THE ROLE OF FUNGI IN THE DETERIORATION OF TROPICAL STORED PRODUCTS

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INTRODUCTION: Fungi are known to cause various types of deterioration and pose hazards to the life of animals and man whenever they infect stored plant products. Fungal deterioration can be defined as any change resulting from the activities of fungi which renders a product unsuitable for its intended use or reduces the economic value of the material. It is also desirable to include those activities of microorganisms which may result in an increase of processing costs or which may affect amenity value (1). Research on stored food crops in most countries has concentrated more on insect than on fungal deterioration (2). This is partly because most stored product insects are visible to the naked eye and the damage they cause is usually conspicuous and quantitative. However, fungi, especially moulds, do cause various types of deterioration of crops and hazards to the life of animals and man whenever they infect stored food products. These have been extensively discussed in many reviews especially by: Christensen (3); Christensen and Kaufmann (4); Hiscocks (5) Raymond (6); and Eggins and Coursey (7). The various types of deterioration will be mentioned and discussed briefly here.

TYPES OF FUNGAL DETERIORATION OF STORED PRODUCTS:

1. Discolouration. Fungi, especially the microscopic species known as "moulds" cause discolouration of produce. Since they themselves are in different colours - green, yellow, black, brown, etc. - they impart these colours on the produce where they grow and thus change the appearance of such produce.

For instance, *Botryodiplodia theobromae* was responsible for the disease of discolouration of groundnuts widely known as "concealed damage" in Alabama while *Macrophomina phaseoli* caused "black nuts" in Gambian groundnuts (8, 9). Discoloured produce is disliked by manufacturers and consumers for a number of reasons. For instance, in the Hand-Picked-Selected (HPS) groundnuts in Nigeria, the more discoloured kernels present, the greater the task of picking them.

Before the 1950's the cause of discoloured grains was not precisely known. For example wheat in storage sometimes develops dark germs, and in the grain trade these were called "sick" wheat, a poor term, since such seeds are dead, not sick (3). Later, studies by Christensen (10) revealed that fungus mycelium were usually abundant on such discoloured embryos. Tuite was able to reproduce these symptoms by inoculating wheat grain with moulds, under conditions favourable to their development. Discoloured grains disfigure the prepared flour by appearing as unsightly specks inside it.

Christensen and Linko (11) obtained samples of wheat from commercial bins and stored these in the laboratory with the same moisture contents as the samples had when received. There was progressive increase in percentage brown or damaged germs as moisture content increased. Colonies of *Aspergillus* sp. per gram of grain also increased proportionally.

Although the micropyle is the common place for infection to begin, fungi, bacteria and actinomycetes can develop in any other region of the grain or fruit causing abnormal colouring, either localised or generalised.

2. Destruction of Viability. One reason why agricultural produce is stored is to use as seed for the next crop. Fungi kill the viability of seeds by infecting and destroying their embryo. There is a considerable body of evidence to indicate that invasion of seeds by storage fungi can drastically reduce the germinability of the seed.

Tuite and Christensen (12) stored samples of barley seeds of 19.4% moisture content at room temperature, some of the samples made free of storage fungi and others inoculated with storage fungi. After 15 days the sample inoculated with storage fungi germinated 72% whereas the sample free of storage fungi germinated 98%. They stated, "All of these species of the *A. glaucus* group as well as *A. candidus* and *Penicillium* sp. invade various parts of the seed, including the germ, and directly cause or contribute to reduction in germination."

Qasem and Christensen (13) adjusted corn free of fungi to different moisture contents, inoculated some samples with various storage fungi and left others uninoculated. They stored the samples at several temperatures and periodically tested them for germinability. The samples inoculated with *Aspergillus candidus* and stored at 18% moisture content and 25°C for 4-1/2 months germinated 9%, the controls germinated 94%.

Lopez and Christensen (14) stored corn at 19-20% moisture content and 20°-25°C, some samples free of fungi, others inoculated with different isolates of *A. flavus*. After 74 days, the samples free of fungi averaged 97% germination, and those inoculated with *A. flavus* averaged 13%.

Broadbent (15) found samples of mouldy maize from Government farms in Southern Nigeria having germination of 7-14% while the mould free samples had 100% germination (Table 1).

3. Abnormalities in Growth. Groundnut and maize seed contaminated with *A. flavus* produce deformed plants. The infected young groundnut plants have a greatly decreased growth. Leaves

are of a much clearer green than normal. The folioles develop poorly and are elongated in form. During growth, a large number of sick plants die. Others are continually abnormal in appearance, while some evolve into normal plants.

4. Effect on Flavour and Odour. Mouldiness spoils the flavour of stored produce and also that of the product manufactured from it. Mouldy raw or fried groundnuts have very unpleasant, sour taste when consumed and these are usually spit out from the mouth as soon as chewed.

Effect on flavour is the most objectionable character developed by mouldy cocoa beans and manufacturers claim that amounts as low as 4% mouldy beans can be detected by taste in a sample of chocolate which has passed through all the normal manufacturing processes (16).

Mouldy produce also has a bad odour ranging from the musty odour of mouldy grains to the foul smell of rotting grain or tubers.

5. Biochemical Changes. The development of moulds leads to great modification in the chemical composition of the infected produce. One of the most important effects is an increase in free fatty acid (F.F.A.). This acid is one of the intermediate products of spoilage in materials that contain fats or oils and the characteristic odours and flavours of these fatty acids are what make partially spoiled fats rancid. It has also long been known that deterioration of stored grains is accompanied by an increase in fatty acids. This is because many species of moulds produce lipases which could hydrolyse fats into fatty acids by the process called Lipolysis, thereby increasing the F.F.A. content of the produce. This makes the oil difficult to refine. Sometimes limits are set for amount of F.F.A. permissible in exportable oilseeds and products. In palm kernel trade it is 4.75%, and for every 1% above this amount there is a financial penalty of 0.75% per ton. Moulds also lead to a reduction in the amount of oil extractable from the oilseeds.

Many instances of deterioration of oilseeds were reviewed by Eggins & Coursey (7). These include the work of Barbosa (17) who showed that total losses of oil content and increases on FFA of stored groundnuts in Portugal were associated with the growth of fungi, in particular, *Aspergillus flavus*.

Ward and Diener (18) found that *Aspergillus glaucus* gp., *A. tamarii* and *Penicillium citrinum* cause lipolysis of groundnut oil and reduction in the oil content.

In Nigerian groundnut crop, high acidity of around 5% occurred before 1954 due to high proportion of broken kernels which were easily attacked by moulds. The introduction of shelling machine raised the proportion of whole kernels from 30% to 70% and this reduced the acidity to less than 1%. With a harvest of 700,000 tons, this represents a saving of about £1 million (6).

Coursey and Eggins (19) isolated a number of moulds from palm oil and showed that many of them increased the F.F.A. of palm oil in pure culture studies. Sheridan (20), Coursey and others (21) and Kuku (22) isolated a number of lipolytic fungi from Nigerian palm kernels.

Some work on the effect of moulds on the biochemical property of maize has also shown that the F.F.A. is always increased. Nagel and Semeniuk (23) inoculated corn with pure cultures of nine species of fungi, separately and together. The moulds increased the FFA content of the grains to varying extents from 74.8 units to 384 units.

Goodman and Christensen (24) grew cultures of four species of fungi isolated from mouldy corn - *Penicillium solitum, Aspergillus flavus, A. candidus*, and *A. amstelodami* - on cornmeal to which the oil originally extracted had again been added. All caused an initial increase in fatty acids in the meal containing oil. In these tests the fatty acids were produced as a result of fungus lipases acting upon the corn oil.

The development of moulds on produce causes other modifications; generally an increase in reducing sugars and a loss in protein, which may lead to flours unsuitable for breadmaking. Moreover, mouldy rice grain breaks easily during polishing. If we preserve damp grain in an anaerobic environment, fermentation, release of carbon dioxide, alcohol, and other volatile substances occurs. The compounds formed give a disagreeable taste, which remains even after drying in the open air.

6. Rotting and Caking. Direct spoilage such as rotting of yams and caking of maize is usually caused by extensive mould infection and damage of these products during storage. Studies by Okafor (25), Ogundana (26) and Adeniji (27) have shown that a number of fungi (*Aspergillus niger, Botryodiplodia theobromae, Fusarium moniliforme, Hendersonula toruloidea, Macrophomina phaseoli, Penicillium oxalicum* and *P. sclerotigenum*) caused rotting in Nigerian yams.

Studies carried out by several workers, among whom are Okafor (28, 29) Broadbent (15, 30), and Oyeniran (31, 32), showed that over 30 mould species can be associated with the deterioration of maize in Nigeria. Some of these cause the rotting and caking.

7. Absolute Weight Loss. Attack by moulds does cause an absolute weight loss in stored products. A dry matter loss of 12% was found in Fijian copra during a 14 days' storage due to attack by moulds (6). There is also a weight loss when grain is stored, an estimated possible world loss due to this cause was about 1% (32). The loss in the tropics must be much higher.

Nagel and Semeniuk (23) found that four of the nine moulds they tested induced marked organic matter losses in maize. The greatest loss (approximately 40%) was induced by *Aspergillus flavus, A. niger, Penicillium chrysogenum* in a 4-week period. Losses of 20.1%, 14.5%, 11.9%, 10.4%, and 6.4% in the same period were induced by *A. candidus, Penicillium pallitans, P. rugulosum, Mucor racemosus*, and *Aspergillus amstelodami*, respectively.

8. Heating. When large quantities of damp grain are preserved, we sometimes notice great increases in temperature within the mass; this phenomenon is known as heating. This phenomenone was reported by Okafor (29) who recorded a temperature of 68°C in a mouldy maize stack in Nigeria. Many other instances of heating of grains during storage were reviewed by Christensen and Kaufmann (4) and heating in bulk storage is an evidence of spoilage in progress or spoilage already completed.

9. Preparation of the material for attack by other agents. Mould damage in stored products prepares such materials for attack by other agents of deterioration, especially insects and mites. It is difficult in many foods to separate the deterioration due to insects from that caused by fungi, but that the two are interrelated is in no doubt. What is in that doubt sometimes is the exact sequence of events and the relative damage cuased by the two agents (6).

Christensen and Hodson (34) showed that both insects and fungi are associated in their deterioration of grains and each enhances the activity of the other. Sikorowski (35) reviewed the whole subject and pointed out that storage insects can live, develop, and reproduce entirely on certain fungi and they undoubtedly play an important part as carriers in the spread of fungi.

10. Production of Mycotoxins. Toxin production is the most serious effect of microbiological deterioration of stored products. A number of fungi are known to produce toxic metabolites into the stored products on which they grow, so that when these products are consumed, they cause diseases known as mycotoxicoses. This is a wide subject on which very much has been written (36, 37, 38, 39, 40, 41). Some notable examples of mycotoxicoses are:

(i) Ergotism, a disease of cattle in Central Europe caused by *Claviceps purpurea*

(ii) Facial ecaema of sheep in New Zealand caused by *Pithomyces chartarum*

(iii) Yellow rice disease of man in Japan caused by *Penicillium citrinum, P. islandicum*, and *P. citreoviride*

(iv) Alimentary toxic aleukia (ATA of man and cattle caused by *Fusarium sporotrichiodes, F. poae*, and *F. tricinctum*

(v) The complex known as mouldy corn toxicoses caused by *Penicillium rubrum, Chaetomium globosum, Aspergillus ochraceus*, and other moulds.

(vi) Lastly and most significantly, Aflatoxicosis of poultry and livestock caused by *Aspergillus flavus*.

This last mentioned toxin disease, Aflatoxicosis, has been receiving world-wide attention since 1960 when it was reported to have caused the death of about 100,000 turkeys in Britain (42).

These turkeys were fed with meals containing a particular batch of Brazilian groundnut cake which was infected with *Aspergillus flavus*. The toxic substance was therefore called AFLATOXIN. Our studies in Nigeria have revealed the presence of aflatoxin in Nigerian groundnuts and livestock feed maize, hence the need to take extremely good care of these products during storage (Table I).

Table I. Germination and seedling vigour of the mouldy maize

	Germination %	Seedling height (cm)		
		Minimum	Average	Maximum
Control maize	100	18.0	30.3	38.0
Seed maize				
Sample 1	13.5	5.0	16.6	33.3
Sample 2	7.5	9.0	18.9	32.5

FUNGAL DETERIORATION OF VARIOUS STORED PRODUCTS

1. Cocoa. Early studies on the deterioration of stored cocoa by moulds were carried out on Nigerian cocoa by Laycock (43) and Passmore (44). However, more detailed studies were carried out on Ghanaian cocoa by Bunting (45, 46) and Dade (47) and 12 fungi were isolated from cocoa.

In recent years, studies by Broadbent (48), Oyeniran (49, 50, 51, 52), Oyeniran and Adeniji (53) on Nigerian cocoa have confirmed earlier work and amplified the knowledge on this subject. A total of 32 fungi, the more important of which are indicated in Table II, have been isolated from stored cocoa beans. These were found to enter cocoa beans at different stages from preharvest to storage. For instance:

(i) Before harvest - *B. theobromae*, *Fusarium* spp., *Macrophoma* sp., and *Cylindrocarpon tonkinense*, enter the beans before harvest.

(ii) During fermentation- mostly the thermophilic *Aspergillus fumigatus*, *Mucor pusillus*, *P. varioti*.

(iii) During storage - As a result of insufficient drying, wetting, or moisture absorption, *P. citrinum*, *P. steckii*, *Aspergillus ruber*, *A. chevalieri*, *A. penicilloides*, and *A. candidus*.

The identification of the problems associated with cocoa at these four stages do help immensely to devise control measures which are largely applicable in all cocoa growing areas of the tropical world.

2. Groundnuts. Most of the groundnuts exported from Nigeria are grown in the drier northernly areas of the country, which some others are from areas of higher humidity and rainfall which border

Table II. Some toxic moulds and their toxins

Mould	Toxin
Ammanita phalloides	Phalloidin
Aspergillus chevalieri	Xanthocillin
A. flavus	Aflatoxin
A. fumigatus	Gliotoxin
A. nidulans	Sterigmatacystin
A. ochraceus	Ochratoxin
A. oryzae	Maltoryzine
Fusarium graminearum	Xearalenone
Penicillium citrinum	Citrinin
P. cyclopium	Cyclopiazonic acid
P. frequentans	Citromycetin
P. islandicum	Islanditoxin
P. notatum	Xanthocillin
P. rubrum	Rubratoxin
P. rugulosum	Citreoviridin
P. toxicarium	Citreoviridin
P. urticae	Patulin
Pithomyces chartarum	Sporidesmin

the Niger and Benue Rivers (54). Small quantities are also produced in the Southern parts of the country but these are entirely for local consumption. The problems of fungal contamination of groundnuts in the main growing areas of the North were extensively studied by McDonald and Harkness between 1961 and 1965 following the discovery of aflatoxin in groundnut feeds in U.K. in 1960 (42). Their studies revealed that *Aspergillus flavus* contamination of groundnuts was caused mainly by slow drying after the pods were mature. Further studies revealed the presence of other fungal species such as *Botryodiplodia theobromae*, *Macrophomina phaseoli*, and *Fusarium solani* in shells and kernels in certain conditions (54, 55, 56).

These authors made recommendations as to the time of lifting and windrowing the groundnut plants as well as when to pick the pods during drying. Badly discoloured,broken pods or kernels were to be destroyed.

The mould deterioration of groundnuts during storage and marketing were studied by Broadbent and others. They found that out of 74 market samples of groundnut examined, only 8 were mould free. Most others had less than 2% internally mouldy kernels though some had over 10%. Average internal mouldiness was 2.1%. The degree of internal mouldiness was related to level of moisture content of the samples. Two important factors were thought to influence these moisture contents; there was moisture absorption during storage and marketing. This was more pronounced during the wet season months. Initial under-drying of many samples mainly of local harvest was also found to be responsible. Seventeen mould species were identified, mostly Aspergillii and Penicillia, the most important of which are *Macrophomina phaseoli*, *Aspergillus ruber*, *Aspergillus chevalieri*, *Aspergillus penicilloides*, *Aspergillus amstelodami*, *B. thobromae*, and *A. flavus*. The preponderance of *A. glaucus* group and *A. penicilloides* confirmed the suggestion that the nuts absorbed moisture during storage (57). Halliday (58) had earlier observed such uptake of moisture by bagged groundnuts in Southern Nigeria. Most of the moulds isolated from groundnuts are known to be toxigenic or lipolytic. Sheridan (20) had previously isolated 10 moulds, all Aspergilii from groundnuts in Nigeria and found 9 of them to be lipolytic.

3. Palm produce. (a) Palm oil. Palm oil is normally traded in world markets on a contract basis of 5% free fatty acid, consignments with higher or lower values being debited or credited respectively at a certain rate per ton per percentage of F.F.A. content. While free fatty acids may arise from purely chemical processes, Coursey and others (19, 21, 59) have shown that lipolytic moulds are the main cause of F.F.A. production in Nigerian palm oil. Mould deterioration of palm oil by lipolysis probably occurs between the time the palm fruits are harvested and the oil is expressed and also during storage of the oil obtained. Deterioration occurs at the former stage because the harvested palm fruits are usually stored for several days or even a week or two before oil expression. The purpose of this storage period is to allow the fruits to become less firmly attached to the bunches, so that they can be more easily removed for oil expression. The bunches are often split into sections and sometimes sprinkled with water-both practices which apparently help to loosen the fruits (60, 61) and are normally left in heaps, often under palm fronds.

Not surprisingly, these conditions also greatly favour the growth of moulds. For instance, Broadbent and Kuku (62) found that six batches of palm fruit examined at this stage all showed some visible mouldiness, in one case only four days after harvest. Wilbaux (63) and Simmons (65) found that palm oil from mouldy fruits had a much higher F.F.A. content than that from mould-free fruits. Coursey and Eggins (19) isolated nine different moulds all with lipolytic ability from palm fruits.

Mould deterioration of palm oil during storage had also been studied by Coursey and others (19, 21, 59). All these studies confirmed that increases in F.F.A. content of palm oil was largely attributable to the lipolytic activity of the infecting moulds.

(b) Palm kernels. Sheridan (20), Coursey and others (21) reported on the moulds infecting palm kernels during storage in

Nigeria, and 13 species were identified, eleven of which had lipolytic effect on the palm kernel oil. Later, Eggins and Coursey (59) also recorded three thermophilic moulds - *Chaetomium thermophile*, *Penicillium emersoni*, and *Thermomyces ibadanensis* from a stack of palm kernels which was heated up to 60°C. These authors also confirmed by analysis that higher F.F.A. content was always obtained from palm kernels which were internally mouldy. Riley and Simmons (65) showed that the F.F.A. content of Nigerian palm kernels awaiting shipment for export was shown to be related to their mould content. Detection of such a correlation despite the masking effects of other factors suggests that moulds may play a dominant role in the production of F.F.A. in Nigerian palm kernels.

More recently Kuku (22) with Adeniji (66) and with Broadbent (62) have studied into detail, the various stages at which mouldiness of palm kernels occurs and the factors encouraging such mouldiness. Such factors include overriping of the palm fruits before harvest, non-heating process of extraction of palm oil from palm fruits, abandoning palm kernels in heaps at very high moisture contents and of course moisture absorption by the shelled kernels during storage. Thirty-seven mould species have been isolated from palm kernels in Nigeria and some of these are indicated in Table III.

4. Maize. Maize is probably the Nigerian cereal which is potentially most liable to post harvest mould deterioration, for not only is it grown mainly in the more humid areas of the country but the first crop, which provides about 80% of total production is harvested during the rainy season. In some areas, harvesting may coincide with a short break in the rains, but even so weather conditions greatly retard both pre- and post-harvest drying of the maize.

Mould deterioration of maize can be considered in relation to the method of storage. Storage of the maize on the cob especially in open-sided cribs allows the maize to dry gradually but effectively enough to keep mould infection at check. However, demand by livestock industry in recent years has forced producers of maize into shelling them soon after harvest at moisture contents of 22-25% (67) and selling them to traders or livestock farms who store them as such. Mould deterioration of such batches of maize had been observed on several occasions. Okafor (28, 29) reported on the microorganisms causing deterioration of a stack of maize which was extensively damaged and heated up by the activities of these organisms. He recorded such mesophilic organisms as *Fusarium moniliforme*, *Aspergillus flavus*, and *Rhizopus arrhizus*, and thermophilic fungi - *Thermomyces lanuginosus*, *Mucor pusillus*, and a *Rhizomucor* sp.

Broadbent (15, 30) and Oyeniran (31, 32) did extensive work on post harvest deterioration of maize in Nigeria. They have found that up to 30 mould species are responsible for this and they

Table III. Some fungal species and the stored products from which they were isolated in Nigeria

Fungal species	Stored products from which they were isolated				
	Cocoa	Ground-nuts	Palm kernels	Maize	Yams
Absidia corymbifera	+			+	
Aspergillus amstelodami		+	+		
Aspergillus candidus	+			+	
Aspergillus chevalieri	+	+	+	+	
Aspergillus flavus	+	+	+	+	
Aspergillus fumigatus	+	+	+	+	
Aspergillus melleus		+		+	
Aspergillus niger	+	+	+	+	+
Aspergillus penicilloides	+	+			
Aspergillus restrictus	+		+		
Aspergillus ruber	+	+	+		
Aspergillus tamarii	+	+	+	+	+
Aspergillus terreus		+	+	+	
Aspergillus versicolor	+	+		+	
Botryodiplodia theobromae	+	+		+	+
Fusarium moniliforme		+		+	+
Fusarium semitectum		+			
Fusarium solani	+				+
Hendersoluna toruloidea					+
Macrophomina phaseoli		+			+
Mucor pusillus	+			+	
Paecilomyces varioti	+		+	+	
Penicillium citrinum	+	+	+	+	
Penicillium decumbens	+			+	
Penicillium frequentans			+		+
Penicillium oxalicum					+
Penicillium steckii	+		+	+	
Penicillium variabile	+	+		+	
Rhizopus arrhizus	+			+	
Syncephala strum racemosum	+		+	+	

infect improperly dried grains as well as grains stored in conditions where they can absorb moisture. The most important species are shown in Table III. Aflatoxin contamination is also a problem in maize because *Aspergillus flavus* is the most prominent species infecting the grains during storage.

5. Yams: Yams are stored in Nigeria in two basically different ways-as the fresh tuber or as processed, dried yam. Considerable losses often occur during tuber storage.

Coursey (68, 69, 70) suggested that losses of 10-20% after 3 months storage and of 50% or more after 6 months may be usual in Nigeria. One of the main causes of these losses is microbiological rotting of these yams during storage. The incidence of rotting in stored tubers has been studied by several workers (25, 27, 68, 71, 72) and seems to vary considerably with locality, storage method and time, yam species and even individual tubers. Coursey (68) for example, found that sometimes less than 5% of tubers showed rotting after storage for 4-5 months, while in others it was up to 50-70%. As already noted, rotting usually leads to considerable weight losses; Adesuyi (72) for instance recorded a weight loss of about 30% after 14 weeks' storage.

While both moulds and bacteria have been implicated in the deterioration of stored yams (25), only the former have been isolated from deteriorating yams. Twenty-four of these were tested for their ability to induce rotting under experimental conditions (25,27) but only eight had this ability. It is interesting, although not unexpected, that all the moulds so far isolated are hydro- or mesophilic. Members of the *Aspergillus glaucus* group, for example, are absent.

Ogundana and others (73) have begun to identify the anatomical and biochemical changes which accompany rotting. They have found that infection by four moulds previously isolated from rotting yams (*B. theobromae, P. sclerotigenum, A. niger, and F. moniliforme*) in each case caused clearing of the starch grains within cells and a disintegration of the cell walls. Their biochemical studies showed that the moulds decreased the carbohydrate content (starch especially) of yam discs and produced extracellular pectic and cellulolytic enzymes in culture.

6. Dried yams: Mould deterioration of dried yam has not been seriously investigated. However, some preliminary investigation was done by Broadbent (74) on his observation of sacks of yam slices heavily infected by moulds. Mouldiness was most evident on the broad cut surfaces of the slices and was enough to give these areas a blue-green appearance instead of the normal whitish colour. Microscopic examination showed that mouldiness was mainly due to members of the *Aspergillus glaucus* group, mainly *A. repens, A. chevalieri,* and *A. ruber*. Other species occasionally isolated included *A. flavus, A. tamarii, A. niger, A. clavatus, A. melleus, Penicillium citrinum,* and *Rhizopus arrhizus*. It is probable that the slices were prepared during the wet season and that drying was sufficiently slow and incomplete to allow the growth of both mesophilic and xerophilic moulds. This conclusion is supported by the results of a moisture content survey of market yam slices in Ibadan (75) where high moisture contents were obtained when new

yam slices arrived in the markets. Increases of 2-3% were also recorded in the moisture content of the old yam slices during the wet months as a result of moisture up-take by the yam slices. Mould deterioration of yam slices especially by xerophilic species may be more serious than has hitherto been thought.

7. Processed cassava (gari): Gari prepared from Cassava roots is a very common staple foodstuff in Nigeria. It is one of the foodstuffs which have microbiological problems only during the storage. The process of preparation involves frying the stuff at high temperatures which would have killed all the previous micro-organisms. After preparation however other fungal spores infect the gari and most of them cause the spoilage in the form of discolouration, caking, and off-flavour. Halliday and others (76), Adeniji (77), Opadokun (78), and Oyeniran (79) have shown that gari is susceptible to mould contamination during storage and each author has isolated and identified a number of mould species from samples of gari under various storage and marketing conditions. Some of these are shown in Table III. Adeniji (77) experimentally confirmed that majority of the moulds earlier isolated from gari could individually cause the deterioration of the foodstuff. However, Opadokun (78) did not detect aflatoxin from any of the samples he examined, even though *Aspergillus flavus*, the aflatoxin mould, was one of the fungi isolated.

The most important factor encouraging mould contamination of gari is the high initial moisture content or increase in moisture content during storage. Halliday and others (76) and Oyeniran (79) found that the gari on sale in the markets at certain times of the year had moisture contents much higher than the safe level of 12.7-13.6%. They also found that the mould deterioration of gari of high moisture content is much higher when stored in air-tight condition such as sealed polythene bag than in hessian, while gari of very low moisture contents can keep safe in sealed polythene. The setup of free fatty acid in the oil used in the yellow gari was also suspected to occur.

CAUSES OF FUNGAL DETERIORATION OF STORED PRODUCTS:

1. Important Role of Moisture. The primary cause of fungal deterioration of stored products is moisture, which as we all know is an essential pre-requisite for microbiological activity. Moisture in stored produce is divisible into two main types: the chemically bound water which is part of the intrinsic composition of the commodity itself and physically bound water, some of which is loosely held onto the commodity. Moisture content of stored produce therefore refers to the physically bound water (80).

However, it is not the moisture content as such that is the controlling factor in biological deterioration; it is the Relative Humidity (R.H.) of the air within and around the commodity. This is the ratio in percentage of the weight of water contained in a sample of air at a given temperature to the weight of water which would be contained in that sample if it were saturated at the same temperature.

Biological activity occurs only in the presence of moisture and limits of R.H. can be specified within which biological agencies causing deterioration can develop.

Germination occurs at	95% R.H. or over
Bacteria grow at	90% R.H. or over
Fungi grow at	70% R.H. or over
Mites infest at	60% R.H. or over
Insects infest at	30-95% R.H.

Even though R.H. is the controlling factor, attention is usually focussed on the moisture content because R.H. of produce is difficult to measure while moisture content is not. Both are related and from a measurement of the moisture content of a commodity, the equilibrium R.H. can be deduced.

It is known that microbiological activity is reduced to a minimum at R.H. 70% or less. Seventy percent R.H. has therefore been regarded as a "safe" limit and commodities with moisture contents in equilibrium with R.H. 70% are relatively safe from microbiological deterioration.. Such moisture contents for a few commodities are shown in Table IV.

Table IV. Moisture content equilibrium (at 27°C) values of produce at relative humidity 70%

Commodity	Moisture content percent
Maize	13.5
Wheat	13.5
Sorghum	16.0
Millet	16.0
Paddy	14.0
Cowpeas	13.5
Beans	15.0
Groundnuts (shelled)	7.0
Cottonseed	10.0
Cocoa beans	7.0
Copra	5.8
Palm kernels	5.7
Gari (white)	12.7
Gari (yellow)	13.6

From: Hall (81) and other sources.

Moisture plays its role in causing microbiological deterioration in some specific ways.

(i) Condensation and moisture migration - In bulk grain storage bins, condensation occurs on the inner side of the top during cool weather especially at night following hot weather during the day. Warm air will move from the warm centre of the bulk and when it gets to the cool grain near the surface or at the side, condensation will occur and some water will be formed which will lead to mould attack setting in. The moisture will continue to move 'gradually' into the bulk of grain causing further damage.

(ii) Leakage - Wherever there is a leakage in the storage structure it is possible for water to drip into the commodity stored and thereby cause deterioration.

(iii) Hot spots - This is an interesting phenomenon in bulk grains. It is usually started by a concentration of insect activity which causes heating, sometimes to considerable temperatures. When the hot air from such a pocket moves to cooler grains, condensation occurs and moulds and bacteria develop round the pocket of grains. The microorganisms increase the temperature of the pocket and when the area becomes too hot for the insects, they move out, causing further damage.

(iv) Moisture absorption - Most stored products are hygroscopic, that is, they will exchange moisture with the atmosphere of storage until an equilibrium is reached. This means that when stored in an atmosphere of high relative humidity, literally, 'damp atmosphere,' dry produce will gain moisture. Therefore the relative humidity of storage is essential. An occasional check is necessary on the moisture content of produce stored in atmospheres with fluctuating relative humidities. It is also possible for produce stored in bags to absorb moisture through the floor if placed directly on the floor of the store.

(v) Mechanical or other damage - When produce is mechanically damaged or wounded by other agents such as insects or rodents, they become more liable to mould attack which automatically begins on the wounded or damaged surface or spot. This is because such exposed surfaces are damper and act more or less like a culture medium for moulds to grow. It is a common feature of all stored produce - grains, tubers, cocoa beans, groundnuts, etc. This is the reason why some storage moulds are found on grains at harvest, in addition to a few field fungi which naturally attack them at that stage.

2. Other causes: Other causes that are not directly linked with moisture content can briefly be mentioned.

(i) Preharvest infection - Produce destined for storage is sometimes infected by moulds before harvest. Most of the species of fungus involved at this stage are field fungi while a few storage fungi also come in especially following natural or artificial wounds. Some examples are attack of cocoa beans by *Botryodiplodia theobromae* and other moulds, attack of groundnuts by *Macrophomina* *phaseoli*, and attack of maize by *Fusarium moniliforme* and *Penicillium citrinum*.

(ii) Attack during preparation: Moulds attack some produce during the process of preparation of such produce for the market, as a result of some lapses in cultural practices. For example, during cocoa fermentation, moulds infect and penetrate the beans if the fermenting mass of beans is not stirred or mixed thoroughly at intervals during the process. In palm produce, moulds attack the fruits and sometimes the kernels when they are heaped on the ground just before dehusking. In groudnuts the crop has to be lifted at certain times to avoid mould contamination.

CONTROL OF FUNGAL DETERIORATION IN STORED PRODUCTS:

I shall just run through some of the ideas that have been suggested on control of fungal deterioration of stored products beiefly. For this purpose a distinction can be made between produce that is stored dry - such as grains, pulses, cocoa, groundnuts, palm kernels, etc., and those which are stored with high water content, such as yams. However, some of the measures suggested will certainly apply to both types.

(A) Dry produce: For produce that can be stored dry, the important thing is to get the produce dry (that is to safe moisture content), as soon as possible after harvest and keep it dry during storage. This can be achieved by:

1. Either retaining maize, millet, guineacorn, etc., on the cob or head and store in a condition where gradual drying by heat or aeration takes place such as the ventilated crib. Otherwise provide artificial drying if storage as shelled grains is desired. The rachis tends to afford some protection to the grain when unshelled.

2. Cool artificially - or sun-dry produce before bulk storage to avoid moisture formation and migration. For the same reason sufficient shades should be provided for metal silos to prevent fluctuations in temperature inside the grain bulk.

3. If possible, store dried produce in airtight conditions to keep away from fluctuating atmospheric relative humidity which could lead to increase in moisture content, e.g. store in polythene bags, or polythene-lined sacks, airtight warehouses.

4. Prevent pockets of heavy insect activity which could lead to localised moisture increases and mould growth in bulk of grain by proper application of insect-control measures.

5. Avoid mechanical and other types of damage on produce before storage.

6. Keep away produce from wetting and moisture absorption. Store produce away from walls and use dunnage for bagged produce stacked in stores to keep them off the floors.

Other methods of controlling deterioration of dry produce are:

1. Preharvest infection - Sort out and discard produce which bear evidence of pre-harvest mould infection. They serve as rich

sources of fungal inoculum for otherwise healthy produce when stored together in the same structure.

2. Use of fungicides - In the case of stored grains not destined for consumption some fungicides such as captan, benomyl, thiabendazole, borax, etc., have been used to control fungal attack. Their use has been limited because of the toxicity.

3. Addition of chemical preservative agents - The addition of antiseptics to foodstuffs allows for better preservation under certain conditions. The utilisation of these products is subject to regulations in most countries.

Examples of such chemical preservatives are: Propionic acid, sorbic acid, glycerol, sulfur dioxide, and benzoic acid. Their use in many instances has also been limited to livestock feeds.

4. Other methods of control - Other methods by which fungal development in stored products can be controlled are refrigeration, irradiation, and storage under inert atmosphere. These methods are not widespread because of the cost and high technical expertise required to use them.

(B) Storage of tubers: Storage of tubers poses problems different from those of grain or other dry produce, because it is important to maintain a high water content. Storage of yams must be with good ventilation and high and low temperature extremes must be avoided.

It is important to handle healthy tubers carefully to avoid bruising. Application of wood ash or whitewash to bruises was reported to decrease rot, and Coursey (65) observed the beneficial effect of powdered lime milk and copper oxinate on the incidence of weight losses recorded during storage.

Ogundana and others (73) found benomyl and thiabendazole effective in reducing the activities of fungi in causing yam rot during storage, but these chemicals are rather toxic. Research is currently in progress at the Nigerian Stored Products Research Institute on the use of safer fungistatic chemicals to preserve yams against microbiological rot during storage. Adesuyi (72) successfully stored yams for up to six months by use of curing method, cutting of sprouts from healthy undamaged tubers, use of low temperatures and irradiation techniques.

CONCLUSION: I have in the foregoing paragraphs highlighted the role of fungi in the deterioration of stored products as well as made brief mention of the knowledge of the problem as derived from studies by various workers. It is pertinent to say here that the knowledge is far from complete and experts should still endeavour to find complete solutions to the various aspects of the problem, as the struggle of man against the menace of microorganisms continues.

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