

JFM 00MS1

# Mould spoilage of cereals during transportation by sea from Latin America to Europe Mechanisms, impact and management

D.A.A. Mossel

*The Netherlands Government's University at Utrecht, Utrecht, The Netherlands*

Safe water contents of consignments of cereals to be shipped overseas can be calculated from the relation between mould-free storage time and storage conditions (temperature of the environment,  $a_w$  of the cereal), corrected for heterogeneity of water distribution, content of damaged kernels and degree of infestation by insects. The validity of this model was substantiated by the inspection of shipments and theoretical data from the literature. This predictive model can usefully be substituted for previously used, ill-defined criteria like average or any portion's water content and should prompt the trade to sell consignments of cereals on the basis of dry substance.

**Key words:** Mould deterioration; Cereal; Mycotoxin; Water activity; Water vapour migration; Predictive modeling

## Essentials of management of mould spoilage of cereals

Large consignments of cereals shipped from certain production areas often arrive at their ports of destination partly mouldy (Milton and Jarrett, 1969; 1970; Sauer and Burroughs, 1980; Christensen and Meronuck, 1986). Sometimes this also happens during the otherwise untroubled trade in maize between South America and The Netherlands. Dormant spores of moulds invariably occur in cereals and other dry bulk foods and are of no immediate concern. However, their germination and particularly subsequent outgrowth of mycelia, and metabolism, with a risk of mycotoxins spreading from the areas attacked by moulds throughout the entire consignment may lead to severe financial losses (Lillehoj et al., 1976, 1980; Shotwell and Hesselstine, 1983).

Fortunately, there is no lack of scientific data on which to base attempts to control this type of deterioration. It has been demonstrated that mould spoilage starts in small areas within a large consignment which have a water content slightly exceeding the analytically determined 'average' moisture content of the lot (Christensen and Kaufmann, 1975). This allows spores of the most xerotolerant moulds

---

*Correspondence address:* Department of the Science of Food of Animal Origin, Faculty of Veterinary Medicine, The Netherlands Government's University at Utrecht, P.O. Box 80175, 3508 TD Utrecht, The Netherlands.

(Pitt and Christian, 1968; Dallyn and Fox, 1980; Rao and Kalyanasundaram, 1983) to germinate and produce mycelium. Mould metabolism then produces heat and water vapour (Festenstein, 1966) which may become sufficient to allow germination of and toxin formation by less xerotolerant mould spores (Magan et al., 1984). This will trigger a chain reaction ultimately resulting in massive colonisation by moulds, actinomycetes and bacteria, and heating of particular areas of consignments to about 60°C (Lacey, 1980). While this type of deterioration can be controlled by ventilation during storage in bins (Sauer and Burroughs, 1980; Christensen and Meronuck, 1986), this cannot be achieved during transportation in ship holds (Sellam and Christensen, 1976).

### The Kreyger predictive model

#### *Principle*

Kreyger (1972) in The Netherlands developed a predictive model showing how consignments of cereals could be protected against mould growth during sea voyages.

First, for every type of cereal, the relation between mould-free storage time, water content and storage temperature is assessed in model experiments in small

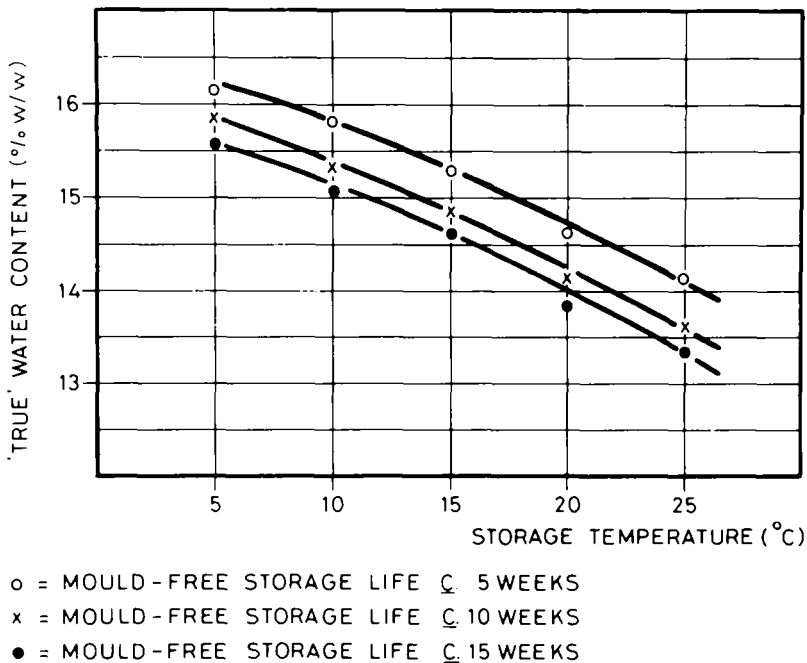


Fig. 1. The relation between mould-free storage life of cereals, water content and temperature of loading and shipment.

desiccators. A first approximation maximum safe water content at a given duration of sea transportation can then be calculated as in Fig. 1.

This approximate safe water content must be decreased further to allow for conditions favouring mould development in cereals, such as (i) heterogeneity of water distribution in a consignment and possible moisture migration during transit (Christensen and Meronuck, 1986); (ii) the proportion of damaged, or broken kernels (Qasem and Christensen, 1960); (iii) the degree of infestation by insects (Lillehoj et al., 1980).

#### *Validation of the model by inspection of consignments arriving in The Netherlands*

The validity of Kreyger's approach was tested by an inspection of sixteen shipments of maize from South America upon arrival at Rotterdam. The results are presented in Fig. 2. The open circles indicate safe water contents calculated by the model described in the previous section, depending on temperature at loading and

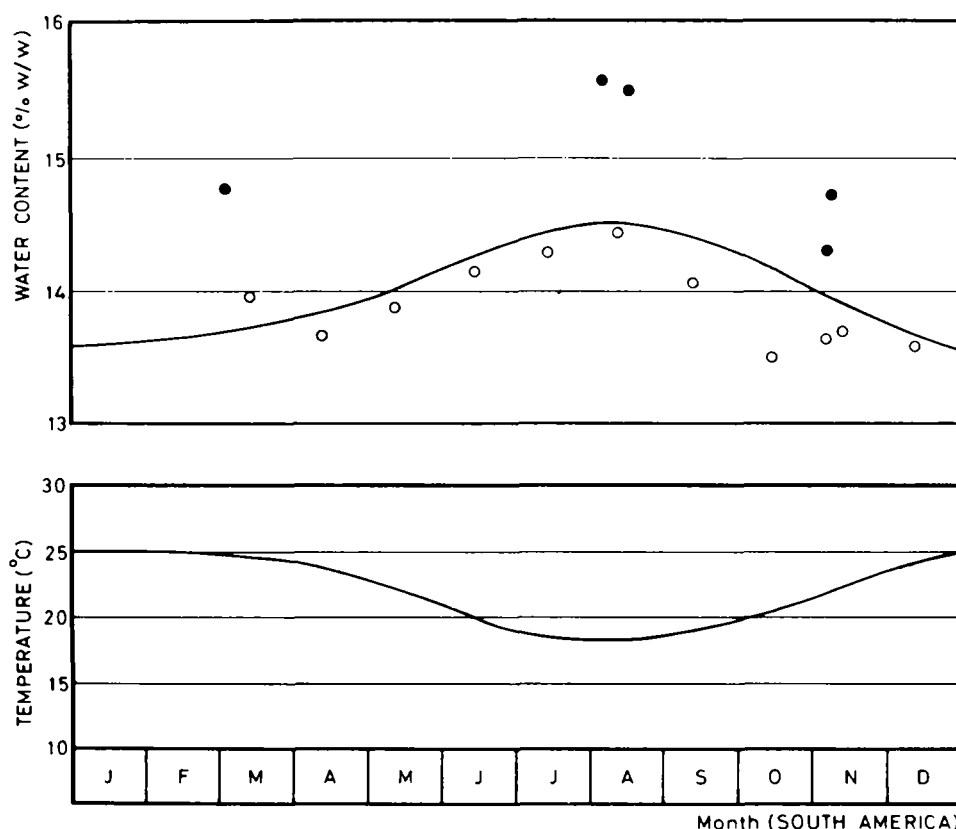


Fig. 2. Validation of the phantom curves by actual shipping experience of consignments of cereals. O, consignments arriving mould- and heat-free. ●, consignments found to have been colonized by moulds.

duration of sea voyage. Consignments satisfying this requirement have never been found spoiled by moulds upon arrival in the port of destination. The closed circles represent the water content at loading of lots that had arrived with frank heating damage.

The almost perfect agreement between predicted and practically determined safe water contents confirms the validity of Kreyger's predictive model. This approach to management of mould deterioration and local heating of cereals during transportation by sea could advantageously replace the customary policy, where average moisture contents of shipments upon loading are relied on. This attribute varies tremendously within consignments considered homogeneous (Christensen and Meronuck, 1986) and even more so between various smaller lots, which are often blended before being shipped (Sauer and Burroughs, 1980).

### Theoretical foundation and impact for the trade

First and foremost it was interesting to study to what degree the Kreyger model fitted into fundamental data in the food mycological literature. When the worst case scenario approach is applied to the data of Fig. 1, then a water content according to the Kreyger model of about 13.3% should fully protect consignments of maize when transported for 15 weeks at temperatures not exceeding 25°C. Though the sorption isotherms of maize, like those of all other cereals vary markedly with experimental conditions (Christensen and Kaufmann, 1969; Pixton and Warburton, 1971; Kreyger, 1972) a water content of 13.3% corresponds, within the confidence limits originating from hysteresis, with an  $a_w$  value of about 0.64. The limiting  $a_w$  for the most xerophilic fungi, i.e. *Eurotium echinulatum* (Snow, 1949) and *Xeromyces bisporus* (Pitt and Hocking, 1982) was established at  $a_w = 0.62$ . Hence, also in this respect the predictive model of Kreyger seems to be a reliable one.

The international trade would be well advised to consider adopting the Kreyger model, obviously after trying it out at a much larger scale than was within our reach. The low range of water contents which the model requires will of course surprise the trade somewhat and also raise the question of who will bear the cost of the markedly lower water content recommended by the new model when compared with the conventional, much higher moisture levels. A possible solution might be to consider selling cereals henceforth on a dry substance net basis rather than on a wet basis. After all, the consumer is primarily interested in the constituents other than water. Moreover, the trade will face markedly less problems and episodes of management by crisis once moulding and heating of cereals during sea voyages has been brought under control which is well within reach as our studies indicate.

### References

- Christensen, C.M. and Kaufmann, H.H. (1969) Grain Storage. The Role of Fungi in Quality Loss. University of Minnesota Press. Minneapolis, MN.

- Christensen, C.M. and Kaufmann, H.H. (1975) Control of post-harvest losses caused by fungi in food, feed and grains. *Feedstuffs*, March 10, pp. 34–35.
- Christensen, C.M. and Meronuck, R.A. (1986) *Quality Maintenance in Stored Grains and Seeds*. University of Minnesota Press, Minneapolis, MN.
- Dallyn, H. and Fox, A. (1980) Spoilage of materials of reduced water activity by xerophilic fungi. In: G.W. Gould and J.E.L. Corry, (Eds.), *Microbial Growth and Survival in Extremes of Environment*. Academic Press, London, pp. 129–139.
- Festenstien, G.N. (1966) Biochemical changes during moulding of self-heated hay in Dewar flasks. *J. Sci. Food Agric.* 17, 130–133.
- Kreyger, J. (1972) Drying and storing grains, seeds and pulses in temperate climates. Publication 205, Institute for Storage and Processing of Agricultural Produce, Wageningen, The Netherlands, 333 pp.
- Lacey, J. (1980) Colonisation of damp organic substrates and spontaneous heating. In: G.W. Gould and J.E.L. Corry (Eds.), *Microbial Growth and Survival in Extremes of Environment*. Academic Press, London, pp. 53–70.
- Lillehoj, E.B., Fennell, D.I. and Hesseltine, C.W. (1976) *Aspergillus flavus* infection and aflatoxin production in mixtures of high-moisture and dry maize. *J. Stored Prod. Res.* 12, 11–18.
- Lillehoj, E.B., Kwolek, W.F., Horner, E.S., Widstrom, N.W., Josephson, L.M., Franz, A.O. and Catalano, E.A. (1980) Aflatoxin contamination of preharvest corn: role of *Aspergillus flavus* inoculum and insect damage. *Cereal Chem.* 57, 225–257.
- Magan, N., Cayley, G.R. and Lacey, J. (1984). Effect of water activity and temperature on mycotoxin production by *Alternaria alternata* in culture and on wheat grain. *Appl. Environ. Microbiol.* 47, 1113–1117.
- Milton, R.F. and Jarrett, K.J. (1969) Storage and transport of maize. 1. Temperature, humidity and microbiological spoilage. *World Crops* 21, 356–357.
- Milton, R.F. and Jarrett, K.J. (1970) Storage and transport of maize. *World Crops* 22, 48–49; 96; 98–99.
- Pitt, J.I. and Christian, J.H.B. (1968) Water relations of xerophilic fungi isolated from prunes. *Appl. Microbiol.* 16, 1853–1858.
- Pitt, J.I. and Hocking, A.D. (1982). Food spoilage fungi. I. *Xeromyces bisporus* Fraser. *Food Res. Q.* 42, 1–6.
- Pixton, S.W. and Warburton, S. (1971) Moisture content/relative humidity equilibrium of some cereal grains at different temperatures. *J. Stored Prod. Res.* 6, 283–293.
- Qasem S.A. and Christensen, C.M. (1960) Influence of various factors on the deterioration of stored corn by fungi. *Phytopathology* 50, 703–709.
- Rao, G.L. and Kalyanasundaram, I. (1983) Osmophilism in food grain storage fungi. *Mycopathologia* 83, 3–7.
- Sauer, D.B. and Burroughs, R. (1980) Fungal growth, aflatoxin production and moisture equilibration in mixtures of wet and dry corn. *Phytopathology* 70, 516–531.
- Sellam, M.A. and Christensen, C.M. (1976) Temperature differences, moisture transfer and spoilage in stored corn. *Feedstuffs* 48, No. 36, 28; 33.
- Shotwell, O.L. and Hesseltine, C.W. (1983) Five-year study of mycotoxins in Virginia wheat and dent corn. *J. Assoc. Off. Anal. Chem.* 66, 1466–1469.
- Snow, D. (1949) The germination of mould spores at controlled humidities. *Annal. Appl. Biol.* 36, 1–13.