18/6/79	65.0	60.0	6.0
25/6/79	22.5	44.0	6.0
2/7/79	-	-	-

*Each figure is an average of three replications; 15 plants per replication.

on variety TVX 12-01 E. The pattern of disease increase was the same for all the three varieties that got infected. There was a slow increase at the beginning when the inoculum was low, followed by a sharp rise, and then a decline which was due to lack of healthy tissue for infection.

Comparison between the three varieties was made using incubation period, rate of disease increase and spread of the disease. The disease increase rate for each week (recording) was computed using the following formula adopted from Van der Plank (1963).

$$R = \frac{1}{t_2 - t_1} \log_e \frac{X_2}{X_1}$$

where R is the disease increase rate, X_1 is the severity on date t_1, X_2 is the severity on date t_2 and e is the natural logarithm.

The incubation period was 11 days for variety TVX 1836-473 E and 18 days for Emma B and KCIP 83-SP 28. The rate of disease increase was highest for variety KCIP 83-SP 28, followed by TVX 1836-473 E and Emma B respectively (Table 4).

FIGURE 16 PERCENTAGE NUMBER OF LEAVES INFECTED PER PLANT AGAINST DAYS AFTER INOCULATIONS.

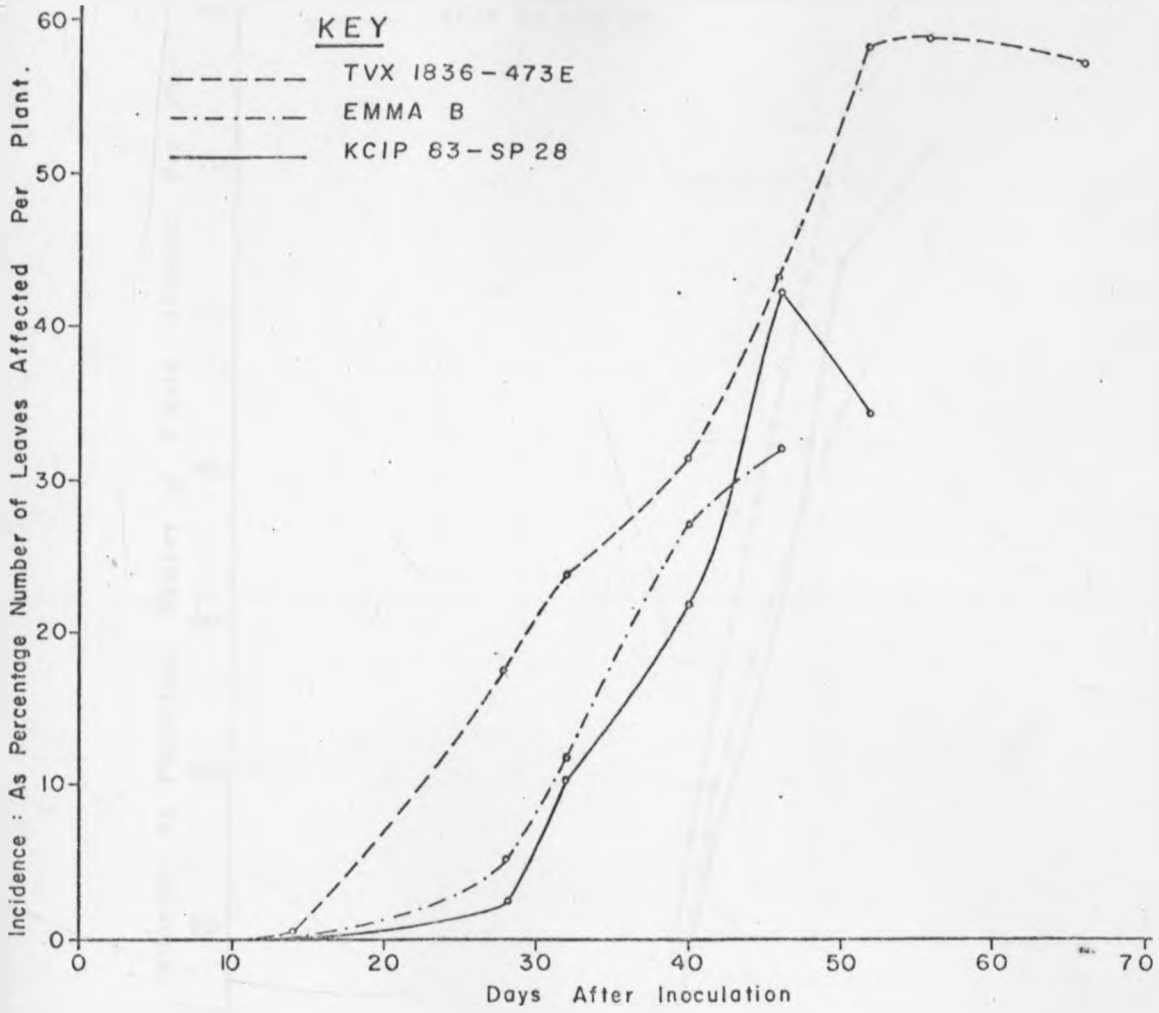


FIGURE 17 PERCENTAGE NUMBER OF PLANTS INFECTED PER PLOT AGAINST DAYS AFTER INOCULATION

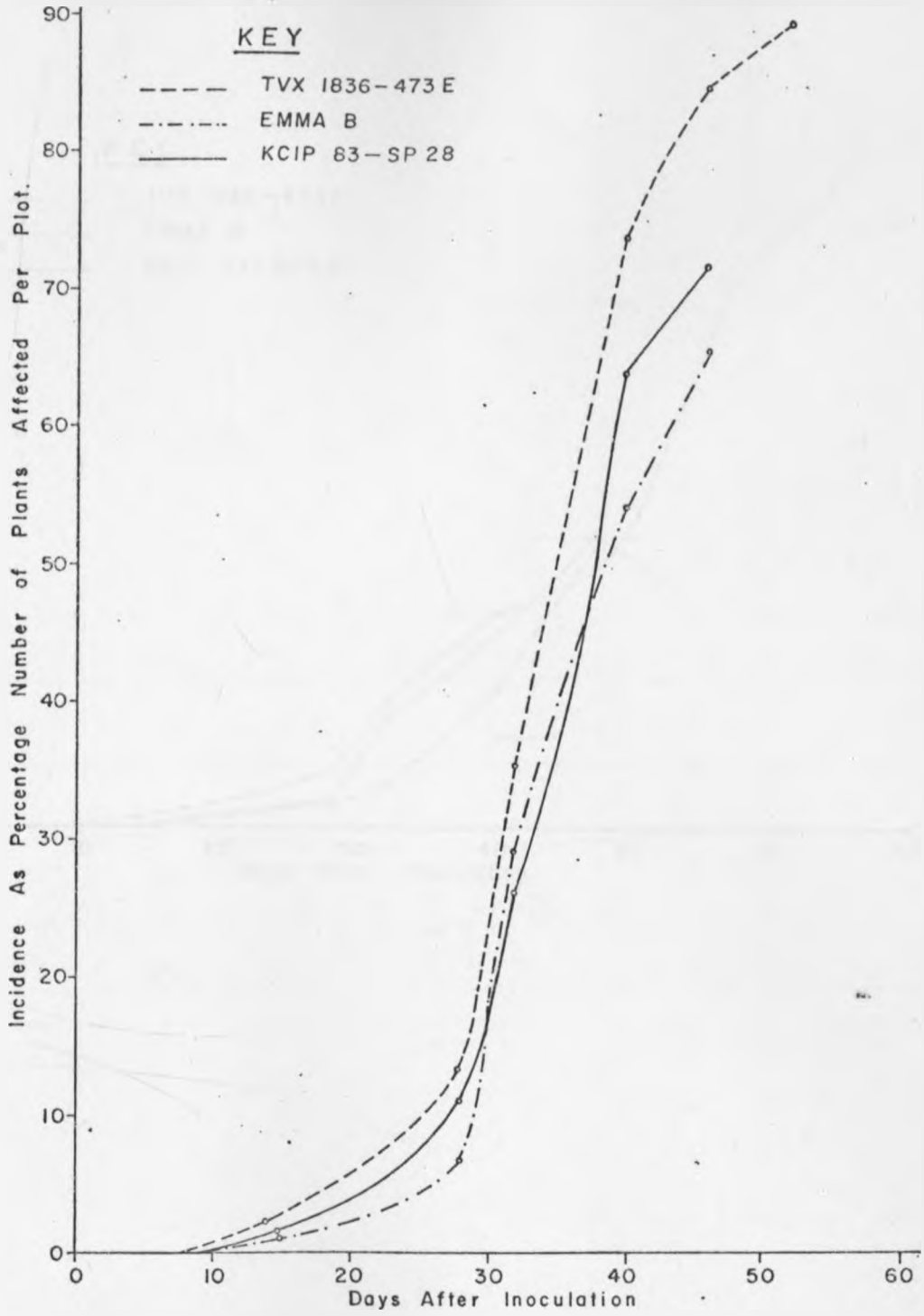


FIGURE 18 MEAN SEVERITY AGAINST DAYS AFTER INOCULATION

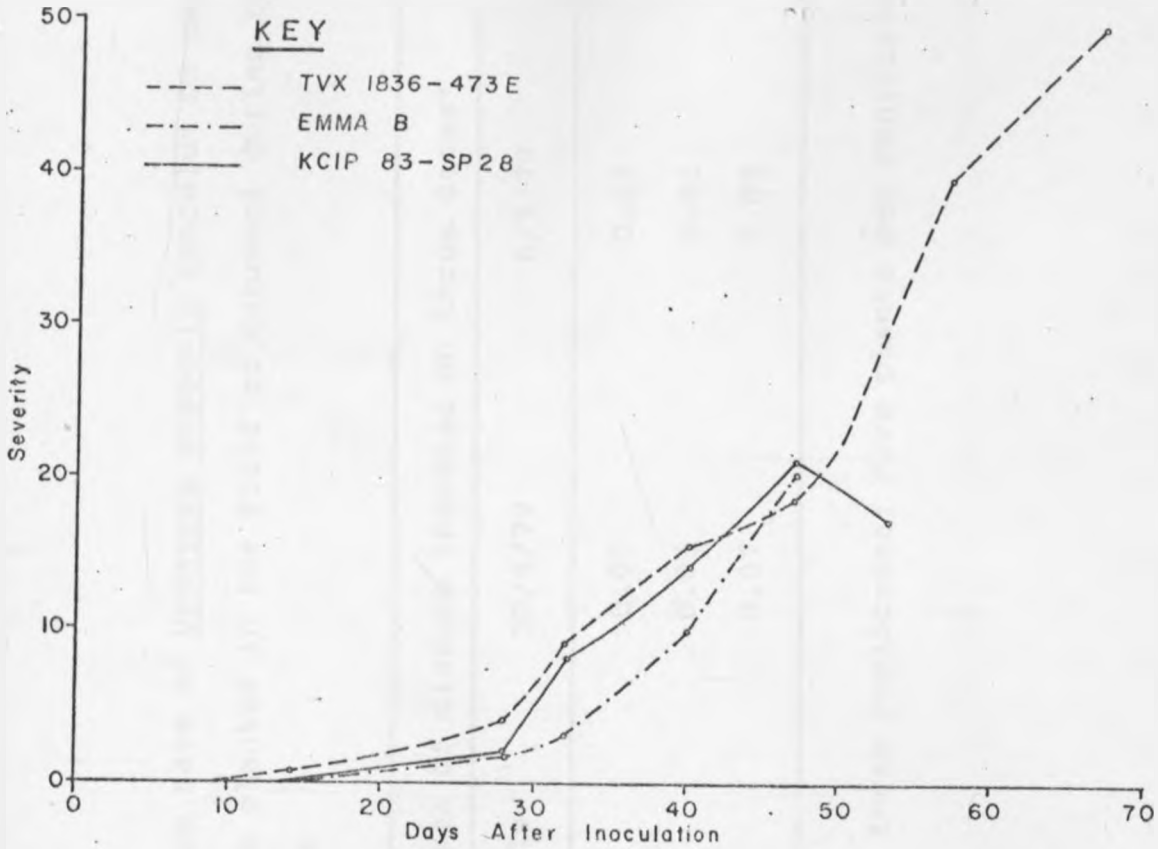


Table 4: Comparative increase rate of Uromyces phaseoli inoculum on three varieties of cowpea planted in the field at Katumani during the short rains in 1978

Variety	Rates of disease increase on three dates*		
	22/1/79	30/1/79	6/2/79
TVX 1836-473 E	0.23	0.07	0.03
Emma B	0.13	0.05	0.02
KCIP 83-SP 28	0.35	0.07	0.05

* Each figure is an average of three replicates; five plants per replication.

The pattern of spread was the same with the three varieties but was faster with variety TVX 1836-473 E than other varieties. Initially the plants next to the inoculated ones got infected fast. The initial spread was either by contact, wind or rainsplash. Twenty-eight days after inoculation, plants at the western end of some plots had rust indicating spread either by wind, insects or human beings. By 52 days after inoculation, more plants on this particular side of all infected plots had more infected plants than other sides. Examination of the meteorological data revealed that wind blew mostly from the eastern to the western side. This confirmed the fact that spread of this disease further from inoculated plants was due to wind.

An attempt was made to find out if any correlation existed between disease development and environmental conditions such as temperature, rainfall and relative humidity in the field. Each of the environmental factor was defined in several variables each of which was correlated with disease severity increase rate for six weeks in the short rainy season of 1978 and the long rainy season of 1979 (Table 5). It should be noted from the table that no significant correlation coefficient at 5 percent level was obtained.

Table 5: Environmental variables and their correlation with the development of cowpea rust severity increase rate

SHORT RAINY SEASON 1978

Week	Disease increase rate (R)	Total rain-fall (mm)	Temperature				Humidity		
			lowest temp.	highest temp.	mean temp.	intervals of 15 - 25°C	highest in per-cent	lowest in per-cent	inter-vals of 90percent or more continuous in hours
			(°C)	(°C)	(°C)	(hrs)			
(a)	(b)	(c)	(d)	(e)	(f)	(g)	(h)	(i)	(j)
1	0.14	0.60	14.20	24.20	18.25	299	100	39	222
2	0.23	4.50	15.00	23.30	19.15	96	100	53	75
3	0.07	40.00	14.40	24.80	19.60	192	100	60	131
4	0.03	43.10	12.90	24.80	18.85	168	100	63	119
5	-0.08	4.10	13.20	26.60	19.90	134	100	48	88
6	0.07	0.00	11.90	25.40	18.50	76	100	49	61
r^b		0.52	0.51	0.69	-0.71	0.04	0.00	0.39	0.02

.../cont.

Table 5: continued

LONG RAINY SEASON 1979

(a)	(b)	(c)	(d)	(e)	(f)	(g)	(h)	(i)	(j)
1	0.03	23.50	13.70	22.90	18.09	123	100	65	126
2	0.00	13.60	11.00	23.50	17.52	209	100	60	148
3	0.03	0.30	8.50	25.20	17.18	208	100	46	160
4	0.15	0.00	8.40	24.00	16.54	103	100	49	105
5	-0.02	0.09	7.80	23.00	15.84	110	100	50	99
6	-0.01	8.10	6.80	22.00	15.84	90	100	44	99
r		0.26	0.02	0.43	0.12	0.18	0.00	0.07	0.09

b:r is the correlation coefficient

Uredospore dissemination

a) Contact

Out of forty healthy seedlings of variety TVX 1836-473 E that had been placed next to diseased plants, thirty-three (82.5%) got infected. Symptoms of rust appeared after eleven days on leaves that had been in contact with diseased ones as necrotic flecks.

Contact between healthy and diseased leaves occurs frequently in nature and undoubtedly results in the spread of the disease.

b) Wind

All slides exposed had uredospores when examined (Table 6). More uredospores were collected between 11 am. and 1 pm. and least between 9 am. and 11 am. each day. Slides in the windward direction had more uredospores trapped than other slides.

Mode of survival

Results expressed as number of seedlings infected and percentage infection are given in Table 7.

No infection occurred with seedlings grown in soil collected from an infected field. Seedlings which germinated from seeds collected from infected pods were also healthy. Only seedlings which had infected debris dusted on them became infected. No infection occurred on plants grown in soil incorporated with infected debris.

Host range

The following legumes were included in this study:

Medicago sativa, Vicia faba, Phaseolus mungo, Phaseolus aureus, Pisum sativum, Cajanus cajan,

Table 6: Average number of uredospores caught on vaseline coated slides at different hours of the day in the rust affected field at Katumani in 1979

Date	Average number of uredospores caught on vaseline coated slides at different times of the day*				
	9am. - 11am.	11am. - 1pm.	1pm. - 3pm.	Total	Mean
8/6/79	8.5	7.2	11.3	27.0	9.0
20/6/79	9.8	10.5	9.3	29.6	9.9
29/6/79	13.0	15.0	12.2	40.2	13.4
7/7/79	10.5	13.0	12.5	36.0	12.0
13/7/79	8.3	9.3	9.0	26.6	8.9
24/7/79	5.7	8.2	6.5	20.4	6.8

*Average of six slides

Table 7: Survival of Uromyces phaseoli var vignae on various sources

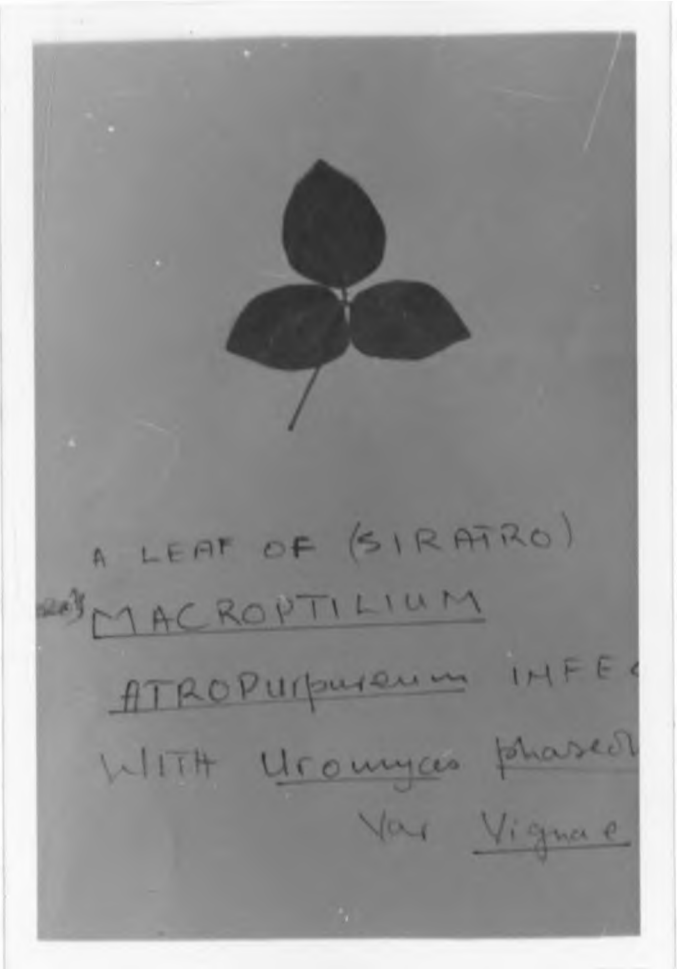
Source	Number of seedlings used*	Number of seedlings infected	Percentage infection
Infected soil	24	0	0
Seeds from infected pods	24	0	0
Plant debris dusted on the leaf	24	14	58.33
Plant debris incorporated in the soil	24	0	0

*Six pots were used; four seedlings per pot.

Trifolium semipilosum, Glycine wightii, Desmodium unicinatum, Dolichos lablab, Trifolium repens, Stylosathesis guyansis, Macroptilium atropurpureum (formerly Phaseolus atropurpureus), Centrocema pubescens, Cicer arietinum, Glycine max, Lens esculentum, Indigofera endocaphyla, Stylosathesis humulus, Vicia villosa, Melilotus alba, Crotalaria spectabilis, Glycine javanica, Lathyrus odorontus, Trifolium subterranean, Phaseolus lathyroides, Crotalia intermidia, Trifolium pratense, Crotalia joncea, Vigna parviflora, Indigofera sublata, and several varieties of Phaseolus vulgaris.

Among legumes tested only Phaseolus aureus, Macroptilium atropurpureum and Vigna parviflora got infected. Symptoms appeared as necrotic flecks after 6, 8, and 10 days on Vigna parviflora, Phaseolus aureus and Macroptilium atropurpureum respectively. Twenty days after inoculation, the pustules on the three legumes had ruptured releasing dark yellow uredospores. In cross inoculation tests, typical symptoms as described earlier were obtained on cowpea cultivar TVX 1836-473 E from inoculum from either legume.

Figure 19



A leaf of Macroptilium atropurpureum infected by Uromyces phaseoli var vignae

Varietal reaction

Glasshouse observations revealed that different cowpea cultivars differed in reaction to U. phaseoli. The results obtained are given below. Out of seventy-six cultivars tested, 1 was rated highly resistant, 25 resistant, 35 moderately resistant, 12 susceptible and 3 highly susceptible.

Highly resistant (1)

BR 1: TVX 12-01 E.

Resistant (2 - 3)

BR 1:105, BR 1: 107, BR 2: 106, BR 2: 108, BR 2 : 115, BR 2:111, BR2:107, BR2:117, BR2:118, BR3:113, BR3:120, BR3:TVX 66-2H, BR3:ERC 67-1F, BR3:Machakos 79, BR3:TVX 88-63, Machakos 68, BR3:TVX 1850-01E, BR3:TVX 1948-01F, BR3:105, BR3:109, BR3:108, BR4:TVX 3091-H, BR4:TVX 1193-7D, BR4:TVX 7-5H, Kakamega 2.

Moderately resistant (4 - 5)

BR1:102, BR1:101, BR1:110, BR1:104, BR1:103, BR2:104, BR2:109, BR2:112, BR2:110, BR2:102, BR3:112, BR3:119, BR3:110, BR3:Vita 5, BR2:TVX 3875g, BR3:TVX 181-4g, BR3:TVX 119-012H, BR3:TVX 33-11, BR3:Vita 1, BR3:1FE Brown, BR2:103, BR3:101, BR3:SVS, BR3:TVX 8875, BR3:TVU 1850-DIF, BR4:107,

BR4:102, BR4:ER1, BR4:ER7, Katumani I, Kakamega 8, Katumani 2, ER1 - 1, BR 3:TVX 1843-01E, BR3:VITA 4.

Susceptible (6 - 7)

BR1:108, BR2:114, BR2:116, BR3:118, BR3:White wonder trailing, BR3:TVX 1952-01F, BR3:TVX 1843-1L, BR4:TVX 1576-01F, BR4:104, KCIP 83-SP 28, ER 1-2, local variety.

Highly susceptible (8 - 10)

BR3:Vita 3, BR8:TVX 1836-473 E, BR5:106.

Chemical control

a) Inhibition of uredospore germination of U. phaseoli var vignae by different fungicides at 500 ppm.

The percentage germination and the calculated percentage inhibition are given in Table 8.

All fungicides gave some control to uredospore germination, however, statistically only baycor, bayleton, benlate, calxin, plantvax and captan gave significantly lower germination than the control. There were highly significant differences among fungicidal means (Appendix VIIB). Baycor was the most effective fungicide with the highest percentage uredospore inhibition (100%).

Table 8: Efficacy of different fungicides (at 500 ppm.) to inhibition of uredospore germination of *Uromyces phaseoli* var *Vignae*

Fungicides	Percentage germination after 24 hours*	Percentage inhibition of uredospores after 24 hours
Captan	56.5	24.7
Sulphur	71.7	4.4
Benlate	36.4	51.5
Plantvax	41.6	44.5
Dithane M45	69.9	6.8
Zineb	55.5	26.1
Baycor	0.0	100.0
Bayleton	34.2	54.4
Calyin	40.6	45.8
Control	75.0	-
Blitox	40.3	46.3

*Each figure is an average of four slides.

10 - 30 uredospores per slide.

The second was bayleton (54.4%) followed by benlate (51.5%), blitox (46.3%), calxin (45.8%), plantvax (44.5%), zineb (26.1%) and captan (24.7%) respectively. Dithane M45 and sulphur were rated inferior to others.

In another series of experiments, baycor, bayleton, and benlate were also evaluated at 50, 200, 350, 500, 650, 800, 1100, 1250, 1400 and 1550 ppm. The data obtained was subject to probit analysis by Finney's method (Finney, 1971). LD 50 value was determined and the results are given in Table 9.

LD 50 value in case of baycor and bayleton was lower than 50ppm. Benlate had LD 50 value of 260 ppm. The efficacy of baycor and bayleton in comparison with benlate differed widely.

b) Effect of time of spraying on disease development using 10 fungicides in the glasshouse

All chemicals were effective when sprayed onto the plants before inoculating them with a uredospore suspension (Table 10). However, when sprayed 24 hours after inoculation with uredospores, only baycor and bayleton gave complete control of the disease. These two were followed by calxin, plantvax, dithane M45, blitox and sulphur respectively. Zineb, captan and benlate were not effective as compared to the control.

Table 9: Estimation of LD 50 of three fungicides against Uromyces phaseoli var vignae by probit analysis

Fungicide	Doses in ppm.											Ld 50	
	50	200	350	500	650	800	950	1100	1250	1400	1550	Log	ppm
BAYCOR													
No. of spores observed	61	53	65	55	57	62	49	48	51	72	63		
No. of spores killed	55	50	62	55	57	62	49	48	51	72	63		
Percentage killed	90.16	94.34	95.38	100	100	100	100	100	100	100	100	<3.91	<50
Calculated probit	6.29	6.58	6.68	7.36	7.38	7.41	7.32	7.31	7.33	7.46	7.41		
BAYLETON													
No. of spores observed	67	51	61	71	69	67	76	57	84	56	65		
No. of spores killed	34	31	40	55	55	54	70	53	79	54	62		
Percentate killed	50.75	60.78	65.57	77.46	79.71	80.60	92.11	92.98	94.05	96.43	95.38	<3.91	<50
Calculated probit	5.02	5.27	5.40	5.75	5.83	5.86	6.41	6.47	6.56	6.80	6.68		
BENLATE													
No. of spores observed	62	55	51	58	66	50	49	62	64	45	52		
No. of spores killed	25	25	30	44	41	38	40	51	53	37	49		
Percentage killed	40.32	45.45	58.82	75.86	62.12	76.00	81.63	82.26	82.81	82.22	94.23	5.56	260
Calculated probit	4.76	4.89	5.22	5.70	5.62	5.71	5.90	5.93	5.95	5.92	6.57		

Table 10: Effect of time of spraying on disease development using 10 fungicides

Fungicide	Fungicide sprayed prior to inoculating with uredospores*		Plant inoculated with uredospores before spraying with fungicide*	
	incidence	severity	incidence	severity
Zineb	9.33	2	94	8
Blitox	3.5	2	45	4
Benlate	-	1	83	7
Calxin	-	1	22.5	3
Plantvax	-	1	20.3	4
Dithane M45	-	1	44.6	4
Captan	-	1	84.4	8
Bayleton	-	1	-	1
Baycor	-	1	-	1
Sulphur	41.22	5	98	6
Control	96.8	8	98.7	8

* Average of three replications; 15 seedlings per replication.

c) Effect of fungicidal sprays on cowpea rust development and yield in the field

Results as mean percentage, number of leaves affected and percentage leaf area covered are given in Tables 11 and 12. For the long rainy season (1979) yields, total cost of spraying and net profit are also given.

The cost of rust control per hectare was calculated by adding the cost of the fungicides to labour cost and cost of hiring a sprayer. The net benefit resulting from fungicide treatment was obtained by subtracting the total cost of the fungicidal application from the market value of the increase in yield of grain over the control.

All fungicidal treatments gave some control of cowpea rust. However, they exhibited important differences in their efficacy over control. Baycor, a systemic fungicide, gave the best control and was substantially superior to blitox and dithane M45. The resulting increase in yield (55.27%) suggests that this chemical can be used economically for the control of cowpea rust.

Bayleton gave good control of the disease being very close to baycor as regards incidence

and severity. However, yield increases over control was much less than that given by baycor (29.96%).

The intensity of cowpea rust was seemingly reduced by dithane M45 and blitox. However yields significantly over the control plots were not obtained.

Table 11: Effect of fungicidal sprays on cowpea rust during short rains 1978: Incidence and severity

Fungicide	Incidence as percentage no. of leaves affected per plant	Severity as percentage leaf area covered by rust*
Dithane M45	30.85	12.67
Blitox	16.89	9.95
Bayleton	7.16	2.30
Baycor	2.59	2.00
Control	31.47	43.80

*Average of four replications; four plants per replication.

Table 12: Effect of fungicidal sprays on cowpea rust during the long rains 1979 at Katumani: Incidence, severity and grain yield

Fungicide	Severity*	Incidence*	Yield in kg/ha**	%age yield increase over control	Total cost of operations Kshs. cts	net profit Kshs cts
Dithane M45	15.26	20.84	602.40	6.33	470 00	-326 60
Blitox	12.37	39.64	653.40	15.33	378 00	- 30 60
Bayleton	2.33	6.28	736.27	29.96	248 00	430 88
Baycor	2.13	6.01	879.70	55.27	190 80	1061 80
Control	45.24	58.52	566.55	-	-	-

* Average of four replications; six plants per replication.

** Average yield of five central rows of four replications.

Figure 20

Cowpea plot sprayed with Baycor

Figure 21

Cowpea plot sprayed with Dithane M45

Figure 22

Cowpea plot without any fungicidal application

Figure 23

Cowpea plot sprayed with Blitox

Figure 24

Cowpea plot sprayed with Bayleton

DISCUSSION

Cowpea rust caused by U. phaseoli var vignae is a major factor limiting cowpea production in Kenya. Susceptible varieties have their pod formation suppressed resulting in high yield reduction. Several epidemics of cowpea rust have been noted in Eastern, Coast and Nyanza provinces of Kenya. The rust generally builds up rapidly during the rains and attains epidemic proportions yearly. Although the disease is economically important, little information is available on its nature and etiology in this country. In this study symptomatology, histopathology and chemical control aspects have been studied. Epidemiology including pathogen survival and dissemination have also been considered.

The incubation period of U. phaseoli var vignae was found to be six to seven days provided environmental conditions were suitable for disease development. Symptoms observed were similar to those reported by other researchers (Gay, 1971; Williams, 1975; Sokhi and Sokhi, 1976). Only one ring of sori was noted during this investigation. The numerous rings of sori noted by

Gay (1971) and Sokhi and Sokhi (1976) were not observed. This may probably be due to the fact that conditions such as temperature and relative humidity were not conduicive for the development of several rings.

Uredospore germination and its subsequent infection occurs mostly at cool temperature and high humidity. During this investigation, highest percentage uredospore germination occurred when uredospores were mounted in sterile tap water, dried and then incubated at 20°C and 100 percent relative humidity. However, germination occurred within a wide range of temperature, humidity, liquid media and pH. These results, coupled with the fact that infection was observed within almost the same range of temperature and humidity, may account for the occurrence of cowpea rust annually in Kenya.

Germination of cowpea rust uredospores was found to occur at temperatures between 10°C and 30°C. These results are similar to what has been reported by other workers. Johnson (1912) and Mains (1915) found that temperatures between 10° and 30°C were necessary for good uredospore germination and that the optimum was between

12 and 18°C. Naito (1954) reported moderate germination of uredospores at 10 - 25°C. Waters (1928) found the optimum temperatures for U. appendiculatus on Phaseolus vulgaris to be 19 - 25°C.

The minimum time required for uredospore germination was found to be four hours. This is a longer period than what has been reported by some workers. Gay (1971) reported germination after one hour in one percent agar at 20°C; while Sokhi and Sokhi (1976) observed germination of uredospores after two hours at 18.28°C in 100 percent relative humidity. The differences in time of uredospore germination between the present results and those reported by others may be due to various factors such as the age of uredospores, number of spores per test container, and storage period prior to germination. Gay (1971) and Sokhi and Sokhi (1976) did not mention the number, the age or the storage period prior to germination tests of uredospores in their investigations. During the present study 10 - 30

uredospores were observed per microscopic field. Uredospores were taken from 11 - 13 days old pustules and were used within two hours of detatching the infected leaf. Storage was also found to reduce percentage germination and increase the minimum time required for germination during this study. That the number of spores in the test vessel and storage period prior to germination affect percentage germination has been reported with uredospores of Puccinia graminis pers. f. sp. tritics (Allen, 1955). Allen (1955) found that the larger the number, the slower the spores germinated, and with very large numbers there was no germination at all. He further noted that uredospores seeded within a few days after harvesting , germinated after one hour while those that had been in storage for longer periods germinated more slowly and after prolonged storage germination required a day or more.

Penetration and substomatal vesicle formation were not observed until 72 and 96 hours respectively. The time was longer than what has been reported before by Heath (1972) who recorded penetration through the stomata six hours after inoculation and formation of substomatal vesicle after twenty-four hours. Differences occurred probably because

of the environmental conditions where the experiments were carried out. Heath (1972) did his experiments in a controlled environmental chamber maintained at a day temperature of 20 ± 1°C, night temperature of 18 ± 1°C and light of 1,600 ft - C for sixteen hours. While the present investigation was carried out in the laboratory at room temperature (20 ± 2°C). The differences in temperature and light might have affected the time of penetration and substomatal vesicle formation. These two factors have been reported to affect the formation of infection type structures in Puccinia graminis tritici (Sharp et al., 1958; Robert, 1958).

Temperature, humidity and plant age were found to be important factors in disease initiation and development. These factors affected incubation period, incidence and severity of cowpea rust. The optimum temperature and humidity for disease development were found to be around 20°C and 100 percent relative humidity. With these two conditions disease intensity was maximum while incubation period was shortest. No infection occurred at 30°C and in 70 percent relative humidity. The minimum temperature for infection was around 15°C, while the maximum was about 25°C. Similar observations on temperature

effect have been made on Puccinia graminis tritici by Large et al. (1958). He found maximum pustule counts at temperatures between 70°F (21.11°C) and 77°F (25°C) with very little infection at 85°F (29.44°C) and 60°F (15.55°C). That high humidity favour disease development has also been reported by Yarwood (1961) with bean rust. He observed greater production of uredospores at high humidity than at low humidity. Ten times as many spores were produced at high humidity as compared to low humidity.

The optimum age of the plant for disease development was 18 days. However, the optimum leaf age was two to three days regardless of the plant age. This means that fresh infection of young leaves can take place provided the plant is still producing young leaves and therefore rust can be present in the field for most of the growing period.

The spread of uredospores in the field was found to be mainly by wind and probably contact. Survival of uredospores was by infected debris and probably volunteer crops. The practice in Kenya is that when the crop has been harvested, the remaining debris are sometimes left in the field for some time. These serve to retain the

rust spores until the subsequent crop is grown. Also volunteer crops that usually come up in between seasons may serve as a source of primary inoculum. With the help of wind, the uredospores can be spread to other cowpea crops in the nearby fields and cause infection. It is therefore suggested that if the crop be promptly ploughed deep after harvest or burnt, this potential source of infection could be minimised. U. phaseoli var vignae does not survive on seed or in soil.

Cowpea rust was found to be limited in its host range. Out of the thirty-three legumes tested, only three got infected, and moreover, one of the infected one was a Vigna spp. and the other (Phaseolus aureus) is sometimes included in Vigna spp. and called Vigna aureus. This means that only one legume (Macroptilium atropurpureus) which is not a Vigna spp. was affected.

Dolichos lablab has been reported to be affected by cowpea rust (Fromme, 1924; Hiratsuka et al., 1955). No infection was found with the inoculations made on this crop. This means that either the variety used was resistant or there are different races of U. phaseoli var vignae one of which attacks Dolichos lablab and is not found around Kabete or Katumani.

There was a wide difference in the reaction of cowpea varieties to U. phaseoli infection. This provides considerable scope to the plant breeder and plant pathologist to evolve desirable resistant lines through breeding.

Among the ten fungicides tested, baycor completely inhibited uredospore germination in the laboratory and disease development in the glasshouse. It also gave the best control and increased yield when applied in the field. Bayleton became the second best giving complete control of the disease in the glasshouse. Benlate ranked third in uredospore inhibition in the laboratory but gave poor results in the glass-house when applied 24 hours after inoculation.

All fungicides with the exception of sulphur gave good control of the disease when applied 24 hours before inoculation. However, when sprayed 24 hours after inoculation only baycor and bayleton gave complete control. This means that only baycor and bayleton had preventive and curative activity on cowpea rust. The others were only protective in action against this disease. The results obtained for sulphur in this investigation are contrary to what has been reported on bean rust which is closely related to cowpea rust. Howland (1966) reported

effective control of bean rust with sulphur. With the present results obtained from the laboratory and the glasshouse, it seems sulphur is not useful in controlling cowpea rust.

From the findings of this study, I would suggest that the following aspects need further investigation:

a) Identification of strains of U. phaseoli var vignae in Kenya.

b) A study of the factors affecting different stages of infection process of cowpea rust.

c) Breeding for disease resistance to cowpea rust in Kenya.

d) Further epidemiological studies to find out if there is any correlation between disease and environmental factors under field conditions.

CONCLUSIONS

Germination of uredospores occurs within a wide range of temperature, relative humidity, liquid media and pH. The optimum conditions for uredospore germination are when spores are mounted in sterile tap water, dried and incubated at 20°C in 100 percent relative humidity. Storage of uredospores reduce their percentage germination. Disease development also occurs within a wide range of temperature and relative humidity with heaviest infection at 20°C in 100 percent humidity. These findings on germination and disease development may probably account for the occurrence of cowpea rust annually. Plant and leaf age also have an effect on disease development. The older the plant or the leaf the less Susceptible it is to *U. phaseoli* var *vignae*. The incubation period of this fungus is six to seven days provided environmental conditions are suitable for disease development. Cowpea rust is spread by wind and probably contact. Survival is mainly on infected debris and probably on volunteer crops. The fungus is quite limited in its host range attacking mainly the *Vigna* spp. Different cowpea cultivars differ widely in their

reaction to this pathogen. The disease can be controlled economically by the application of baycor and bayleton.

REFERENCES

ALLEN, P. J. (1955). The role of self inhibitor in germination of rust uredospores. Phytopathology 45:259-266.

ANON (1969). Ministry of Agriculture, Machakos District. Annual report p. 13.

ANON (1977). Kenya Statistical Abstracts, 1977 p. 111-112.

BAZIRAKE, C. B. (1975). Fungicide efficacy studies on bean rust Uromyces appendiculatus (Pers) leu. Tropical pesticides research institute Arusha, Tanzania, 18p.

CONOVER, R. A. (1957). Control of pole bean rust with maneb-sulphur dust. Proceedings flad. horticultural society 69: 247-250.

DALE, W. T. (1955). A preliminary list of Jamaicanuredinales. Mycol. pap. Commonw myc. Inst. 60. 21p.

DEIGHTON, F. C. (1949). Plant pathology report. Depart. of Agric. Sierra Leorne. p. 27-28.

DE SOUSA DA CAMARA, E., DE OLIVEIRA, A. L. B., and DA LUZ, C. G. (1941). Uredinales aliquot Lusitaniae I. (Some rusts of Portugal I). Agron. Lusit. i. 410-434. Abstr. in R.A.M. 20:136.

DOIDGE, E. M. (1948). South African rust fungi. Part V. Bothalia 4:859-918.

EMECHEBE, M. A. (1975). Some aspects of crop diseases in Uganda. 42p. Makerere University.

FAHMY, J. (1935). The rust of cowpea I. The disease Bull. Ministry Agric. Egypt. 144:1019.

FINNEY, D. J. (1971). Probit analysis. 333p. Cambridge Univ. Press. Cambridge. Third edition.

FROMME, F. O. (1924). The rust of cowpeas. Phytopathology 14:67-79.

GAY, D. J. (1971). An apparent new race of cowpea rust on Vigna. Pl. Dis. Reptr. 5:384-386.

HARDWICK, N. V., GREENWOOD, A. D., WOOD, R. K. S. (1971). The fine structure of the

haustorium of Uromyces appendiculatus in Phaseolus vulgaris. Canad. Jour. Bot. 49:383-390.

HARDWICK, N. V., GREENWOOD, A. D., and WOOD, R.K.S. (1975). Observations on the structure of uredospores of Uromyces appendiculatus. Trans. Br. Mycol. Soc. 64:289-293.

HARTER, L. L. and ZAUMEYER, W. J. (1935). Studies on bean rust caused by Uromyces phaseoli typica. Jour. Agric. Res. 50: 737-739.

HEATH, M. C. (1971). Haustorial sheath formation in cowpea leaves immune to rust infection. Phytopathology 61:383-388.

HEATH, M. C. (1972). Ultrastructure of host and non host reactions to cowpea rust. Phytopathology 62:27-38.

HEATH, M. C. (1974). Light and electron microscope studies of the interactions of host and non host plants with cowpea rust Uromyces phaseoli var vignae. Physiol. Plant. Path. 4:403-414.

HIRATA, S. (1953). On the rust fungi of cowpea, kidney bean and small red bean. Ann. Phytopath. Soc. Japan 16:13-18.

HIRATSUKA, N. and SHIMABUKUBO, S. (1956). Uredinales of Rhukyu islands. Contribution to the rust flora of Eastern Asia VIII. Bull. Fac. Agric. Univ. Rhukyus I. p 1-56. Abstr. in R. A. M. 35:125.

HOWLAND, A. K. and MACARTNEY, J. C. (1966). East African bean rust studies. E. Afr. Agric For. Jour. 32:208-210.

JACKS, H. and BRIEN, R. M. (1955). Screening tests with fungicides for control of french bean rust (Uromyces appendiculatus (Pers.) Unger). N. Z. S. Sc. Tech. Sect. A37. p. 62-67. Abstr. in R. A. M. 35:263.

JOHNSON, E. C. (1912). Cardinal temperatures for the germination of uredospores of cereal rusts. Abstr. in Phytopathology 2:47.

LARGE, C. T., KINGSOLVER, C. H., MITCHELL, J. E. and CHERRY, E. (1958). Determination of the effect of different temperatures on

uredial infection with Puccinia graminis var tritici. Phytopathology 48:658-660.

LATCH, C. M, and HANSON, E. W. (1962). Comparison of three stem diseases of melilotus and their causal agents. Phytopathology 52:300-315

LITTLEFIELD, L. J. and BRACKE, E. C. (1971). Ultrastructure and development of uredospores or namentation of Melampsora Lini. Canad. Jour. Bot. 49:2067-2073.

MAINS, E. M. (1915). Some factors concerned in the germination of rust spores. Mich. Acad. Sci. Rep. 17:136-140.

McBRYDE, M. C. (1936). A method of demonstrating rust hyphae and haustoria in unsectioned leaf tissue. Amer. Jour. Bot. 23:686-688.

MEHTA, P. N. (1969). The cowpeas improvement programme at Kabanyolo. Proc. 12th. Meeting specialist Comm. Agric. Bot. Sept. 1969.

MENDGEN, K. (1978). De Infektionsverlauf von Uromyces phaseoli bei anfeilligen undresistenten Bohnensorten. Phytopath. Z. 73:295-313.

MUKUNYA, D. M. (1978). Diseases of cowpea recorded at Katumani in the first Annual report. Cowpea Improvement Programme in Kenya. 8-10.

NATTRASS, R. M. (1932). Annual report of the Mycologist for the year 1932. Ann. Rept. Depart. of Agric. Cyprus for the year 1932. Abstr. in R. A. M. 11:742.

NATTRASS, R. M. (1934). Annual report of the mycologist for the year 1934. Rep. Dept. Agric. Cyprus. Abstr. in R. A. M. 14:741.

NAITO, N. (1951). On the influence of temperature to germination of urediniospores of Uromyces appendiculatus (Pers). Fr. parasitica on bean. Tech. Bull. Kaga. Waken Agric. Coll. 1, (3):14-17.

OGLE, H. J. and JOHNSON, J. C. (1974). Physiologic specialisation and control of bean rust (Uromyces appendiculatus). Queensland Jour. Agric. and Animal Sciences. 31(1): 71-82.

OGUNMODEDE, B. B. and OYUNUGA, V.A. (1970). Vitamin B Content of cowpea. (Vigna ungiculata walp). J. Sci. Fd. Agric. 21:81-91.

OLAND, K. and STABURSUIK, A. (1970). Requirements of proteins and amino acids and their availability in Uganda. Mimeograph p. 10.

RAWAL, R. O., SOKHI, H. S. and SOKHI, S. S. (1974). Effects of levels of N.P.K. on cowpea rust caused by Uromyces phaseoli var vignae. Indian Phytopath 27:405.

ROBERT, G. E. (1958). The influence of light and temperature on the formation of infection-type structures of Puccinia graminis var tritici on artificial substrates. Phytopathology 48:649-652.

SASS, J. E. (1958). Botanical microtecnnique. Third edition. p. 52-77. The Iowa State University Press.

SAVULESCU, T. and RAYSS, T. (1936). Contribution a 'letude de la mycoflore de

palestine (A contribution to the study of mycoflora of Palestine). Ann. Cryptog. evot. Abstr. in R. A. M. 15:683.

SELLSCHOP, J. P. F. (1962). Cowpeas. Vigna ungiculata (L) Walp. Field Crop Abstr. 15:259-266.

SEMPIO, C. (1938). Primo contributo alla conoscenza dell' azione ascercitata de vari fattori embiental: su alcune malattie parassitarie di piante cultivate (ruggine de Fagiolo. Abstr. in R. A. M. 38:345.

SHARP, E. L., SCHMITT, C. G., STANLEY, J. M. and KINGSOLVER, C. H. (1958). Some critical factors involved in establishment of Puccinia graminis tritici. Phytopathology 48:469-474.

SHIPTON, W. A. and BROWN, J. F. (1962). A whole leaf clearing and staining technique to demonstrate host pathogen relationship of wheat stem rust. Phytopathology 52:1313.

SOKHI, S. S. and SOKHI, H. S. (1976). Epidemiological studies on rust of cowpeas. Plant

diseases. Notes and News in Pans 22: 92-94.

STEVENS, N. E. (1916). A method of studying the humidity relations of fungi in culture. Phytopathology 6:428-432.

SWEDEN, J. D. (1921). Report of the government Botanist for the period 1st April to 3rd December 1920. Ann. Rept. Dept. of Agric. Uganda, for the nine months ending December 31:p. 43-46.

TENG, S. C. (1932). Fungi of Hanking II. Contr. Biol. Lab. Sci. Soc. China. Bot. Ser. VIII I:5-48.

VAN DER PLANK (1963). Plant diseases. Epidemics and control. 349 p. Academic Press.

WALLACE, G. B. (1945). Report on a plant disease survey in the lake and western provinces on the central railway. March-April 1945 by the plant pathologist. Myc. Circ. Dept. Agric. Tanganyika 17:11p.

WALLACE, G. B. and WALLACE, M. M. (1949). A list of plant diseases of economic importance in Tanganyika territory. Myco. papers No. 26. Comwn. Myc. Inst., Kew. Surrey.

WATERS, C. W. (1928). The control of teliospore and uredospore formation by experimental methods. Phytopathology 18: 157-213.

WHETZEL, H. H. (1906). Bean rust. Cornell. Agric. Exp. Station Bull. 239:298-299.

WILLIAMS, R. J. (1975). Cowpea diseases in Nigeria. PANS 21:253-267.

YARWOOD, C. E. (1939). Relation of moisture to infection with some downy mildews and rusts. Phytopathology 29:933-945.

YARWOOD, C. E. (1956). Simultaneous self inhibition of uredospore germination. Mycologia 48:20-24.

YARWOOD, C. E. (1961). Uredospore production by Uromyces phaseoli. Phytopathology 50:22-27.

APPENDIX II A

Percentage uredospore germination of Uromyces phaseoli var Vignae at different temperatures for different periods of time

Temperature in °C	Percentage germination after hours*					
	4	6	8	10	24	48
10	0.0	0.0	0.0	1.9	3.7	3.7
15	0.0	5.3	7.9	18.4	48.7	51.3
Room temperature (20±2°C)	1.2	4.4	15.4	27.9	58.8	60.3
20	4.8	21.0	33.9	37.1	82.3	83.9
25	0.0	0.0	2.8	4.2	13.9	13.9
30	0.0	0.0	0.0	3.3	8.3	8.3

*Each figure is an average of four slides. 10-30 uredospores per slide.

APPENDIX II B

Germination of uredospores of Uromyces phaseoli var vignae at different temperatures

Temperature in °C	Number of uredospores germinated*				Total	Mean
	1	2	3	4		
10	0	1	0	1	2	0.5
15	9	9	11	10	39	9.8
Room temperature (20 ± 2°C)	10	11	10	10	41	10.3
20	15	8	13	16	52	13.0
25	1	2	5	1	10	2.5
30	1	2	2	0	5	1.3
Total	37	33	41	38	149	
Mean	6.2	5.5	5.8	6.3		

*10-30 spores per slide.

APPENDIX II C

Germination of uredospores of *Uromyces phaseoli* var *Vignae* at different temperatures.

Analysis of variance

Source	df	ss	MSS	F
Blocks	3	5.46	1.82	
Treatments	5	583.71	116.74	35.92**
Error	15	48.79	3.25	
Total	23	637.96		

LSD at 1 percent level = 3.07

APPENDIX III A

Percentage uredospore germination of *Uromyces phaseoli* var *vignae* at different humidities for different periods of time at 20°C

Relative humidity	Percentage germination after hours*					
	4	6	8	10	24	48
100	13.3	30.7	49.3	58.7	60.0	73.3
98	8.3	20.0	38.3	48.3	56.7	56.7
95	0.0	11.1	28.9	31.1	33.3	33.3
90	0.0	10.9	14.6	16.4	21.8	25.5
80	0.0	0.0	1.9	3.7	3.7	3.7
70	0.0	0.0	0.0	0.0	2.0	2.0

*Each figure is an average of four slides; 10 - 30 uredospores per slide.

APPENDIX III B

Germination of uredospores of Uromyces phaseoli var vignae at different humidities

Relative humidity	Number of uredospores germinated*				Total	Mean
	1	2	3	4		
100	13	12	17	13	55	13.8
98	8	5	9	12	34	8.5
95	4	3	5	3	15	3.8
90	3	2	3	6	14	3.5
80	2	0	0	0	2	0.5
70	0	1	0	0	1	0.3
Total	30	23	34	34	121	
Mean	5.0	3.8	5.7	5.7		

*10 - 30 uredospores per slide.

APPENDIX III C

Germination of uredospores of *Uromyces phaseoli* var *Vignae* at different humidities.

Analysis of Variance

Source	df	SS	MSS	F
Blocks	3	13.46	4.49	
Treatments	5	541.71	108.34	38.83**
Error	15	41.79	2.79	
Total	23	596.96		

LSD at 1 percent level = 2.84

APPENDIX IV A

Percentage uredospore germination of *Uromyces phaseoli* var *vignae* in different liquid media

Liquid media	Percentage uredospore germination after hours*				
	6	8	10	24	48
host extract	7.7	15.4	21.2	50.0	75.0
sterile tap water	12.8	19.2	25.5	57.5	83.0
rain water	1.9	11.5	34.6	53.9	80.8
sterile distilled water	0.0	2.9	11.4	21.4	22.9
dew from cowpea plant	3.2	6.5	29.0	52.2	58.1
Extract from Whatman No. 1 filter papers	0	13.3	24.4	33.3	44.4
sterile stream water	2.1	19.2	34.1	63.8	72.3

*Each figure is an average of four slides; 10-30 uredospores per slide.

APPENDIX IV B

Germination of uredospores of *Uromyces phaseoli* var *vignae* in different liquid media

Liquid media	Number of uredospores germinated*				Total	Mean
	1	2	3	4		
host extract	10	8	10	11	39	9.8
sterile tap water	8	8	10	12	38	9.5
Rain water	11	10	8	13	42	10.5
sterile distilled water	5	4	4	3	16	4.0
dew from cowpea plant	10	8	12	6	36	9.0
extract from Whatman No. 1 filter papers	5	4	6	5	20	5.0
sterile stream water	8	12	5	9	34	8.5
Total	57	84	55	59	225	
Mean	8.1	7.7	7.9	8.4		

* 10-30 uredospores per slide

APPENDIX IV C

Germination of uredospores of *Uromyces phaseoli* var *Vignae* in different liquid media.

Analysis of variance

Source	df	SS	MSS	F
Blocks	3	2.10	0.70	
Treatments	6	151.21	25.20	6**
Error	18	75.65	4.20	
Total	27	228.96		

LSD at 1 percent level = 3.15

APPENDIX V A

Percentage uredospore germination of Uromyces phaseoli var Vignae in different pH at 20°C in 100 percent relative humidity

pH	Percentage germination after hours*					
	4	6	8	10	24	48
3.0	0.0	8.7	12.4	28.3	52.2	65.2
3.5	6.7	23.3	27.6	30.0	61.7	66.1
4.0	0.0	15.0	24.0	38.3	65.0	71.4
4.5	0.0	12.5	19.3	36.8	58.9	71.7
5.0	5.1	17.0	28.2	45.8	61.0	73.3
5.5	0.0	12.7	25.1	49.2	65.1	76.2
6.0	0.0	6.1	11.4	22.5	51.0	67.4
6.5	0.0	11.9	21.7	35.8	55.2	64.2
7.0	7.5	25.0	29.0	35.0	62.5	62.5

*Each figure is an average of four slides; 10 - 30 uredospores per slide.

APPENDIX V B

Germination of uredospores of *Uromyces phaseoli* var *vignae* in different pH

pH	Number of uredospores germinated*				Total	Mean
	1	2	3	4		
3.0	6	6	8	10	30	7.5
3.5	9	11	9	10	39	9.8
4.0	10	12	10	8	40	10.0
4.5	10	9	14	10	43	10.8
5.0	16	11	7	10	44	11.0
5.5	12	10	16	10	48	12.0
6.0	8	10	8	7	33	8.3
6.5	12	10	11	10	43	10.8
7.0	6	8	5	6	25	6.3
Total	89	87	88	81	345	
Mean	9.9	9.7	9.8	9.0		

*10 - 10 uredospores per slide.

APPENDIX V C

Germination of uredospores of *Uromyces phaseoli* var *vignae* in different pH.

Analysis of variance

Source	df	SS	MSS	F
Blocks	3	4.31	1.44	
Treatments	8	112.00	14.00	3.04*
Error	24	110.44	4.60	
Total	35	226.75		

LSD at 5 percent level = 2.21

APPENDIX VI A

Percentage uredospore germination of *Uromyces phaseoli* var *vignae* stored (at 2 - 4°C) for different length of time

storage period in hours	Percentage germination after hours*					
	4	6	8	10	24	48
2	0.0	3.2	15.1	35.5	71.0	75.8
24	0.0	3.9	16.6	47.1	74.5	76.5
48	0.0	0.0	5.8	13.0	39.1	46.4
96	0.0	0.0	4.8	11.3	32.3	43.6
168	0.0	0.0	0.0	5.3	31.6	36.8
336	0.0	0.0	0.0	3.1	30.8	33.9
504	0.0	0.0	0.0	2.8	27.8	29.2
672	0.0	0.0	0.0	0.0	23.0	26.2
840	0.0	0.0	0.0	0.0	22.4	25.9
1440	0.0	0.0	0.0	0.0	9.3	16.0
2160	0.0	0.0	0.0	0.0	6.4	7.9

*Each figure is an average of four slides; 10 - 30 uredospores per slide.

APPENDIX VI B

Germination of uredospores of *Uromyces phaseoli* var *Vignae* after storage (at 2 - 4°C) for different length of time

storage period in hours	Number of uredospores germinated*				Total	Mean
	1	2	3	4		
2	14	10	12	11	47	11.8
24	10	9	8	12	39	9.8
48	10	11	7	4	32	8.0
96	9	6	7	5	27	6.8
168	5	8	8	7	28	7.0
336	5	5	6	6	22	5.5
504	7	4	6	4	21	5.3
672	4	6	7	5	22	5.5
840	5	4	4	3	16	4.0
1440	3	1	3	5	12	3.0
2160	2	1	2	1	6	1.5
Total	74	65	70	63	272	
Mean	6.7	5.9	6.4	5.7		

*10 - 30 uredospores per slide.

APPENDIX VI C

Germination of uredospores of *Uromyces phaseoli* var *Vignae* after storage (at 2 - 4°C) for different length of time.

Analysis of variance

Source	df	SS	MSS	F
Blocks	3	6.73	2.24	
Treatments	10	346.55	34.66	13.13**
Error	30	79.27	2.64	
Total	43	432.55		

LSD at 1 percent level = 1.90

APPENDIX VII A

Effect of different fungicides (at 500 ppm) on uredospore germination of *Uromyces phaseoli* var *Vignae*

Fungicide	Number of uredospores germinated*				Total	Mean
	1	2	3	4		
Captan	5	8	7	6	26	6.5
Sulphur	11	10	9	8	38	9.5
Benlate	8	4	2	4	18	4.5
Plantvax	4	5	10	6	25	6.3
Dithane M45	8	7	5	9	29	7.3
Zineb	7	5	9	10	31	7.8
Blitox	6	6	7	8	27	6.8
Baycor	0	0	0	0	0	0.0
Bayleton	5	3	4	1	13	3.3
Calxin	8	5	6	5	24	6.0
Control	8	9	10	8	35	8.8
Total	70	62	69	65	266	
Mean	6.4	5.6	6.3	5.9		

*10 - 30 uredospores per slide

APPENDIX VII B

Effect of different fungicides (at 500ppm) on uredospore germination of *Uromyces phaseoli* var *vignae*.

Analysis of variance

Source	df	SS	MSS	F
Blocks	3	3.73	1.24	
Treatments	10	284.41	28.44	9.51**
Error	30	89.77	2.99	
Total	40	377.91		

$\dot{d}$' at 1 percent level = 2.88

LSD at 1 " " = 2.04

$\dot{d}$' refers to Dunnets test for comparing with control.

APPENDIX VIII A

Effect of fungicidal sprays on cowpea rust during the long rains 1979 at Katumani. Grain yield in grams

Fungicide	Yield in grams of the five central rows				Total	Mean
	1	2	3	4		
Baycor	1165	1038	1146	1167	4416	1104
Bayleton	918	910	882	986	3696	924
Dithane M45	681	852	804	687	3024	756
Blitox	912	727	864	777	3280	820
Control	847	726	531	742	2846	711.5
Total	4523	4253	4127	4359	17262	
Mean	904.6	850.6	825.4	871.8		

APPENDIX VIII B

Effect of fungicidal sprays on cowpea rust during the long rains 1979 at Katumani. Grain yield in grams.

Analysis of variance

Source	df	SS	MSS	F
Blocks	3	16877.40	5625.80	
Treatments	4	392208.80	98052.20	11.85
Error	12	99257.60	8271.47	
Total	19	508343.80		

d' at 1 percent level = 135.02