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G. Semeniuk
Iowa Agricultural Experiment Station

J. C. Gilman
Iowa Agricultural Experiment Station

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RELATION OF MOLDS TO THE DETERIORATION OF CORN IN STORAGE, A REVIEW[1]

G. SEMENIUK AND J. C. GILMAN

INTRODUCTION

The pre-war developments in the growing, harvesting, and marketing of corn in the United States necessitated a carry-over of large corn surpluses from one year to the next as a means of price and supply stabilization. Iowa, alone, had a carry-over of corn greater than all the other corn producing states together. Much of this corn was government owned and stored in large quantities in shelled form for indefinite periods in elevators and specially constructed steel bins. The unprecedented nature of this venture and the likelihood of its return prompted an evaluation of the problems in corn deterioration. The present review attempts to assemble the published information on corn in storage, with special reference to the role that microorganisms, particularly the fungi, may assume in its deterioration.

As might be expected, the bulk of the literature on this topic is of American origin. Nowhere in the world is corn production and its storage on so large a scale as in the corn belt of the United States. One-half of the world production arises in this area of fertile soil and unusually warm, humid climate (Conrad, 1942.) Although Argentina holds second place in world production, the corn produced is of the flint type and, because of the dry fall climate, dries down to moisture limits safe for storage and for shipment. In South Africa, and the Soviet Ukraine, similar climatic conditions prevail, thus reducing the storage problem, although some dent corn is produced in these areas. European corn, outside of that raised in the Ukraine, for the most part is grown on small holdings by peasant farmers who carefully tend to the drying of the harvested crop by exposure to the sun in dry places. In the Netherlands Indies, where the climate is exceedingly humid, corn is rapidly exported or consumed. Hence the problem of spoilage in stored corn is of primary concern only in the United States where the softer dent types predominate and where the climate is sufficiently humid to affect preservation.

This review then will outline the changes in corn that constitute spoilage and the factors involved in causing them.

DETERIORATION IN STORED CORN

Among the first evidences of deterioration, heating of the corn in the bin or other storage space is of primary importance. Duvel (1909), who was among the first investigators to report on this condition, observed a temperature of 133°F. eight inches below the surface of

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an elevator bin after two months of winter storage. Subsequent investigators (Duvel and Duval, 1911, 1913; Shanahan, Leighty and Boerner, 1910; Boerner, 1919; Ward, 1930; and others) noted similar temperatures in their investigations of the problem. Their observations with the exception of Ward (1930) were made on shelled corn stored in various situations; in elevators, in box-cars and ship holds during transport and in storage hoppers. The latter made his observation on ear-corn stored in a tight silo but here also heating was the primary indication of deterioration.

Accompanying heating, Duvel and Duval (1911) found a loss in total weight, a decrease in bushel weight from 54.7 to 50 lbs., a decrease of moisture content from 18.8 per cent to 14.7 per cent, a decrease in sound corn from 97.1 to 1.1 per cent, and a loss in germinability from 89.6 to 1 per cent.

Contributing factors to heat production were a high initial moisture content of the corn when placed in storage and the air temperature during the storage period. Duvel (1909) observed heating in corn stored with 17.8 per cent moisture in an elevator bin, and with 18.8 per cent moisture in a hopper (Duvel and Duval 1911.) Later, Duvel and Duval (1913) observed heating in carload lots of corn with initial moisture contents of 21.6, 19.8 and 18.2 per cent. Lots with lower initial moisture contents did not heat. Observations on the condition of export corn reaching European ports during 1906 to 1909 (Shanahan, Leighty and Boerner, 1910) were in general agreement with these just cited. Greater damage occurred in corn of 16.1 to 20.6 per cent moisture than in corn of lower moisture content. Some damage also occurred in corn of 14.1 to 16.0 per cent moisture, and one cargo out of eleven with 12.0 to 14.0 per cent moisture also was spoiled.

More intensive investigation of the conditions under which deterioration occurred was undertaken by Boerner (1919) on further shipments of corn to European ports in 1910, 1911, and 1912. High initial moisture content again was primary, but the position of the corn in the hold; whether it was subject to condensation moisture under decks, or heating by engines or boilers, the condition of the corn itself as to germinability and acidity at time of stowage were all found to be contributory. The last two factors, low germinability and high acidity, were considered to be signs of incipient spoilage. Corn stowed away from artificial sources of heat reached a temperature of 148°F. but when adjacent to the boilerroom its temperature rose to 155°F. This latter effect of the external temperature upon the degree of heating confirmed the earlier observations of Duvel and Duval (1913) that corn of 22.0 per cent moisture shipped in December, when only five days showed a maximum temperature above 40°F. and none greater than 50°F., did not heat, although later shipments in March, April and May with lower moisture contents showed considerable damage. Bailey (1917b) also confirmed this tendency when he observed earlier heating in corn placed in an inside bin as compared to an outside bin.

Other changes in addition to temperature rise have been observed

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in bins of spoiled corn. Bailey pointed out that heated corn was discolored at 37.8°C. and became "mahogany" or dark brown at higher temperatures. Many observers have noted the moldy appearances of the mass of corn in the bin and its musty odor. In some instances the corn became matted by growth of the mycelium, in others the mold appeared only as a blue-green discoloration of the germ, the condition called "blue-eye" (Koehler, 1938; Marchionatto, 1942) in the trade.

Accompanying these external characteristics certain internal changes have been observed, although they are still not entirely understood. Alsberg and Black (1910) early observed spoilage to be accompanied by an increased titrable acidity of alcoholic extracts of such kernels. The source of this acidity was later found to be the fatty constituents of the germ (Besley and Baston, 1914; Winton, Burnet and Bornmann, 1915). That such changes are not always caused by spoilage but take place in apparently sound corn has been observed by several workers, particularly in corn-meal. Winton, Burnet and Bornmann (1915) observed titrable acidity of corn-meal to double after 24 weeks storage at moistures of 15.04 to 11.41 per cent. McHargue (1920) observed similar increases, and Weiser (1920), after comparing corn germ materials that had been heated to 70-80°C. with similar unheated materials, concluded that the increased fatty acid content was the result of enzymatic activity. The heated corn showed no increase in four to seven months, but the unheated material exhibited higher acidity at the end of a single month. Willets and Kokoski (1935) correlated the acidity changes with temperature, and after analysis considered that the higher acidity was an oxidative change, despite the fact that the high acid samples showed a lower aldehyde value. Recently, Zeleny and Coleman (1939) pointed out that three acidic substances were concerned in this titration; namely, dicarboxylic amino acids, inorganic acid phosphates and free fatty acids.

Comparison of oil constituents of shelled corn of approximately 20 per cent moisture at different periods after contamination by spores of Penicillium were made by Rabak (1920). After 55 days, when the color of the kernels had become a dirty gray, the oil was found to be very dark brown in color with much solid material separating out on standing. The color was disagreeably strong, sour and musty, the taste strongly bitter. Chemical analysis revealed decided increases in specific gravity, refractive index, free acids, soluble acids, hydroxylated acid and unsaponifiable constituents, with decreases in volatile acids, insoluble acids, and unsaturated acids. In addition, the amino acid and the reducing sugar content of the other parts of the kernel increased. McHargue (1920) also noted the darkened color and musty odor of the oil from spoiled grain and found the titration of such oil required 1450 N/1 alkali per kilogram for neutralization.

The chemical changes just noted are now being used as indicators of incipient spoilage, since early determination would allow proper care to prevent further deterioration in storage or shipment. Black and Alsberg (1910) suggested the use of titrable acidity of alcoholic extracts of corn in question, rather than tests that were dependent on substances elaborated by molds, which had been suggested by other workers. Such tests were the $FeCl_3$ test for phenolic compounds and the Ori test for substances that decompose H_2O_2. Standardization of the acidity tests was suggested by Besley and Baston (1914) and improved by Zeleny and Coleman (1939). These last found that fat acidity values were more reliable indices of soundness in corn than was the percentage of damaged kernels. From their data they developed a "soundness score" which took into account: damaged kernels, germination, fat acidity, amino acid acidity and phosphate acidity. They considered reducing sugar values to hold some possibility as an indicator in spite of the fact that such sugars were in some cases consumed by micro-organisms, a fact that would interfere with their reliability.

CONDITIONS FOR DETERIORATION

From the foregoing discussion the primary condition of the environment in places where corn was deteriorating was one of moisture. From the time of the early observations of Duvel (1909) who found heating in corn of 17.8 per cent moisture content, through to those of the present, moisture content of the spoiling corn has been cited, and attempts have been made to assign a maximum point for safe storage. The many recommendations are far from uniform. From South Africa, Burtt-Davy (1910) set 12 per cent as the highest limit for shipment while Saunders (1930) set it at 12.5 per cent. In the United States, Wallace and Bressman (1937) considered 17.5 per cent moisture safe for shipment on the continent, and 15 per cent for storage. Kelly (1933) differentiated between summer and winter storage, setting the safety limits at 14 and 16 per cent respectively. From 12 to 14 per cent was the figure suggested by Rainey and Fogle (1926). Bailey (1921) and Barre and Cotton (1942) considered 13 per cent as the upper limit, a half per cent lower than that set by the Commodity Credit Corporation and many state agricultural experiment stations. Davies (1928) considered 12 per cent as the upper limit. In South Africa, 14 per cent moisture is considered safe for storage in air-tight drums (Kerle, 1934; McKeon, 1933; Wenholz, 1927) although Sellschopp (1935) placed this value at 12.5 per cent. In Rumania, Slusanschi (1939) considered 13 per cent moisture safe for storage.

This disagreement among observers as to the moisture limits within which corn may be stored is in part explainable on the basis of the hygroscopicity of shelled corn. Biggar (1918) early noted that the total water uptake was greatest for Blue Flower corn, less for Reid's Yellow Dent and least for U. S. selection No. 93, a flint corn. Bailey (1921) exposed samples of three varieties, Boone County White Dent, Johnson County White Dent and sweet corn to various atmospheric humidities over sulphuric acid solutions at 25°C. until constant weight was attained. He found that the sweet corn showed lower hygroscopicity than the Boone County White, while Johnson County White

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showed the greatest. The average hygroscopic moisture was 8.25 per cent at 4.8 per cent relative humidity; 10.61 per cent at 54.1 per cent r. h.; 13.64 per cent at 71.3 per cent r. h.; 15.04 per cent at 78.7 per cent r. h.; and 17.57 per cent at 85.4 per cent r. h. Similar determinations by Coleman and Fellows (1925), using relative humidities from 15 to 100 per cent, established a curvilinear relationship. Close agreement to this relationship, but for narrower humidity ranges, has been obtained by Alberts (1926), Ward (1930), and Koehler (1938).

The factors influencing hygroscopicity have been investigated as well. The maturity of the kernels, the condition of the endosperm, whether starchy or horny, the oil and protein content, the effect of previous drying and mutilation of the pericarp have all been the subject of investigation. Temperature relations were also observed.

In relation to maturity, Dungan (1924) found that the order of hygroscopicity was correlated with decrease in proportion of soft starch, being greatest in the milk stage, less in the dent stage and least when the kernels were fully mature. With water absorption for beginning germination, Sprague (1936) noted higher moisture percentages in immature (sugary) corn than in mature (starchy) corn when either the entire kernel or the endosperm alone was considered. For germination, the water content necessary was 35 per cent for the endosperm and 60 per cent for the embryo.

In the case of the endosperm condition, Alberts (1927) observed that floury corn absorbed more water from humid air and lost more to dry air than did horny corn. Greater hygroscopicity was observed by Koehler (1938) in strains of Reids Yellow Dent than in hybrids of distinctly horny type.

In relation to the oil and protein content, Koehler (1938) found that strains of Illinois corn with low protein and low oil content showed greater uptake of water over 10 per cent calcium chloride solutions than did similar strains with low protein and high oil content. It might well be noted in this connection that Dungan (1924), studying water absorption in corn immersed for 24 hours, found greater absorption in strains of high oil and low protein content over that in strains of low oil and high protein. He concluded that the oil content was of little significance but that low protein allowed more rapid absorption than was obtained with high protein containing strains.

In regard to the effect of previous drying on hygroscopicity, opinions differ. Ward (1930) found greater hygroscopicity in cobs, less in shelled corn and least in ear corn before drying, and a reverse relationship after drying at 95°C. Koehler (1938) denies any difference between previously dried and non-dried corn.

Mutilation of the pericarp, cracks and knife-cuts, resulted in increased rate of water exchange (Alberts, 1927) although the ultimate moisture content remained unaffected (Koehler, 1938). Killing the germ by low temperature had no effect on hygroscopicity.

The temperature relations of hygroscopicity were investigated by Alberts (1926) who found that with yellow dent corn at temperatures of 0, 10, 20, and 30°C., the hygroscopicity was dependent on temperatures only at the extremes, 100 and 9.7 per cent. At intermediate relative humidities, 20 to 90 per cent, temperature showed no effect. Again as in the case of oil and protein content, water absorption behaved differently in that a direct relationship to temperature was observed by Dungan (1924) between the water absorbed by corn immersed for 24 hours, and the temperature between 5° and 30°C.

Molds growing over the surface of the kernels were observed by many investigators but data on their influence on hygroscopicity were collected only by Koehler (1938). He reported that such growth increased the water absorption 1.7 per cent. His observations were made on corn held in atmospheres of 100 per cent relative humidity in the presence and absence of formaldehyde.

RESPIRATORY ACTIVITIES IN CORN OF DIFFERENT MOISTURE CONTENT

The foregoing changes during spoilage and the relationships of moisture and temperature to their occurrences indicate that without question they were the result of biological activity of the corn and the accompanying microflora. From the respiratory equation for the complete oxidation of carbohydrates, $C_6H_{12}O_6 + 6O_2 = 6CO_2 + 6H_2O + 673$ kg. cal., use of one or all units of the equation under controlled conditions affords a convenient measure of the intensity of this activity. Bailey (1921) measured the respiratory activities of shelled corn of different moisture contents. He observed greater respiratory rates with greater moisture content in the corn, such that the acceleration rate approached a sigmoid curve. Previously heated corn adjusted to different moisture contents respired at a rate equivalent to normal corn with 1.5 to 2.0 per cent more moisture. At 14.8 per cent moisture, such heated corn respired twice as much as normal corn. At 14 per cent moisture, respiration of 6 months old corn was nearly twice that of freshly harvested corn. Foreign materials and cracked corn increased corn respiration rates slightly.

Comparison of the respiratory rates of corn with those of other grains, as obtained by other workers (Coleman, Rothgeb and Fellows, 1928; Bailey, 1940), revealed corn to be near the top of the list in its rate of respiration. A straight line relationship was obtained between log CO_2 produced and per cent moisture content of the grain when a correction factor was applied to the evolved CO_2. This correction factor was different for the different grains (Bailey, 1940).

Heat accumulation in corn of different moisture content was noted by James, Rettger and Thom (1928) to begin in cornmeal of between 15 to 18 per cent moisture and in cracked corn at 16 per cent moisture. Zeleny (1940) noted the heating tendency of corn to be a function of the moisture content and the fat acidity. With other grains, Ramstad and Geddes (1942) observed soybeans to heat at 15.6 per cent moisture but not at 14.7 per cent. Bakke and Noecker (1933) observed heating of oats at 16.78 per cent moisture but not at 15.00 per cent or lower. Larmour, Clayton and Wrenshall (1935) noted heating in wheat of

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between 16.1 and 18.1 per cent moisture. Under natural conditions, Bailey (1917, a, b) observed no heating of wheat of 14.5 per cent moisture or lower.

These observations measured the total respiratory rate and heat production of the sample and did not separate the respiratory rates of the various biological members of that sample. The microflora, including the fungi, bacteria and actinomycetes, of the corn undoubtedly are responsible for some of the CO_2 evolved and would account for some of the discrepancies recorded in Bailey's data, such as higher respiratory rates of 14 per cent moisture corn after 6 months of storage, cracked corn, heated corn, and of corn containing chaffy materials. While the experiments of Larmour, Clayton and Wrenshall (1935) appear to answer this objection to Bailey's respiration measurements (Bailey, 1921), this objection is by no means answered at the higher moisture levels since under the protection of CCl_4 the former workers obtained nearly equal wheat respiration rates at 18 and at 12 per cent moisture.

Heat production under pure culture conditions has been found to be the property of many fungi, bacteria and actinomycetes (Miehe, 1907, 1930; Hildebrandt, 1927; James, Rettger and Thom, 1928; Norman, 1930; Gilman and Barron, 1930; Harrison, 1934; Carlyle and Norman, 1941). Carbon dioxide liberation and heat evolution have been observed to parallel one another under these conditions (Harrison, 1934; Norman, 1930; Carlyle and Norman, 1941). The apparent absence of thermogenic capabilities with some organisms is strongly suggested by the adiabatic conditions maintained by Ramstad and Geddes (1942) which perhaps in part answers the doubt raised by Carlyle and Norman (1942) as to the non-existence of such organisms.

THE MICROFLORA OF CORN

Alsberg and Black (1913) associated *Penicillium puberulum* and *P. stoloniferum* with maize deterioration. McHargue (1920) was able to isolate a number of organisms from samples of shelled corn and corn meal used in laboratory experiments on spoilage. *Penicillium expansum* was identified as the dark bluish mold occurring on the corn germs, *Aspergillus glaucus* as the organism growing in clusters on the germs which was often followed by *A. albus*, and *Citromyces sp.* The latter organism frequently was found growing vigorously on the degerminated portion of the corn but never on the germ. Thom and Le Fevre (1921) made microbial analysis of many samples of cornmeal. Samples of sound, bolted, yellow and white cornmeal in retail stores on plating showed high counts of fungi and bacteria. *Aspergillus repens, A. niger, A. flavus, Fusarium spp., Mucor spp.*, some unidentified fungi and bacteria of the Micrococcus, Mesentericus and Aerogenes groups were the organisms encountered. Meal prepared from the whole kernel corn received by millers showed greater microbial counts than similar bolted meal (bran and tips of kernels removed). *Rhizopus nigricans, Aspergillus repens, Fusarium* spp. and some *Mucor* spp. were recoverable from practically all samples of such cornmeal. Of less frequent occurrence were *Syncephalastrum* sp., Penicillia of the group with submerged orange mycelia, *Citromyces* sp. and *Pencillium oxalicum*, while of occasional occurrence were *Aspergillus flavus*, *A. niger*, *A. tamari* and *A. fumigatus*. *Penicillium luteum*, *P. purpurogenum*, *Cladosporium* sp. and *Alternaria* sp. were encountered frequently but were considered only as contaminants from the soil. Of the bacteria, *Bacterium aerogenes* was most prevalent followed by lactobacilli and micrococci. Aerobic spore formers of the Mesentericus groups and in one case *Bacillus niger* were of infrequent occurrence.

The condition of corn kernels known in the grain trade as "blue eye" was studied by Koehler (1938). Penicillium species were the only organisms isolated and these fell into four groups: (a) members of the *P. chrysogenum* series; (b) *P. palitans* (member of the *P. viridicatum* series); (c) members of the Fasiculata group from *P. cyclopium* through the *P. viridicatum* series and (d) a non-worked group. In Argentina, Marchionatto (1942) found *P. viridicatum* responsible for this condition.

HUMIDITY RELATIONS OF FUNGI

Before discussing the humidity relations of the specific corn fungi a brief review of the general situation in regard to fungi and moisture will allow a better understanding of the question. Walderdorff (1924) was the first to consider this relationship by determining the limiting humidities over different concentrations of NaCl which would just support growth.

Walter (1924) classified micro-organisms as 1. Xerophytic species whose lower limits of relative humidity requirements lie between 85 and 90 per cent; 2. Mesophytic species whose lower limits of relative humidity requirement lie between 90 and 95 per cent; 3 Hydrophytic species whose lower limits of relative humidity requirement lie above 95 per cent. Four fungi were studied, two of which, *Aspergillus glaucus* and *Penicillium glaucum*, fell in the Xerophytic group while the other two, *Rhizopus sp.* and *Phycomyces nitens* fell in the Mesophytic group. Bacteria were found to have high relative humidity requirements. *Bacillus mycoides*, *Bacterium coli*, *Bacterium prodigiosum* and *Micrococcus roseus* grew only very slightly at 96 per cent r. h. as their lower limit. Yeasts were found to be more tolerant to lower humidities than bacteria but less so than the filamentous fungi. However, the relative humidity requirement for yeasts varied according to the source of yeast, for yeast isolated from beer, (normally not containing much sugar) did not grow at a relative humidity of 95 per cent while a yeast isolated from condensed milk grew at a relative humidity of 90 per cent. The latter yeast grew as normal yeast at high humidities but beginning with a relative humidity of 98 per cent became more mycelial-like until at 90 per cent r. h. the growth was strictly mycelial.

Following up this work, Bavendamm and Reichelt (1938) studied the relative humidity requirements of 11 different wood destroying fungi. Of this number only two organisms, *Merulius lachrymans* and *Poria vaporaria* fell in the mesophytic group of Walter. One organism, *Stereum frustulosum*, grew at a lower relative humidity than that set by Walter. On extrapolation from the growth curve the lower limit was found to fall on the 81.5 per cent mark. The remaining eight organisms showed humidity requirements ranging between 85.6 and 90 per cent as their lower limits for growth. These were *Trametes radiciperda, Coniophora cerebella, Fomes fomentarius, Lenzites abietina, L. sepiaria, Pholiota squarrosa, Ceratostomella piceae* and *Clitocybe mellea.* Zeller (1920) obtained some spore germinations of *Lenzites sepiaria* at 63 per cent r. h. on sap wood shavings of *Pinus echinata* but marked increases in percentage germination began only with relative humidities greater than 90 per cent.

Recently, because of better measurements of relative humidity and appreciation of modifying factors, Heintzeler (1939) was able to reconstruct Walter's classification into the following: 1. Xerophytic species whose germination limit on solid substrata lie below 80 per cent r. h., e. g. *Aspergillus glaucus, A. niger*, and *Penicillium glaucum;* 2. Mesophytic species whose lower germination limits lie between 80 and 90 per cent r. h., e. g. *Sporodinia grandis, Rhizopus nigricans, Phycomyces nitens* and *Ustilago avenae;* 3. Hydrophytic species whose lower germination limit lies above 90 per cent r. h.; 4. A group intermediate between two and three, e. g. Oidium lactis. The lower limiting relative humidity values obtained were as follows:

Species	Relative humidity limits	
	for germination	for germination and sporangia formation
Aspergillus glaucus	73.3 (70.8)	78.1
A. niger	79.0	81.8
Penicillium glaucum	77.8	80.5
Sporodinia grandis	83.3	91.0
Rhizopus nigricans	84.1	89.2
Phycomyces nitens	86.0	94.2
Ustilago avenae	87.8	......
Oidium lactis	89.8	......

As to the minimum relative humidity requirements of other fungi, information is available in only a few instances. Tomkins (1929-30) found *Aspergillus citri* to grow at 83.8 per cent r. h. while *Trichoderma lignorum* germinated and grew at 96 per cent r. h. and germinated only at lower relative humidities with 81.6 per cent as minimum. *Colletotrichum gloeosporioides* developed at a lower relative humidity limit of 89.3 per cent. Tammes (1937) found 78.4 per cent

r. h. as minimum for *Aspergillus sydowi* while Groom and Panisset (1933) found 81 per cent for *Penicillium chrysogenum* at 25°C.

Temperature-humidity interaction on the development of fungi.

The temperature-humidity interaction in the development of fungi was studied by several investigators. Tomkins (1929-30) found temperature-growth curves for *Alternaria citri* and *Trichoderma lignorum* to be similar at different humidities, with optimum growth occurring at temperatures of 30° and 25°C., respectively. Narrower temperature growth limits were obtained at lower relative humidities. The least minimum relative humidity permitting fungus growth was found to be somewhere between 10°-30°C. for *Penicillium glaucum, Rhizopus nigricans, Phycomyces nitens, Oidium lactis* (Heintzeler, 1939), 25°C. for *Trichoderma lignorum* (Tomkins, 1929-30) and *Penicillium chrysogenum* (Groom and Panisset, 1933), 27°C. for *Aspergillus sydowi* (Tammes, 1937), 30°C. for *Alternaria citri* (Tomkins, 1929-30) and *Aspergillus glaucus* (Heintzeler, 1939). Tammes (1937) considered the temperature influence to be on the viscosity of the plasma which in turn affected the diffusion rate. Heintzeler (1939) considered temperature to influence the entire life process so that at the optimum temperature the greatest resistance is afforded to the unfavorable influence of relative humidities.

Relation of nutrients tot the development of fungi at different humidities.

Tomkins (1929-30) observed that supplying nutrients to the fungus decreased the latent period of fungus spore germination, increased percentage germination and rate of germ tube elongation, and permitted germination at a greater range of humidities. Groom and Panisset (1933) observed mildewing of book binding materials by *Penicillium* sp. (presumably *P. chrysogenum*) at minimum relative humidities of 72.6 per cent while on plain glass slides germination of *P. chrysogenum* spores was obtained at 81 per cent minimum r. h. Barton-Wright and Tomkins (1940) observed molding of wheat bran at 75 per cent minimum r. h. while wheat flour molded at near 82.5 per cent minimum r. h. Macara (1943) observed 75 per cent as the minimum relative humidity for the molding of meat.

Adaptation of fungi to development at lower relative humidities.

Errera and Raciborsky, respectively, according to Heintzeler (1939), were able to demonstrate adaptation of *Aspergillus niger* and *A. glaucus* to growth on nutrient solutions containing high concentration of NaCl. Orban (Heintzeler, 1939) was unable to demonstrate such adaptation for *Phycomyces nitens*. By another method, Heintzeler (1939) sought to determine whether adaptation was possible to lower than minimum relative humidities. Her study of *Rhizopus nigricans* showed no adaptation while a slight tendency in this direction was shown in the first generation of growth by *Aspergillus glaucus*. This adaptation, however, did not increase with subsequent generations of growth. Lower relative humidity limits for growth of *Penicillium glaucum* and *Rhizopus nigricans* were obtained on nutrient liquid

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media containing different concentrations of sugar or salts than on solid substrata without the salts.

RELATION OF MOISTURE TO THE DEVELOPMENT OF FUNGI ON CORN

Thom and LeFevre (1921) observed marked multiplication of molds and bacteria in samples of cornmeal with approximately 20 per cent moisture, of which the predominant organisms were molds. Species of yeast, Mucor and Penicillium were present while *Aspergillus flavus* was the predominate fungus. In cornmeal of near 13 per cent moisture, lower numbers of active species of molds were found.

Aspergillus repens was the predominant fungus in cornmeal of 13 to 15 per cent moisture. *Aspergillus flavus* began activity in 16 per cent moisture cornmeal. Above this moisture other molds followed with the order of abundance being from the greatest to the least: *A. repens, A. flavus, Actinomyces sp., Penicillium sp., Citromyces sp., Fusarium sp., Aspergillus candidus, A. ochraceous, A. tamari* and *A. niger.* In instances where meal prepared from Fusarium and *Diplodia zeae* infected corn was mixed with ordinary meal, no development of either of these organisms occurred to the extent that they became dominant. Bacterial activity was observed to follow after that of the molds.

Koehler (1938) determined the critical moisture limits of shelled Reid's Yellow Dent corn permitting growth of certain fungi under pure culture conditions.

Species	Moisture content of grain showing	
	Some fungous growth	No fungous growth
Aspergillus glaucus group	14.3	14.0
A. versicolor	15.0	14.2
A. wentii	15.4	14.5
A. ochraceous	15.6	14.5
Penicillium notatum	15.6	15.0
P. viridicatum	17.6	16.8
P. palitans	18.0	17.6
Aspergillus flavus	18.3	18.0
Aspergillus tamarii	19.8	18.7
A. niger	20.1	19.1
Penicillium oxalicum	20.8	19.0
P. expansum	20.8	20.1
Diplodia zeae	21.9	21.0
Gibberella saubinetii	22.3	21.2
Nigrospora sphaerica	22.5	21.1
Cephalosporium acremonium	23.4	22.1

Members of the *Aspergillus glaucus* group grew at a lower moisture content of the grain than any of the other fungi, with 14.3 per cent moisture being the lower limit for fructification on the kernels. This value is somewhat higher than that claimed for the same group by Thom and LeFevre (1921) who considered it to be slightly above 12.5 or 13 per cent. *Aspergillus versicolor*, *A. wentii* and *A. ochraceus* developed at moistures only slightly higher than that for *A. glaucus* while *A. flavus*, *A. tamarii*, and *A. niger* developed only at considerable higher moisture. The limit of 18.3 per cent moisture here determined for *A. flavus* was higher than that indicated by Thom and LeFevre (1921).

The species of Penicillium had higher moisture requirements as a group than did the *Aspergillus spp.* and showed no development of fructifications at moistures below 16.3 per cent. Pure culture inoculation revealed 15.6 per cent moisture as the lower limit for development of *Penicillium notatum.* Under similar conditions the lower moisture limits for the development of *P. viridicatum*, *P. palitans*, *P. oxalicum*, and *P. expansum* were 17.6, 18.0, 20.8 and 20.8 per cent, respectively. The condition known as "blue-eye" was induced under pure culture conditions with *P. notatum* in two per cent of the kernels at 16.7 per cent moisture, in ten per cent of the kernels at 17.7 per cent moisture and in 60 per cent of the kernels at 19.0 per cent moisture, and with *P. palitans* in ten per cent of the kernels at 19.5 per cent moisture and in 50 per cent of the kernels at 21.2 per cent moisture. At the lowest moisture levels "blue-eye" appeared as a narrow strip over the germ, a condition called "hair-line blue-eye" by grain inspectors. No typical "blue-eye" was produced by *P. oxalicum* and *P. expansum.*

Differences of lower moisture limits for the development of *Fusarium moniliforme* on samples of corn naturally infected were explained as strain differences of the fungus. In some tests the fungus grew at a low moisture level of 18.4 per cent while in other tests this limit was 21.2 per cent. Above 21 to 24 per cent moisture active development of the fungus usually occurred.

The remaining fungi studied by Koehler (1938), namely, *Diplodia zeae*, *Gibberella saubinetii*, *Nigrospora sphaerica*, and *Cephalosporium acremonium*, exhibited high moisture requirements of 21.5 to 23.5 per cent moisture in the corn. Their appearance and development on corn, however, was greatly influenced by the competition of other organisms, in the presence of which higher moistures in the grain were necessary for their appearance than in the absence of such competition.

SUCCESSION OF AND COMPETITION BETWEEN FUNGI ON CORN

McHargue (1920) observed that *Aspergillus albus* usually followed *A. glaucus* and *Penicillium expansum.* Koehler (1938) observed that the *Aspergillus glaucus* group never failed to appear at 14.5 to 15.5 per cent moisture in corn and sometimes without apparent competi-

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tion from other organisms. Some other *Aspergillus spp.* appeared at slightly higher percentages of moisture and some *Penicillium spp.* regularly appeared at 17 and 18 per cent moisture. With corn of 17 to 23 per cent moisture sometimes *Penicillium spp.* and sometimes *Aspergillus spp.* predominated. At moisture above 23 to 26 per cent the "blue eye" condition of corn was likely to become obliterated by other fungi. At these high moistures, *Fusarium moniliforme* would usually predominate over the *Penicillium spp.* and *Aspergillus spp.*, but if *Diplodia zeae* was present in sufficient quantities it would become predominant over *Fusarium moniliforme*. *Gibberella saubinetii* did not become aggressive until the moisture reached 26 per cent or over while *Nigrospora sphaerica* and *Cephalosporium acremonium* required moistures of near 30 per cent.

SUMMARY

Deterioration of shelled corn in storage has been a problem of concern to elevator-men and shippers for many years and will continue to cause concern as long as corn remains a primary crop plant. Heating, loss of germinability, decrease in weight per bushel, and increase in fat acidity are the obvious changes accompanying the process, while changes in protein content and loss of vitamin A also occur.

Observations and experimental data show the water relations of the corn, both the moisture content of the grain and the relative humidity of the atmosphere in which the corn is stored, to be the principle factors in the problem of safe storage. The hygroscopicity of the corn contributes to the importance of the relative humidity, and is in turn affected by the type of kernel, starchy corn, for example, showing greater water absorption than flinty. Temperatures of storage also have an effect; higher temperatures increase the speed of deterioration and the possibilities of spoilage, whereas, low temperatures are favorable to safe storage.

The conditions under which deterioration occurs and the changes which follow its initiation indicate that it is primarily a biological decomposition. Examinaton of affected bins disclosed the presence of many fungi, among which species of Penicillium, Aspergillus and Rhizopus were predominant. The moisture requirements of these fungi are lower than the requirements of those that ordinarily attack corn in the field. Although the latter might be expected to be carried into storage, their moisture requirements make them of minor significance in the corn storage problem.

From the point of view of practice, drying shelled corn to a point below that required for the growth of fungi, approximately to a 12 per cent moisture content, and storing under conditions that prevent atmospheric condensation with subsequent absorption of this moisture by the corn are the essential requisites of safe storage.

BOTANY AND PLANT PATHOLOGY SECTION,
IOWA AGRICULTURAL EXPERIMENT STATION,
AMES, IOWA.

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