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Peanut Rust in West Africa:

A New Component in a Multiple Pathosystem

Peanut (*Arachis hypogaea* L.) has been cultivated in West Africa for centuries. It was probably introduced into several areas on the western and eastern coasts of Africa by European sailors in the early 16th century. The new crop was adopted by African farmers, some of whom already cultivated a leguminous crop, the Bambara groundnut (*Voandzeia subterranea* Thou.), that had a similar habit, hypogeous pods, and similar cultivation requirements. In relatively recent times, peanut became an export crop in some parts of Africa, such as Senegal and Nigeria. Peanut is predominantly a food crop in many African countries.

Among the numerous diseases (2) that affect peanut in Africa, peanut rust holds a particular position. The spread of this disease, caused by *Puccinia arachidis* Speg., is a recent example of a pandemic in the tropical world (1). Whereas peanut rust was confined to tropical America and China until 1969, it suddenly appeared in southern Asia and Oceania during the early 1970s and in Africa a few years later. Peanut rust was first noticed in the Ivory Coast in 1976 and in Senegal in 1980.

The appearance of the new disease created a serious problem. Scientific information on the epidemiology of peanut rust and on its importance to farmers in Africa was badly needed. Its importance among the many disease constraints was unknown. An analysis had to be made of its possible future impact with increased agricultural intensification. Control methods needed to be evaluated within the context of management strategies relevant to the present and future status of peanut cultivation in Africa. In this article we report the results of efforts of a joint program by ORSTOM, the Wageningen Agricultural University, and IRHO on peanut rust epidemiology and control. Most of the information was obtained from research in the Ivory Coast. The

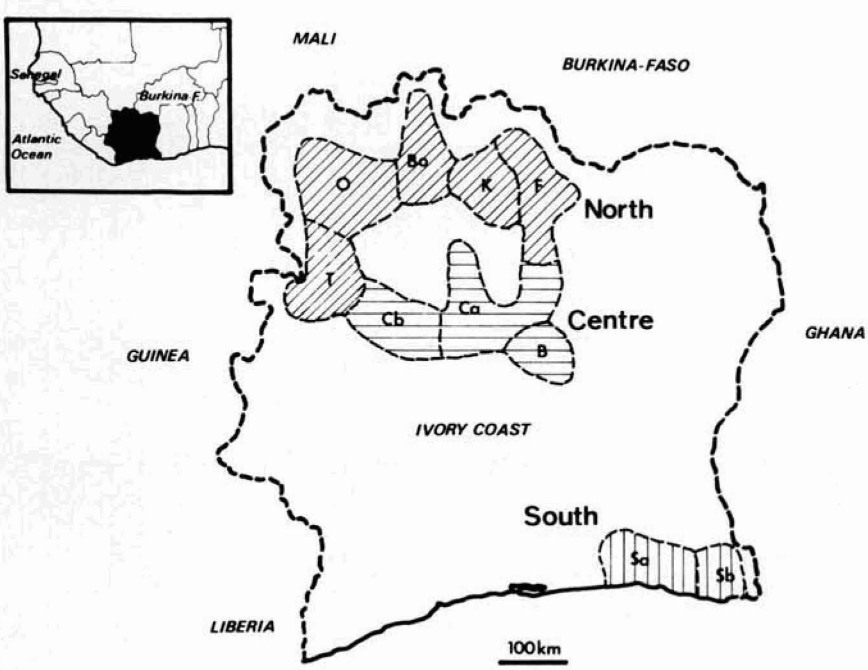


Fig. 1. Regions of the Ivory Coast where the survey for peanut fungal diseases was conducted during 1983–1985.

range of climates, agroecological situations, and cultural practices in the Ivory Coast is so broad that the results presented here are considered to be representative for peanut as a food crop in West Africa.

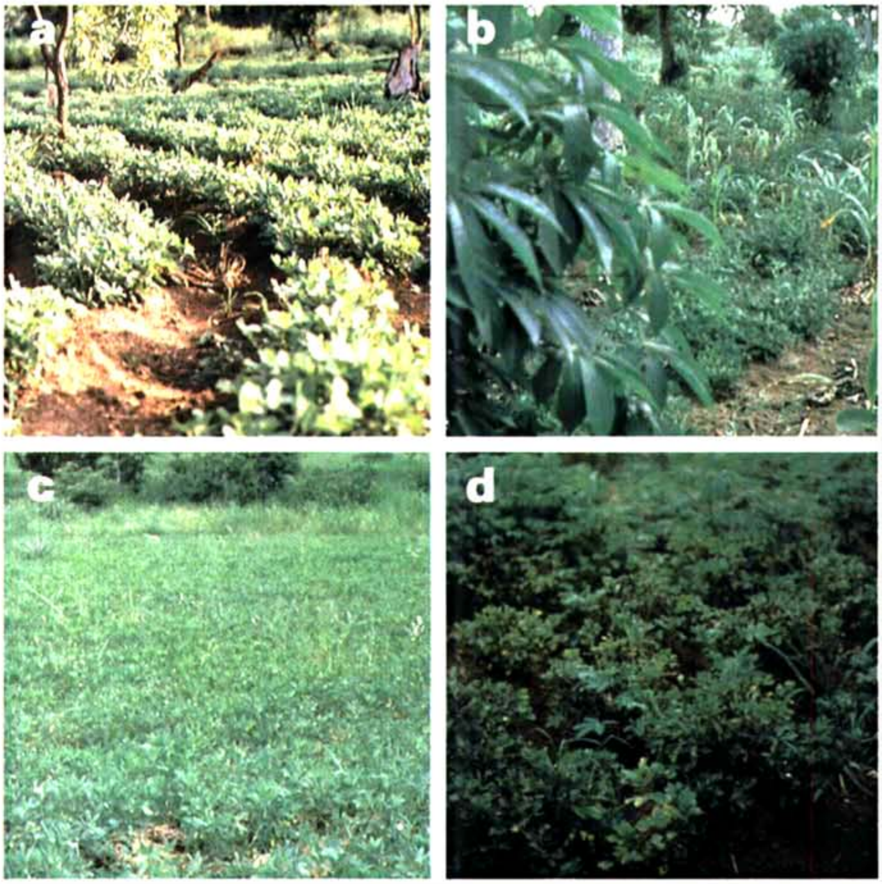


Fig. 2. Peanut crops in the Ivory Coast: (A) Cultivation on ridges at low crop density with good weed control, in the north. Cultivation on (B) shallow ridges in association with maize and cassava and (C) on flat land with random seed placement and moderate plant density, both in the central region. (D) Cultivation on mounds in association with cassava, in the south; note high intensities of Cercospora leaf spot and virus (probably peanut chlorotic rosette and eyespot) diseases.

Fig. 3. Peanut in mixed cropping in the Ivory Coast: (A) With maize, in the central region, (B) with millet and tomato, in the north in a moist valley bottom, and (C) with cowpea and Bambara groundnut, in a household garden in the north.

A Survey of Peanut Crops in the Ivory Coast

Peanut is traditionally grown by smallholders. The average pod yields are low, within the range of 800–1,200 kg/ha. Usually, the area of land allocated to peanut crops does not exceed the consumption needs of family or village, and, therefore, peanut is not a major crop, with about 60,000 ha grown annually. Although most of the acreage is in the northern and central savanna regions (Fig. 1), peanut is also cultivated in the southern rain forests. Superimposed on these great ecological differences is a large variation in farming systems—from shifting, slash and burn, cultivation in the south to partially mechanized cultivation with crop rotation in the north. In no case are artificial fertilizers or pesticides applied directly to peanut crops. Peanut is also grown as a household garden crop for consumption by the family, especially the children, and as a market crop in moist valley bottoms, for sale on local markets. For garden and market crops, high levels of management are used in the form of labor and natural fertilizer (manure or household wastes).

A survey of peanut fungal diseases was conducted from 1983 to 1985 in several regions of the Ivory Coast with the following objectives: 1) to describe peanut fields, cultural practices, climatic conditions, and intensities of various diseases; 2) to investigate the association of the most frequent fungal diseases, including rust, with climate, crop growth and development, and cropping techniques; 3) to compare the results of the survey with results from experiments on peanut rust epidemiology; and 4) to use the survey data to provide a basis for risk assessment of rust in the Ivory Coast. The survey included 309 fields in different parts of the country, in different seasons, at different crop development stages. Each field was visited once, each providing a unique data set on intensity of diseases, crop growth and development, and cultural practices.

The survey results illustrated some of the differences among regions (Fig. 2), with two extremes distinguished. In the north, long-cycle (120–145 days) cultivars are common and are frequently cultivated in relatively large (1 ha or more) fields. The crops are sown every year soon after the onset of the rainy season. Planting is done on raised beds at low seeding rates (Fig. 2A). In the south, short-cycle (90 days) cultivars are grown almost continuously on small (usually less than 1 ha), scattered fields (Fig. 2D). The crop is usually sown at variable seeding rates and is carefully weeded. These extremes represent general but statistically significant (6) trends. Large variations among fields are found (Fig. 2). Peanut is frequently grown in association with other crops, and the nature and pattern of the mixture result in differences in the canopy structure of the resulting crop. The most frequent association is maize/peanut (Fig. 3A), but cassava/peanut (Figs. 2B and 2D), millet/peanut (Fig. 3B), Bambara groundnut/cowpea/peanut (Fig. 3C), and tomato/peanut (Fig. 3B) are also encountered.

Among 18 fungal pathogens identified on peanut in the Ivory Coast (6), six were observed frequently and assessed during the survey: rust (*P. arachidis*) (Fig. 4A), Personata (late) leaf spot (2) (*Phaeoisariopsis personata* (Berk. & Curt.) von Arx, *Cercosporidium personatum* (Berk. & Curt.) Deighton) (Fig. 4A), Arachidicola (early) leaf spot (2) (*Cercospora arachidicola* Hori) (Fig. 4A), Aspergillus damping-off (*A. niger* van Tiegh.) (Fig. 4B), Sclerotium stem rot (*S. rolfsii* Sacc.) (Figs. 4C and 4D), and Botryodiplodia collar rot (*Botryodiplodia* sp.) (Fig. 4E). In each field, the severities of the foliar diseases—rust (R), Personata leaf spot (P), and Arachidicola leaf spot (A)—were assessed from 10 plants chosen at random, while the incidences of the wilt diseases—Aspergillus damping-off (N), Sclerotium stem rot (Cr), and Botryodiplodia collar rot (B)—were assessed from a population of approximately 100 plants.

With the exception of Botryodiplodia collar rot, these diseases occur in all regions included in the survey. Table 1 shows large regional differences in disease spectra. The overall importance, with emphasis on foliar diseases, is also shown.

The analysis of the survey data considered quantitative, continuous variables (e.g., disease intensities, weather) and qualitative, discrete variables (e.g., cropping techniques). The distribution of foliar disease severities was asymmetrical and overdispersed. A large number of stands (usually in their early development) were unaffected, some were slightly to moderately affected, and few were severely infected (usually in their late development). Such frequency distributions of disease severities led to the definition of classes with exponentially increasing width (severity) and with similar size (number of fields). The recoding of quantitative variables into qualitative, discrete variables was a preliminary to the analysis of contingency tables (Table 2) and corresponding analysis (1).

In the Ivory Coast, the large variation in agroecological environments was expected to affect the levels of the various considered diseases. As a first step in the analysis of survey data, a general scheme of the development of host crop and of the diseases in an average smallholder's field was made by means of correspondence analysis (6). In Figure 5, a strong correspondence is seen between the development of foliar diseases, represented by paths of increasing severities (R, P, and A, Fig. 5A), and the development and growth of the host crop (AGE and STD, Fig. 5B). The decreasing distance between successive points along the rust (R) and Personata (late) leaf spot (P) paths indicates an accelerated pace in the epidemic buildup to crop maturity. These epidemic trends contrast with that of Arachidicola (early) leaf spot (A), in which an early buildup was followed by a decrease at crop maturity. The epidemic trends for wilt diseases (Cr and N, Fig. 5C) strongly differ from those of foliar diseases, indicating their progressive disappearance from the developing crop. No particular trend was found for Botryodiplodia collar rot, which was represented by a small number of affected stands. The resulting picture, well in agreement with numerous published reports on the behavior of each component of the multiple pathosystem considered (2), was used as a frame of reference for the further analysis of survey data.

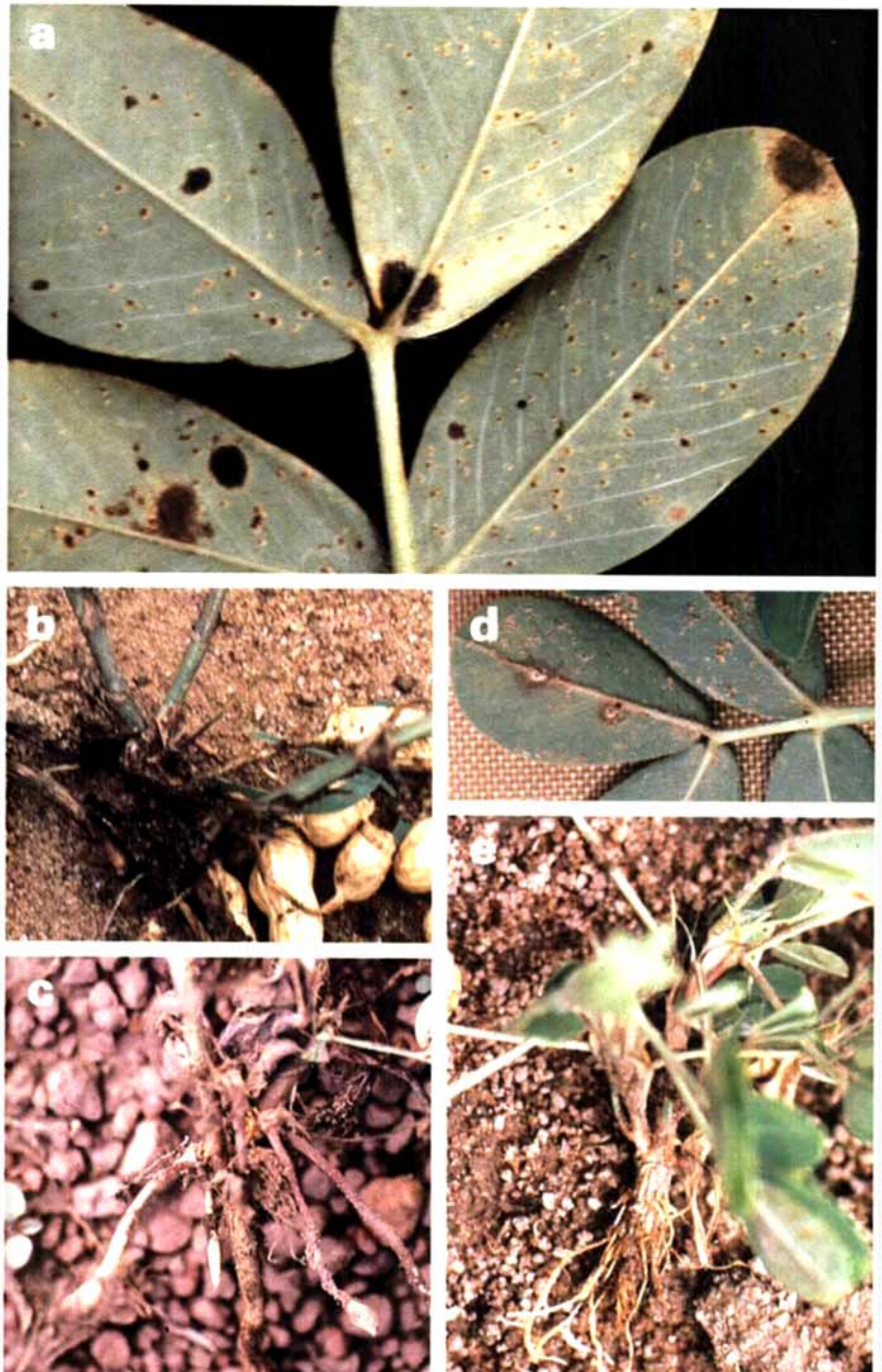


Fig. 4. Diseases of peanut common in the Ivory Coast: (A) Rust, Personata (late) leaf spot (small, dark lesions), and Arachidicola (early) leaf spot (large, brown lesions); (B) Aspergillus damping-off; (C) Sclerotium stem rot, collar symptoms; (D) Sclerotium stem rot, leaf (adaxial) symptoms, with splash-dispersed tan sclerotia at the center of lesions among soil particles; and (E) Botryodiplodia collar rot.

Serge Savary

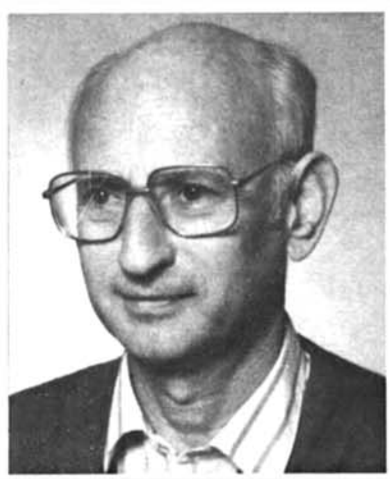
Dr. Savary is a research plant pathologist at ORSTOM, Institut Français de Recherche Scientifique pour le Développement en Coopération. He received his B.S. degree from the Agricultural High School of Montpellier, France, his M.S. degree from the University of Toulouse, France, and his Ph.D. degree from the Wageningen Agricultural University, the Netherlands, under the guidance of Jan C. Zadoks. He has been working at the Adiopodoumé Research Center, Ivory Coast, since 1980, where he is in charge of a research project on groundnut diseases and crop loss assessment in farmers' crops. His research interests also include comparative and analytical epidemiology of fungal foliar diseases.

Michel Noirot

Dr. Noirot is a plant breeding geneticist at ORSTOM. He has been working for 10 years on improvement of grasses in the Ivory Coast. These studies terminated with a "Doctorat d'Etat" from Paris XI University. As a specialist in biometry, he managed simultaneously the computing department of the Adiopodoumé Research Station in the Ivory Coast. He is involved in several research projects in plant pathology and physiology as a statistician advisor.

Jean-Philippe Bosc

Mr. Bosc received his M.S. degree from the Agronomy and Food Industry High School of Nancy, France, where he specialized in plant pathology. He has been working on peanut rust in Burkina Faso (formerly Upper Volta) for 4 years with IRHO, the French Research Institute for Oil and Oilcrops, Paris. He has been involved in research on peanut screening techniques for disease resistance, epidemiology, and fungicide control. His current interest focuses on the research-development interface in disease control for developing countries.



Jan C. Zadoks

Dr. Zadoks completed his studies at the Municipal University of Amsterdam, the city of his birth. He was a research scientist at the Research Institute for Plant Protection (IPO) at Wageningen. In 1961 he entered the service of the Wageningen Agricultural University, where he is professor of plant pathology. He specializes in epidemiology and crop loss assessment. He completed many missions to the tropics and is presently a member of the FAO/UNEP Panel of Experts on Integrated Pest Control. He coauthored *Epidemiology and Plant Disease Management* in 1979 with Richard D. Schein and *Atlas of Cereal Diseases and Pests in Europe* in 1984 with F. H. Rijsdijk.

Assessment of Losses Caused by Peanut Rust

Losses caused by rust in African peanut crops have been poorly documented. The importance of rust compared with that of the leaf spot diseases—the most widespread constraints—was unknown. Crop loss information thus was considered as a prerequisite to further consideration of the peanut rust management problem.

Several experiments were conducted in which the levels of rust and early and late leaf spot diseases were manipulated by means of fungicide combinations. With attainable yields (i.e., disease levels reduced to nil) of approximately 1,700 kg/ha of dry pods, losses as high as 40–70% were observed from rust or leaf spot alone or combined. The results shown in Figure 6 are typical of these trials and suggest that losses are increasing faster with rust than with leaf spot severity.

Such results, obtained at an experiment station, illustrate the possible relationship between yield losses and foliar diseases. However, experimental station studies may not be representative of actual situations in farmers' fields, where attainable yields and disease levels are highly variable. The results shown in Table 3 strongly corroborate the view that attainable yields, disease severities, and resulting crop losses are related (12). On-farm studies should be considered with caution because the fungicide (chlorothalonil) coverage could not be made as continuous as desired, since sprays were applied according to the farmers' technical means. Nevertheless, Table 3 clearly shows that losses were higher in weight (lower in percent) in crops with high attainable yields and that rust severity was higher in these crops.

Experimental Studies on Peanut Rust Epidemiology

The telial state of *P. arachidis* has been described (2,10), but it has not yet been found in Africa. At present, peanut is the only known host of *P. arachidis*.

Epidemics of peanut rust are built up of uredial infection cycles. Monocyclic experiments were conducted on the successive phases of the infection cycle: spore survival, spore germination, infection efficiency, latency period, sporulation intensity, and infectious period (5,12). Temperature strongly affected the monocyclic process. Temperatures of about 27 C were optimal for rust development; infection efficiency, sporulation intensity, and infectious period were highest and latency period was lowest (5). A water-saturated atmosphere or water droplets on the leaf surface were necessary for spore germination (5). Spores deposited under dry conditions strongly adhered to the leaf surface and survived for up to 15 days (50% survival

Table 1. Peanut diseases in the Ivory Coast, with mean regional severities (%) of foliar pathogens at midcycle and mean regional prevalences (%) of wilt fungi

	Regions[a]											
	South		Center		North							
Pathogens	Sa	Sb	Ca+B	Cb	T	O	Bo	K+F	Mean intensities	F^b	χ^{2c}	*P*
Foliar												
Puccinia arachidis	17.0	3.5	0.5	1.9	5.6	1.3	0.7	2.9	4.1	7.4		<0.0001
Phaeoisariopsis personata	20.0	9.4	0.6	4.7	8.2	4.2	2.0	0.8	6.2	3.6		0.0002
Cercospora arachidicola	0.3	0.1	3.9	11.0	12.0	6.6	11.0	2.4	6.2	9.4		<0.0001
Wilt												
Aspergillus niger	7.1		19.0		2.9		9.1	11.0	10.0		10.4	0.05
Sclerotium rolfsii	14.0	37.0	41.0	13.0	12.0	16.0	15.0	11.0	20.0		22.5	0.002
Botryodiplodia sp.	8.8	0	0	0	0	3.2	4.8	5.7	2.9		···	···

[a] See Figure 1.
[b] Fisher *F* test values after one-way ANOVA, with severity data ($0 < x < 1.0$) transformed into $\log_{10}(x + 0.001)$.
[c] Chi-square test values from contingency tables (numbers of fields).

after 6 days at 27 ± 1 C; Michaud, De Jong, and Savary, *unpublished*). Increasing leaf age and plant development were associated with an increase in the latency period (5), and increasing leaf age was associated with a reduction in infection efficiency. Water stress applied to inoculated potted plants prolonged the latency period up to 20%.

Uredospore dispersal was studied in artificial foci established in the field. Aerial dispersal of uredospores had a strong diurnal rhythmicity related to daily variations of relative humidity and wind velocity (5). Rain-induced dispersal was studied by varying the amount and intensity of rainfall with a rainfall simulator (8). The spore liberation mechanisms and the resulting spore flows were considered at the level of the individual pustule and at canopy level. Dry spore dispersal resulting from raindrop impaction on the canopy predominated. An increasing flow of spores that dripped from the canopy to the soil with increasing rainfall amounts suggested that light rain showers were favorable and heavy showers were unfavorable for rust spread.

Artificial foci were also used for studies on short-distance, within-crop rust spread. A significant effect of crop canopy on primary gradients was found; mean values and slopes were higher with increasing plot (canopy) age. Such results, as well as variations in the vertical distribution of disease within the canopy, were attributed to differences in dispersibility of spores and in accessibility of leaves to the spores. The relative shallowness of the gradients in artificial foci corresponds to the usual pattern of peanut rust epidemics in farmers' fields in the Ivory Coast, i.e., general rather than focal (12). This pattern may be due to rapid spread from primary foci within the fields and/or to uniform infection from strong but distant or weak but numerous nearby sources.

Only circumstantial evidence exists for long-distance rust spread. Multivariate analyses of rust severity data indicate that high rust severity is associated with either: 1) low regional crop density in combination with large variance of sowing dates or 2) high regional crop density and small variance of sowing dates. These two types of situations correspond to southern rain forest and northern savanna crops, respectively. Comparison of rust prevalence curves (Fig. 7) from farmers' fields indicated that infection occurred at an earlier development stage and proceeded faster in southern crops than in northern crops. The pattern of the southern rain forest region may be described as explosive, developing on a endemic background (3). Endemicity of groundnut rust in this area may be ascribed to infected volunteer plants and continuous peanut cultivation. In the central and northern savanna regions, delayed general epidemics develop every year. Most of the primary inoculum supposedly originates from the southern source, and disease increase is favored by the aggregation of host crops in space and time.

Table 2. Contingency tables for the analysis of correspondences in a survey of peanut diseases in the Ivory Coast

Personata (late) leaf spot severity classes[a]	Rust severity classes[b]						
R × P	R0	R1	R2	R3	R4	R5	Σ
P0	53	8	1	0	0	0	*62*
P1	14	21	11	13	3	2	*64*
P2	8	13	3	8	5	1	*38*
P3	1	9	5	15	8	6	*44*
P4	0	1	3	8	5	7	*24*
P5	1	2	9	18	14	33	*77*
Crop development stages[c]							
R × STD							
STD1–3	44	6	0	2	0	0	*52*
STD4–5	24	20	5	7	0	2	*58*
STD6–7	5	13	11	17	8	5	*59*
STD8–9	3	10	10	20	13	11	*67*
STD10	1	5	6	16	14	31	*73*
Σ	*77*	*54*	*32*	*62*	*35*	*49*	**309**

[a] P0 = absent, P5 = severe.
[b] R0 = absent, R5 = severe.
[c] STD1–3 = vegetative stages, STD10 = harvest stage.

Distinctive Epidemiological Features of Peanut Rust

The analysis of survey data resulted in an overall, simplified scheme for the epidemiology of peanut rust which could be compared with that of early and late leaf spot diseases. As for weather variables, correspondences were found between maximum rust severities, optimum temperature, and rainfall conditions that were in agreement with experimental results. The behavior of late leaf spot was similar to that of rust, but its weather requirements seemed to be more flexible than those of rust. The variation of early leaf spot severity could not be related to any definite rainfall or temperature patterns, since high disease severities were observed at both extremes of rainfall and temperature.

Except for the effects of leaf age, plant development stage, and water stress on infection efficiency and latency period, little is known about the relations between rust development and the physiological status of the host. It seems that peanut rust development is favored by healthy young plants, as are most other biotrophic pathogens, rather than by stressed senescing ones (12). A correspondence analysis of the relations between cultural practices and crop growth and foliar disease levels supported this hypothesis. In Figure 8, the path representing increasing rust severity (R) resembles that of increasing relative growth (Fr) of the host plants. Increasing levels of rust also correspond to decreasing weed density and, to a lesser extent, to increasing crop density (not shown). In contrast, high levels of early leaf spot correspond to high weed density. In other words, high rust severities (and, frequently, high late leaf spot severities) correspond to well-growing, carefully weeded, relatively dense stands (Fig. 9A). Poorly growing, weed-covered stands (Fig. 9B) correspond to high early leaf spot severities. The conclusions are based on statistically significant associations (contingency tables, chi-square tests; 7).

Components Analysis of Host-Pathogen Interaction

Improvement of rust resistance in peanut varieties should form the basis of future rust control strategies (10). Resistance to rust is thought to be composed of a set of components of resistance (11), such as infection efficiency, latency period, sporulation intensity, and infectious period (9). Data on components of resistance may be transformed into relative values, each representing a more or less effective brake on the infection process (11). Transformed data can be used in a components analysis, where individual phases of the infection process are considered, and a compound resistance can be calculated as the product of relative resistance values (Table 4).

Published results (9,10) and new experiments (Table 4) indicate that

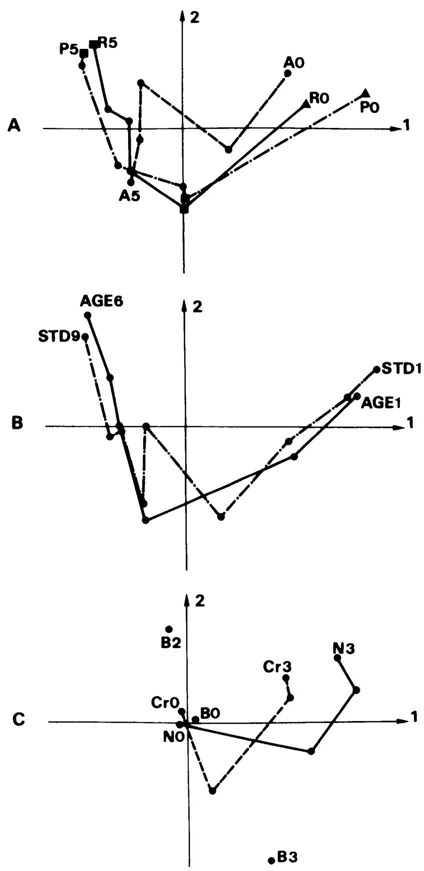


Fig. 5. A survey of 309 smallholders' fields in the Ivory Coast for foliar diseases of peanut was analyzed by means of a correspondence analysis (Benzécri et al [1]). Variability is projected on two axes that account for 72% (horizontal) and 18% (vertical) of total inertia. The points along the curves represent the sequentially coded classes of each variable (see Table 2). Curves proceeding from the lowest to the highest class values represent the "average field" of the Ivory Coast. Curves can be read as "paths." (A) The paths of rust (R) and Personata (late) leaf spot (P) correspond nicely, whereas that of Arachidicola (early) leaf spot (A) deviates. (B) The paths of crop age (AGE) and crop development stage (STD) correspond with those of R and P. (C) The paths of Sclerotium stem rot (Cr) and Aspergillus damping-off (N) proceed in opposite directions, and that of Botryodiplodia collar rot (B) does not indicate an epidemic trend.

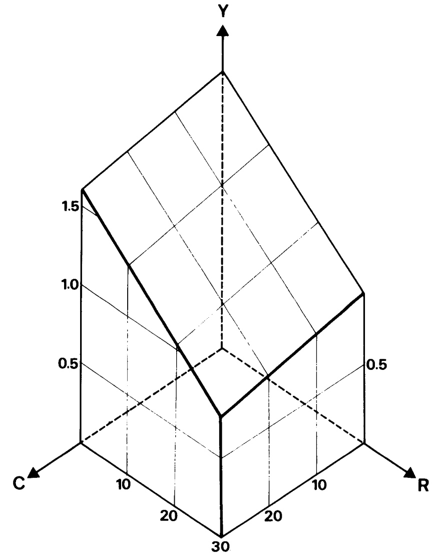


Fig. 6. An experiment on crop loss in peanut laid out as a Latin square with five fungicide treatments ($n = 25$). The plane representing the regression of yield (Y, in kg/ha) on rust (R) and leaf spot (C) severities (in percent) is shown, using the regression equation: $Y = 1{,}771 - 27.4 \times R - 5.8 \times C$, with a coefficient of determination $r^2 = 0.95$.

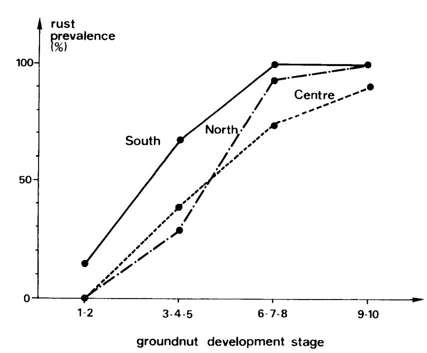


Fig. 7. Data from a 1983–1985 survey of peanut rust in the Ivory Coast plotted as prevalence (percent of fields infected) against development stage (STD) for three regions (south, center, north). Fields become gradually infected as peanut development stage progresses, in accordance with the corresponding paths of R and STD in Figure 5. Differences among regions in initial slope ($P < 0.10$) and curvature ($P < 0.05$) are ascribed to differences in epidemiological patterns.

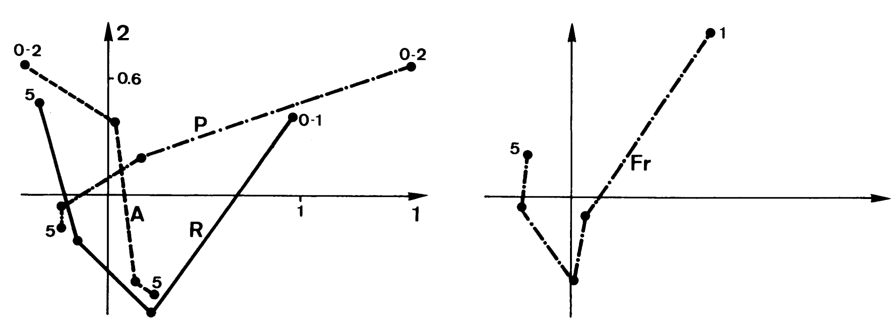


Fig. 8. Correspondence analysis (see Figure 5) of a survey of peanut rust in the Ivory Coast shows "paths" of rust (R), Personata (late) leaf spot (P), Arachidicola (early) leaf spot (A), and relative foliar growth (Fr). The horizontal and vertical axes account for 50 and 47% of inertia, respectively. The paths of R and Fr correspond nicely, those of R and P follow the same general direction (horizontal axis), and those of R and A go in opposite directions.

Table 3. Results of a crop loss experiment with foliar diseases of peanut in the Ivory Coast[a]

No. of plots	Yield range (kg/ha)	Disease severity range (%)		Loss range, kg/ha (%)	Regression equations[b]	r^2
		Rust	Leaf spots[c]			
Total = 30	185–1,875	0.5–25.0	0.7–45.0	0–832 (0–74)	L = − 182 + 0.1 × ABY + 12.4 × R + 13.1 × C	0.58
Low input = 12	185–785	0.5–12.3	4.7–30.0	0–492 (0–74)	L = − 153 − 0.1 × R + 16.8 × C	0.73
High input = 18	1,303–1,875	1.4–25.0	0.7–45.0	127–832 (0–51)	L = − 87 + 14.0 × R + 11.2 × C	0.55

[a] Fifteen pairs of plots, each pair consisting of an untreated and a chlorothalonil-treated plot.
[b] L = loss, ABY = accessible yield as measured in chlorothalonil-treated controls, R = rust, C = leaf spots.
[c] Accumulated late and early leaf spot severities.

resistance of cultivated peanut varieties to rust is incomplete and that the duration of the latency period is strongly related to rust scores in variety trials. Assessment of incomplete resistance is extremely laborious, and a reasoned choice of the phase(s) to be considered is imperative. Some guidance may be derived from model studies (4,11,12).

A simple, deterministic simulation model of peanut rust epidemics was based on results of monocyclic experiments and data on peanut growth and development (Savary, De Jong, Rabbinge, and Zadoks, *unpublished*). Its objectives were: 1) to produce a quantitative synthesis of the available information on peanut rust epidemiology (12), 2) to study rust epidemics under variable field conditions in simulation experiments, and 3) to assess the effects of varying components of resistance on peanut rust epidemics. The model was verified and partially validated by matching its outputs to field data at ORSTOM Experimental Station, Adiopodoumé. The output of one simulation experiment is shown in Figure 10, where the relative resistance values of four components of resistance are set at two levels: RRES = 0 or 0.25. The results confirm that latency period has a strong effect on rust epidemics (mean AUDPC when $RRES_{LAT}$ = 0: 6.61 and when $RRES_{LAT}$ = 0.25: 1.27), whereas infection efficiency (4.71 vs. 3.17) and sporulation intensity (4.72 vs. 3.16) have minor effects and infectious period (3.95 vs. 3.93) has negligible effects. This agrees with experimental results and supports the view that latency period should be a major criterion in the selection for incomplete resistance of peanut against rust.

Table 4. Components analysis of the peanut rust infection cycle for different peanut genotypes in the Ivory Coast, with results expressed as relative resistances (RRES) (11) for infection efficiency (IE), latency period (LP), sporulation intensity (SP), and a combination of the three (C), and with RRES values related to mean rust severity (R)

Genotype	Relative resistance values[a]				R
	$RRES_{IE}$	$RRES_{LP}$	$RRES_{SP}$	$RRES_C$	
PI 393643	0.597	0.381	0.745	0.1695	0.8
PI 393527B	0.793	0.258	0.742	0.1518	0.9
PI 407454	0.831	0.321	0.541	0.1443	1.0
PI 314217	0.803	0.356	0.615	0.1758	2.0
PI 350680	0.676	0.170	0.365	0.0420	2.8
PI 259747	0.279	0.075	0.549	0.0115	6.6
NC Ac 17127	0.234	0.108	0.530	0.0134	9.0
CN 4523	0.672	0.024	0.646	0.0104	9.1
NC Ac 17132	0.514	0.018	0.300	0.0028	10.1
RMP 12	0.296	0.029	0.327	0.0028	14.2
RMP 91	0.272	0.022	0.151	0.0009	16.1
Susceptible check	0	0	0	0	21.8

[a] Calculated as: RRES = 1 − T/S when T < S and as 1 − S/T when T > S, where T and S represent the values of the considered disease variable for the test cultivar (T) and the susceptible check (local cultivar), respectively. The combined resistance value is calculated as: $RRES_C = RRES_{IE} \times RRES_{LP} \times RRES_{SP}$. Exponential regression equations of rust severity on relative resistance values were calculated with the general shape: $R = a \times \exp(b \times RRES)$, with $a > 0$ and $b < 0$; $R = 27.38 \times \exp(-3.55 \times RRES_{IE})$, $r^2 = 0.65$; $R = 14.65 \times \exp(-7.70 \times RRES_{LP})$, $r^2 = 0.88$; $R = 28.13 \times \exp(-3.91 \times RRES_{SP})$, $r^2 = 0.57$; and $R = 11.45 \times \exp(-15.0 \times RRES_C)$, $r^2 = 0.85$.

Table 5. Two-way analyses of variance of infection efficiency (IE), latency period (LP), and sporulation intensity (SP) for 12 peanut rust isolates from several regions of the Ivory Coast tested on seven peanut genotypes[a]

Effects	df	IE		LP		SP	
		F	*P*	*F*	*P*	*F*	*P*
Variety	6	49	<0.001	138	<0.001	31	<0.001
Isolate	11	30	<0.001	7.5	<0.001	3.5	<0.001
Variety × isolate	66	4.8	<0.001	1.9	<0.005	19	<0.001
Residual	336						
Total	419						

[a] Five replications per isolate × genotype were used, a replication consisting of four (IE, LP) or one (SP) detached leaflet(s).

Components analysis can be used to compare pathogen isolates tested on a range of host genotypes. Twelve isolates of peanut rust were collected from several regions in the Ivory Coast, purified (unipustular isolates), and tested on seven peanut cultivars—two resistant (NC Ac 17090 and PI 259747), three moderately susceptible (69101, RMP 12, and RMP 91), and two very susceptible (TMV2 and a local short-cycle cultivar). Table 5 shows the results of two-way analyses of variance of infection efficiency, latency period, and sporulation intensity. For all three variables, significant variety, isolate, and isolate × variety effects were found, notwith-

Fig. 9. Variations in agricultural intensification of peanut cultivation in the Ivory Coast: (A) Well-tended, carefully weeded peanut stand in a household garden in the north. Such crops represent the maximum intensification level in traditional food crops, with high inputs of labor and manure. (B) Poorly growing, weed-infested peanut crop in the north, representative of crops farmers abandon because of low rainfall (as in 1984) or poor weed control. Abandoned crops may ensure rust survival in the dry season and may constitute inoculum sources. Note high intensity of Arachidicola (early) leaf spot.

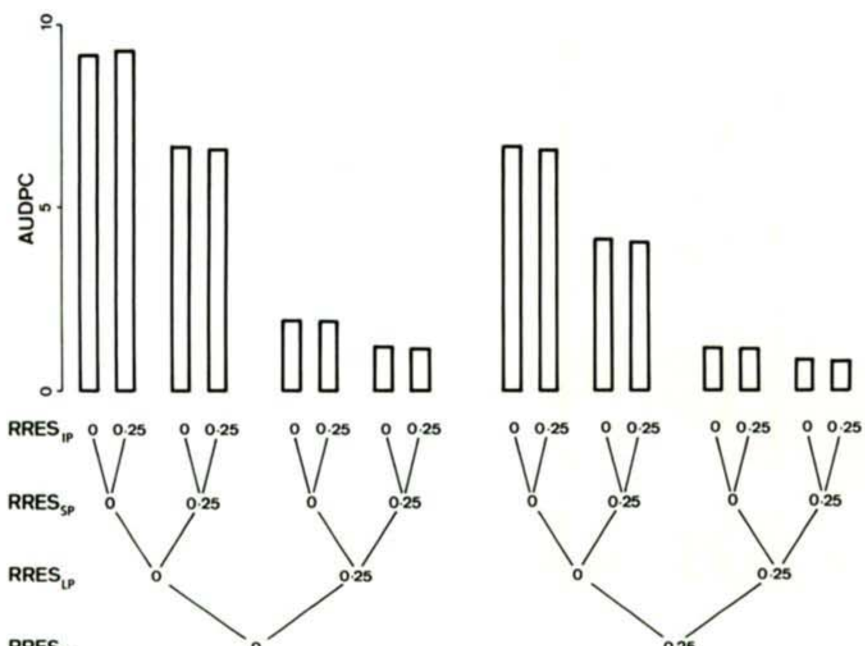


Fig. 10. A simulation experiment on the effects of components of resistance on peanut rust epidemics. The area under disease progress curve (AUDPC, expressed in diseased fractions•days) was calculated for various levels of relative resistance (see Table 4). Increase of $RRES_{LP}$ has a relatively large effect.

standing possible compensatory effect of infection efficiency on sporulation intensity. These results, and especially the significant isolate × variety interactions for infection efficiency and latency period, strongly suggest that rust isolates differ in their pathogenicity and that peanut shows the "small interaction phenomenon" discussed by Zadoks and Van Leur (13). The differences observed for any variable were small, and in no case were the general characteristics (resistant, moderately susceptible, or very susceptible) of the peanut varieties modified. "Small interaction" may or may not be a prelude to physiological specialization; more information is needed.

Projected Evolution of Multiple Pathosystem in a Process of Agricultural Intensification

P. arachidis may be considered as a new component in a multiple pathosystem in which foliar pathogens—especially *C. arachidicola* and *P. personata*—predominate. Peanut rust has distinctive features: 1) marked weather requirements for optimal development, 2) strong dispersal abilities both within and between fields, 3) preference for vigorous plants of well-tended crops, and 4) greater losses in high-yielding crops than in low-yielding ones.

Despite the large environmental diversity encountered in the various regions where peanut is traditionally cultivated, favorable weather and cropping conditions (i.e., continuous cropping in the southern rain forest regions) and strong reproduction and dispersal abilities have allowed peanut rust to become established in the Ivory Coast. It has quickly achieved considerable economic importance. Also, unrecognized genetic flexibility may have helped the pathogen to match host variability.

A survey of farmers' fields provided the information needed to consider the evolution of the pathosystem from an initial equilibrium situation with low yields to an emerging situation with medium to high yields. Extrapolation of the observed trend suggests that the intensification of peanut cultivation foreseen by responsible authorities may lead to increasing risks from the multiple pathosystem and that its new component, rust, would probably contribute significantly to this increase.

The present effort of several research institutes, including ICRISAT and IRHO, to develop rust-resistant peanut varieties is therefore fully justified. The use of fungicides in farmers' crops cannot be considered at present to be a realistic alternative for rust control. Cost/benefit reasoning does not necessarily apply to subsistence crops, and, also, logistic means to carry out the fungicide treatments are lacking. Future control strategies might, however, combine low levels of partial resistance with incomplete fungicide protection, e.g., by seed treatment.

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