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STUDIES ON DRYING STRATEGIES FOR AFLATOXIN CONTROL IN CORN

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Abstract

Aflatoxins are an important problem for the corn industry in Southeast Asia. This paper analyses the current situation in postharvest operations in Thailand and the Philippines with particular emphasis on drying practises. A new approach to drying of corn is proposed in the form of two stage drying with in-store drying as the second stage. Experiments carried out show possibilities and limitations of the system, so far assessed at a pilot scale.

Acknowledgements

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1. Background

Corn is an important crop, second to paddy, in most of Southeast Asia. In Thailand corn is not only a significant export crop but also an ingredient in high demand for domestic feed mills. The latter are supplying feed for the livestock industry which is producing meat and eggs for local and foreign markets. The corn industry in the Philippines supplies mainly national markets. Corn produced in the Philippines targets two main categories of users, namely feed mills supplying livestock raisers and corn mills supplying grits for human consumption. There is a deficit of good quality corn in the Philippines which is covered by imports from the USA and Thailand. The ultimate destination of corn appears to be a factor which determines the perception of quality in each country. The export markets are more discriminating than the local ones and thus define the quality criteria for the corn industry in each of the two countries.

Corn production in the Philippines in the last few years was as follows (data provided by the Agriculture Staff of National Economic and Development Authority of the Philippines):

	in thousands MT			
	1987	1988	1989	1990
Production	4,278.1	4,427.9	4,522.2	4,853.9
Imports	55.8	25.0	176.5	348.3
Food	1,018.1	1,026.9	1,051.7	847.9
Feeds and others	3,253.3	3,287.9	3,728.1	3,814.6

The Thai corn production in 1988 was 4,675 thousand MT of which 75 % were used as feed whereas the remainder were exported. Only an insignificant amount were for human consumption.

In both countries most corn is produced during the wet season, while a smaller proportion of the crop is produced during the dry season. Corn is generally picked by hand, dehusked in the field and transported to the farmer's house for drying. This can either take place in a crib or under the house or on a sunning floor. The initial moisture content can be as high as 30%wb (percent wet basis) or higher. After initial pre-drying, corn is shelled and then sold to the merchant or stored on the farm in expectation of a higher price. During this period of storage more moisture is removed, mainly by sun-drying. There are many variations to this general pattern such as field drying on the stalk, extended storage of cobs in cribs or sheds with a crude ventilation system (bamboo pipes inserted in the piled product), wet shelling, and quick selling to the merchant and many others.

For a long time the main concern of the buyer was the moisture content and to a lesser extent impurities and discolouration (mainly for white corn for human consumption). The research on mycotoxin producing fungi which was carried out in the last thirty years focussed on an important group of moulds, namely those producing aflatoxins. The latter have been related to the occurrence of human liver cancer as well as debility, sickness and consequently reduced growth rate and increased mortality among livestock. Three species of fungi have been identified as capable of aflatoxin production, all belonging to the Aspergillus genus. Those are A. flavus, producing B type, A. parasiticus producing B and G type and the more recently discovered A. nomius producing B and G type aflatoxins. Laboratory studies have shown that only 40% of the strains of A. flavus but all A. parasiticus strains are capable of producing aflatoxins (Pitt, 1992). Note that the presence of moulds does not necessarily imply presence of aflatoxins.

Factors conducive to aflatoxin production are as follows: moisture, temperature, substrate, modified atmosphere and pre-harvest conditions of the crop. Bullerman et al. (1984) reviewed a large number of publications referring to the effects and to the interactions of these factors. The most important ones are moisture and temperature, which may interact with each other or with other factors. Moisture is related relative humidity of the ambient air and water activity of the food stuff. High water activities, in excess of 0.83, are conducive to aflatoxin production within a wide range of temperatures, but the growth of the fungi may occur at lower water activities (0.78 for A. flavus). The critical level of moisture content is 16% for cereal grain and 5-8% for nuts and cotton seed. Temperatures between 25° and 30°C seem to favour aflatoxin production. However, high water activity will cause the fungi to produce aflatoxins at lower temperatures. Cycling or changing temperatures may favour aflatoxin formation by some strains and on some substrates.

Aflatoxins are found amongst crops such as peanuts, most of the tree nuts, corn, sorghum, millet, copra, cotton seed, and figs. Some animal products can accumulate metabolized aflatoxins (M type). These are milk, muscle tissues and eggs. Different food components may enhance the production of mycotoxins, among them certain amino acids, fatty acids and zinc. Varietal differences with respect to these components may produce different levels of susceptibility to the production of aflatoxins. The presence of high levels of CO_2 in the modified atmosphere enclosing a food stuff may reduce the levels of aflatoxin without necessarily inhibiting fungal growth (Taniwaki, 1992). The last factor favouring fungal growth and consequently aflatoxin production is the degree of pre-harvest damage to the crop. This can be caused by drought stress, damage due to hail, harvesting equipment or insects. Time also plays a role, particularly in conditions less favourable for fungal growth. It may take several weeks until aflatoxins are being produced at lower temperatures in spite of adequate moisture levels in the substrate.

Recent research into the biology of aflatoxigenic fungi, as well as the findings of medical and nutritional studies on one hand and the pressure from the market (livestock industry and consumers) on the other, have led to the introduction of limits on the amounts of aflatoxins which are permitted in foods. These limits vary between countries and products. Most European countries have moved towards a limit of below 30ppb (parts per billion) for total aflatoxin concentration in all foods and less than 0.05ppb of M aflatoxin in milk (Gilbert, 1991). In Asia, Taiwan tolerates up to 50ppb of B_1 aflatoxin in cereals and peanuts, Thailand has a tolerance of 20ppb for B and G aflatoxins in all foods and Japan 10ppb tolerance for B aflatoxin in all foods. The Philippines have a 20ppb tolerance for B_1 aflatoxin in coconut and peanut products for export (Van Egmond, 1991).

2. Monitoring of aflatoxin in food

In order to monitor the aflatoxin concentration in food, a number of methods have been developed by different research laboratories over the last twenty years. There are different levels of accuracy ranging from semi-quantitative "field" tests to qualitative methods used as standards by organisations such as AOAC (Association of Official Analytical Chemists), ISO (International Standards Organization) or AACC (American Association of Cereal Chemists). Among the semi-qualitative tests are:

a) BGYF (Bright Greenish Yellow Fluorescence). Ground samples are viewed under long-wave (365nm) ultra-violet light in a viewing box. This method can be used in the field or in the procurement laboratory. (Rural Investment Overseas, 1988)

b) Minicolumn (Holaday-Velasco and Romer). Aflatoxin is extracted from the kernel using a methanol-chloroform mixture and then drained through a minicolumn containing packing material (silica gel and florisil). The sample is viewed in ultra-violet light at 365nm wave length. The time required to analyse one sample is about 30 minutes. This method is inexpensive and rapid but non specific. There are different modifications to the minicolumn method which tend to make it faster and cheaper (Kositcharoenkul et al. 1991).

c) ELISA (enzymelinked immunoassays) which is based on reaction of specific antibodies in the presence of aflatoxins. This test can be used for rapid screening as well as for semi-quantitative determination by taking colour or fluorescence readings. There are commercial kits as well as modified versions of this technique developed by testing laboratories making this method increasingly affordable to the industry.

The qualitative methods comprise TLC (thin layer chromatography) and HPLC (high performance liquid chromatography). They have been tested by a number of collaborative studies and were recommended for adoption as first action methods by the AOAC and official methods by the EC (Van Egmond, 1989 and Gilbert, 1991). It is quite obvious that the capital cost of equipment involved and skills required from the operators will limit the use of these highly accurate methods to the official testing laboratories, universities and large modern industrial plants.

3. Structure of the corn industry in the Philippines and Thailand

The existing systems of postharvest operations in corn in Thailand and the Philippines have many weak points preventing these countries from effectively controlling the aflatoxin problem. However, there is a difference between the two countries in perception of the aflatoxin problem. The Philippines are producing for the domestic market which does not discriminate for quality since poor quality grain can be mixed with good quality imported grain to provide an acceptable final product. The Thai corn industry is more diversified, due to it's important export component. It includes not only grain but also value-added products based on corn (meat). This fact, and also the growing economic prosperity of the Thai domestic consumers, stimulates the demand for grain with low aflatoxin levels.

In the Thai system (Siriacha et al., 1991), earcorn is basically sun dried at the farm level and then either sold to the trader at the first opportunity or stored for a period of time (in expectation of a better price). Although the drying process continues in storage through natural ventilation or further exposure to sun drying, it is during this period that grain is most exposed to infestation by moulds. Mould growth is favoured by high moisture of the grain (including immature grains), high relative humidity and very inadequate storage conditions. However, the initial infection usually occurs in the field, at least for some of the grain. Shelling occurs generally when corn is being sold to the traders. Traders will further sun dry the grain and sell it on assembly or central markets. Merchants at this level will dry corn using either mechanical dryers or, in most cases sun dry on concrete floors. Stirring of grain is performed using tractors fitted with front spreading blades or rear racks. Although sun drying can produce good quality grain, there are serious limitations such as:

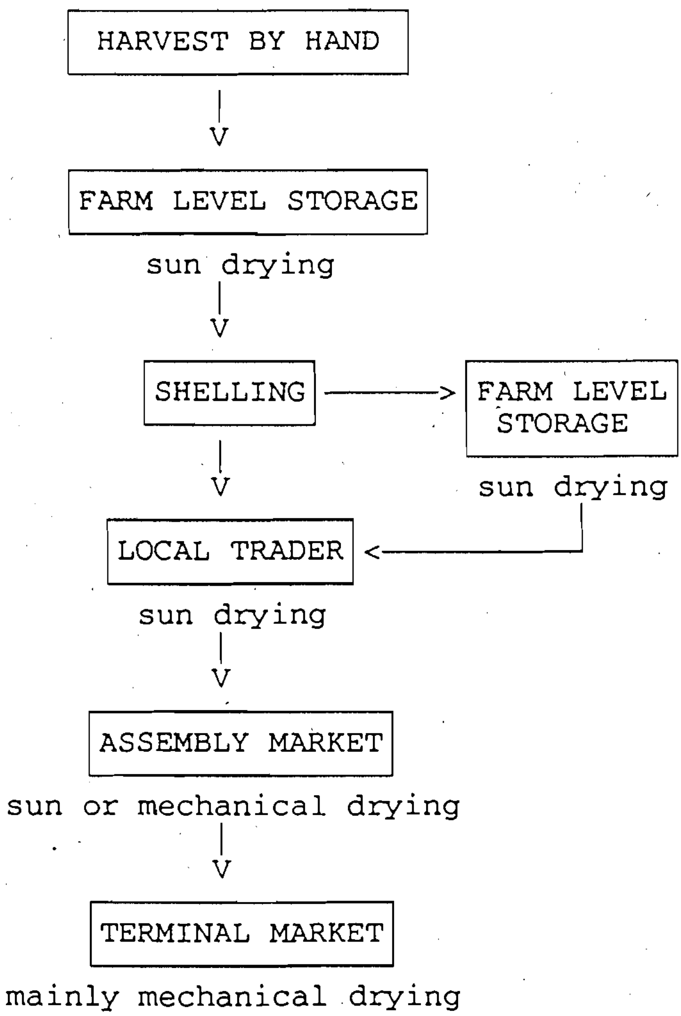
a) availability of sufficient sun drying areas for the amount of grain procured. Wet grain will then be bunched up, particularly when weather conditions are not optimum.

b) duration of drying for high moisture grain if weather conditions are sub-optimum.

c) deficient management of the sun drying operations such as uncleanliness of the floors, inadequate stirring and breakage of grain due to tractor or loaders.

The last stage of postharvest operations takes place at the terminal market: exports' or feedmillers' silos. Corn is delivered by trucks in bags or in bulk and subjected to quality testing (including aflatoxin) on arrival. Lots are separated according to quality. Further drying is performed down to a safe storage level of 14%wb moisture content. Terminal markets are equipped with high capacity continuous flow dryers (35-225 t/hour) as well as with large storage silos or sheds (up to hundreds of thousands of tonnes). Silos are often fitted with aeration fans whereas grain stored in sheds is taken out on the sun floors in order to maintain moisture content at the safe level.

The following flowchart shows the Thai corn postharvest system:



Although the same factors as in Thailand affect the quality of corn in the Philippines, there are additional ones which favour the build-up of aflatoxin (Quitco, 1991). First of all there is the more uniform distribution of rainfall throughout the year in Mindanao, which is the main corn growing area in the country. Consequently, there is less opportunity for sun drying of high moisture corn than in Thailand when the conditions become more favourable towards the end of the wet season (October-November). This, compounded with common practice of wet shelling of corn, results in storage of wet corn at the farm level and rapid increase of aflatoxin levels. Delays in transport from the producing areas in Mindanao to the feedmills in Cebu or Manila due to inadequate storage at the loading terminal, duration and conditions on the ship and delays during unloading are other important factors which cause grain deterioration. At present there are very few corn processing industries in Mindanao (mostly grit producing mills in areas with larger groups of Cebuano population).

There are two basic differences in the way the grain industry tackles the aflatoxin problem in the two countries.

The first one is in the way in which the procured corn is tested, and the second is in the economic incentive compensating the supplier for the low moisture content of his grain.

Since a significant amount of corn produced in Thailand is being exported or used to feed livestock for export markets, the large grain traders have widely adopted aflatoxin tests at procurement level. Semi-qantitative methods, namely BGYF (Bright Greenish Yellow Fluorescence) and a viewing box are the most commonly used. The Thai Department of Agriculture has put considerable effort into modifying the minicolumn (Holaday-Velasco and Romer method) by incorporating locally produced ingredients in order to make it inexpensive. Those methods have so far hardly been adopted by the Filippino feed mills. The latter prefer using feed additives to detoxify their products (hydrated sodium calcium aluminosilicate sorbent is quite widespread).

The pricing systems for corn reflect the difference in quality perception in the two countries. In the Philippines, the National Food Authority is paying P3.08 for the lowest quality mouldy grain and P4.70 for the prime quality aflatoxin free, dry grain. However, this institution can only purchase a limited quantity of grain. The free market pays only P0.20-0.50 more for good quality grain (De Padua, 1992). In contrast to that, the TMPTA (Thai Maize Producers and Traders Scale) has recently been revised giving higher margins for drying than previously. Quality testing now includes measurement of aflatoxin content. The new scale for weight deductions is as follows (as in November 1991):

Moisture content in %	Penalty in kg/tonne
14.6-15.0	6
15.1-15.5	12
15.6-16.0	18
16.1-16.5	24
16.6-17.0	30
17.1-17.5	36
17.6-18.0	42
18.1-18.5	54
18.6-19.0	66
19.1-19.5	84
19.6-20.0	100
20.1-20.5	110
20.6-21.0	125
21.1-22.0	145
22.1-23.0	165
23.1-24.0	185
24.1-26.0	200

Since many of the difficulties experienced by the corn postharvest industry in the Philippines are due to the economic and geographic context, proposed technical solutions are more likely to be adopted in Thailand.

However, we expect that these solutions can also be adopted by the Philippines if some of the current economic constraints have changed and the corn industry has become more responsive to the quality of locally produced grain.

4. Current drying practises

In the chain of postharvest operations described above drying and storage play a key role. Spoilage through moulds can be prevented if the crop is adequately dried. Although other methods have been tried for preventing aflatoxin contamination of grain (such as chemical treatment of wet grain by mainly propionic acid derivatives showing fungicidal activity, or detoxification of animal feed with ammonia or aflatoxin binding agents) these treatments offer only a partial solution to the problem. Another disadvantage of chemical treatments is additional cost and possible side effects (e.g. affecting organoleptic properties of the product).

As far as drying is concerned both countries follow a similar general pattern i.e. sun drying or natural ventilation at farmer's and primary merchant's level and combination of sun drying and mechanical drying from secondary merchant's level upwards. At this level storage is mainly in bags in both countries. The export silos in Thailand and large feed mills will use predominantly mechanical drying and bulk storage.

Concerning mechanical dryers, there are three categories in use in both countries:

a) static batch dryers.

There are different types of dryers such as:

i) flat bed dryers (UPLB or similar designs) used for drying of corn on cob as well as shelled grain. The capacity varies from 2.5 tonnes (UPLB) to 80 tonnes for some of the Thai designs.

ii) columnar batch type dryer designed by Kongskilde, generally with a capacity of 10 tonnes, used for shelled corn

b) recirculating batch dryers of various designs with an average capacity of 7.5t/h and 5% moisture reduction

c) continuous flow dryers

Those are used for high temperature drying (120-150°C) with a cooling stage. The moisture removal occurs in a single pass from 26% down to 14%. There are different designs and a wide range of capacity ranging from 5t/h for the LSU based designs up to 40t/h or more for large tower dryers. Although providing obvious economies of scale, continuous flow dryers are not particularly efficient in removing moisture below 18% and furthermore produce stress cracks which may lead to the production of aflatoxin.

5. Applications of two-stage drying for aflatoxin control in corn

The system which is envisaged in the new ACIAR project proposal 9008 is a two-stage drying process. The first stage of drying removes superficial moisture from the initial level at the time of harvest down to about 18%. For this stage of drying, high drying rates occur, which contribute to mould control without generally affecting other quality parameters. The second stage removes the remaining moisture down to a safe storage level of 14%wb. The second stage drying process involves mainly diffusion inside the grain, and therefore the drying rates are lower, particularly for larger grains. It is mainly at this level that the quality of the grain may be affected by the formation of stress cracks which enhance infestation and growth of moulds.

First stage of drying can be performed in a variety of different ways depending on the size, level of technicity, climatic conditions of the site and other parameters characterizing the user of the technology. Well conducted sun drying may still be an adequate technique if sufficient area of sun drying floors is available. However, where larger throughputs are handled and weather conditions are unstable, high temperature mechanical dryers, mainly of continuous flow type, are the most efficient method of first stage drying. Quite frequently a combination of sun and mechanical drying is used in Thailand. In order to be effective in controlling mould growth first stage drying has to be performed within a day after harvest.

The second stage of drying is the main objective of the research since it is the critical stage of the drying operation due to the high risk of mould proliferation (mainly because of delays in handling between the first and the second stage of drying). There are two ways of removing the residual moisture from 18%wb down to 14%wb:

a) high temperature drying at temperatures lethal to moulds but without deleterious effect on grain,

b) near-ambient in-store drying using relative humidity controllers. This system reduces the growth rate of moulds so that drying is completed before moulds reach critical levels. Furthermore, in-store aeration will be continued during the storage period thus preventing the grain from re-absorbing moisture if the ambient RH is high.

The advantages of the near-ambient in-store drying are that this method requires a lower energy input as well as less grain handling (i.e. conveying between the dryer and the store). If ambient conditions are favourable (low RH) the need for heating inlet air is reduced. The heat input can be lower than the latent heat of vaporisation of water.

On the other hand excessive heating of drying air may favour mould growth at the top of the grain bed and therefore the use of additional heat has to be monitored very closely. There is also another advantage from aerating grain without additional heating which is the cooling effect resulting in lowering the temperature of undried grain making the conditions less favourable for mould growth.

As a result of these considerations a preliminary investigation was undertaken aiming at broadly determining the conditions under which near-ambient in-store drying could prevent the build-up of aflatoxin in corn. The objectives of this research were:

a) to determine the initial and final aflatoxin levels in corn,

b) to determine the energy consumption in drying,

c) to establish the time required for drying corn to a safe storage moisture content

Pilot plant experiments were conducted in late 1991 at the School of Energy and Materials of the King Mongkut's Institute of Technology Thonburi in Thailand.

Three batches of corn were dried in a pilot bin of 0.75m diameter and approximately 1.5m height. The batches were at different initial moisture contents, and were subjected to different drying strategies in order to cover a wide range of situations.

Ambient conditions (temperature and relative humidity), moisture contents and energy consumption have been recorded throughout the tests. Aflatoxin B_1 levels were monitored before and after drying using thin layer chromatography (TLC) method, following the AOAC specifications.

The details for each test were as follows:

<u>Test 1</u>

- Initial moisture content: 23.6%db (19.09%wb)
- Continuous aeration with ambient air (see details in fig. 1.2)
- Air flow: $3m^3/min-m^3$
- Aflatoxin B_1 before and after drying: not detected

<u>Test 2</u>

- Initial moisture content: 34.2%db (25.48%wb)
- Continuous aeration with ambient air (see details in fig. 2.2)

- Air flow: $4.5m^3/min-m^3$

- Aflatoxin B_1 before drying:

depth:	ppb
0.05m	4.4
0.8	35.9
1.4	7.6

Test 3

- Initial moisture content: 20.0%db (16.67%wb)

- Intermittent aeration: 12h on, 12h off during periods of high RH (see details of ambient conditions in fig. 3.3)

- Air flow: $4m^3/min-m^3$

- Aflatoxin B_1 before drying:

depth:	ppb
0.05m	110
0.8	160
1.4	90

The results of the tests can be summarized as follows:

a) drying time

	Test 1	Test 2	Test 3
Initial moisture (%wb)	19.1	25.5	16.7
Final moisture (%wb)	11.5	14.5	12.3
Time in days	10	14	11

The evolution of moisture contents is shown in fig. 1.1, 2.1 and 3.1 respectively.

b) aflatoxin B_1

As mentioned previously, no aflatoxins were detected before and after drying in test 1. The levels of aflatoxin B_1 at different depths of the grain bed are shown in figures 2.4 and 3.4. respectively.

c) energy consumption

For test 1 the energy consumption was as follows:

- electricity consumption approx. 2.3 MJ/kg H_2O

- heat energy consumption approx. 4.6 MJ/kg H_2O

The energy consumption for tests 2 and 3 is shown in fig 2.3 and 3.2 respectively.

6. Conclusions

The preliminary experiments on the use of near-ambient in-store drying as a second stage drying have shown that in spite of the length of the drying process, namely ten to fourteen days, it is still possible to control the build-up of aflatoxin B_1 in corn. This was achieved when the initial moisture content of grain was not higher then 19%wb and was definitely not achieved when it was over 25%wb. This was shown in test 2 when in spite of low initial level of aflatoxin there was a significant increase in the top portion of the grain bed at the end of the experiment. This contrasts with the results of the test 3 when the aflatoxin level remained relatively constant throughout the trial. Results of the test 2 are clearly showing that near-ambient in-store drying is effective only when it is performed rigorously at moisture contents below 19% and therefore cannot be considered as an option for the first stage of drying.

As far as specific energy consumption for near-ambient aeration is concerned the tests have shown figures varying between 1.7MJ/kg evaporated water for the on/off option (test 3) and up to 2.9MJ/kg for continuous ventilation. These figures compare very favourably with those for high temperature dryers: approx. 4MJ/kg H_2O for a mixed flow dryer and 6-9MJ/kg H_2O for a cross-flow dryer without recirculation.

Although the results of these tests appear promising, they are qualified by the limitations imposed by the small size of the pilot bins and the small range of conditions tested. More information is required about the dynamics of the fungal growth and aflatoxin production under different environmental conditions. It is only after such information has been collected, a model established and tested in pilot plant experiments followed by industrial scale trials that recommendations for use of in-store drying can be issued.

7. References

Bullerman, L. B., Schroeder, L. L. and Kun-Young Park 1984. Formation and Control of Mycotoxins in Food. Journal of Food Protection. Vol. 47, 8, p. 637-646.

De Padua, D. 1992. Feasibility Report on Grain Drying in the Philippines. In "Feasibility Report on Grain Drying in the Philippines and Thailand". Unpublished report for ACIAR.

Gilbert, J. 1991. Regulatory Aspects of Mycotoxins in the European Community and USA. In "Fungi and Mycotoxins in Stored Products". ACIAR Proceedings No 36, p. 194-197.

Kositcharoenkul S., Tanaka T., Siriacha P., Arai K., Tonboon-ek P. and Bhudhasamai, K 1991. Simplified Rapid Screening Method for Aflatoxin in Maize. Paper presented at the 14th ASEAN Seminar on Grain Postharvest Technology, 5-8 November 1991, Manila, Philippines.

Pitt, J. 1992. Aflatoxigenic Fungi. Australian Mycotoxin Newsletter. Vol. 3, 1, p. 1

Quitco, Raquel T. 1991. Aflatoxin Studies in the Philippines. In "Fungi and Mycotoxins in Stored Products". ACIAR Proceedings No 36, p. 180-186.

Rural Investment Overseas, 1988. Thai-British Maize Aflatoxin Project. Final report.

Siriacha P., Tanboon-Ek P. and Buangsuwon D. 1991. Aflatoxin in Maize in Thailand. In "Fungi and Mycotoxins in Stored Products". ACIAR Proceedings No 36, p. 187-193.

Taniwaki, M. 1992. Personal communication.

Van Egmond H. P. 1989. Current situation on regulations for mycotoxins. Overview of tolerances and status of standard methods of sampling and analysis. Food Additives and Contaminants. Vol. 6, 2, p. 139-188.

Van Egmond H. P. 1991. Regulatory Aspects of Mycotoxins in Asia and Africa. In "Fungi and Mycotoxins in Stored Products". ACIAR Proceedings No 36, p. 194-197.

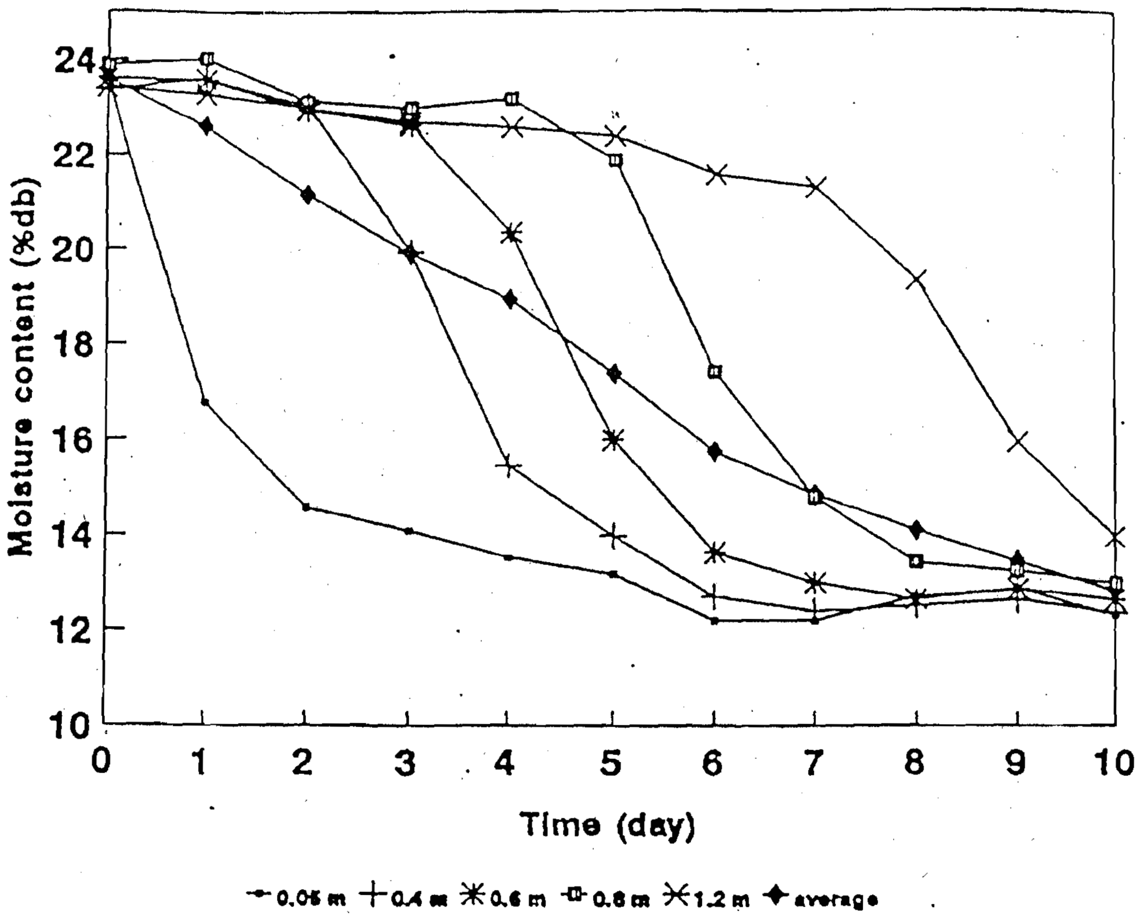


Figure 1-1 Evolution of moisture content (Test No.1)

$\dot{m} = 3 m^3/min - m^3$

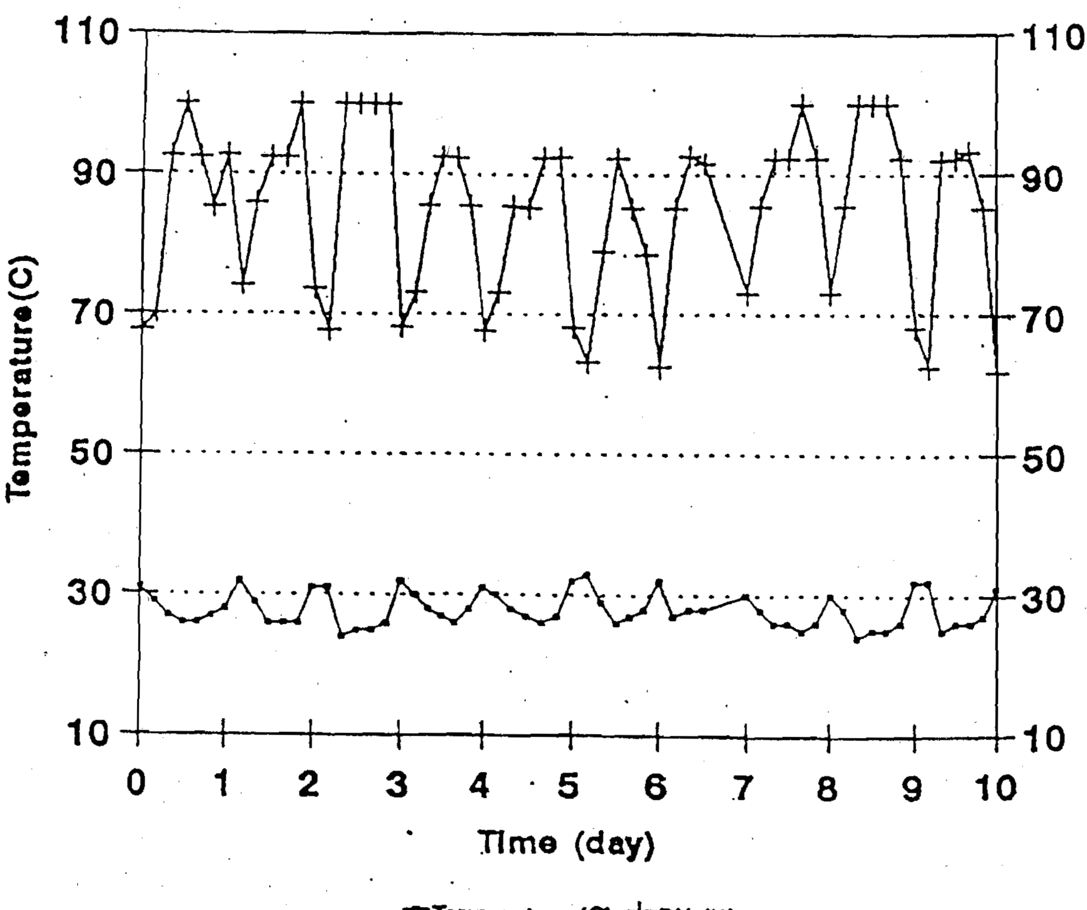


Figure 1-2 Ambient air condition (Test No.1)

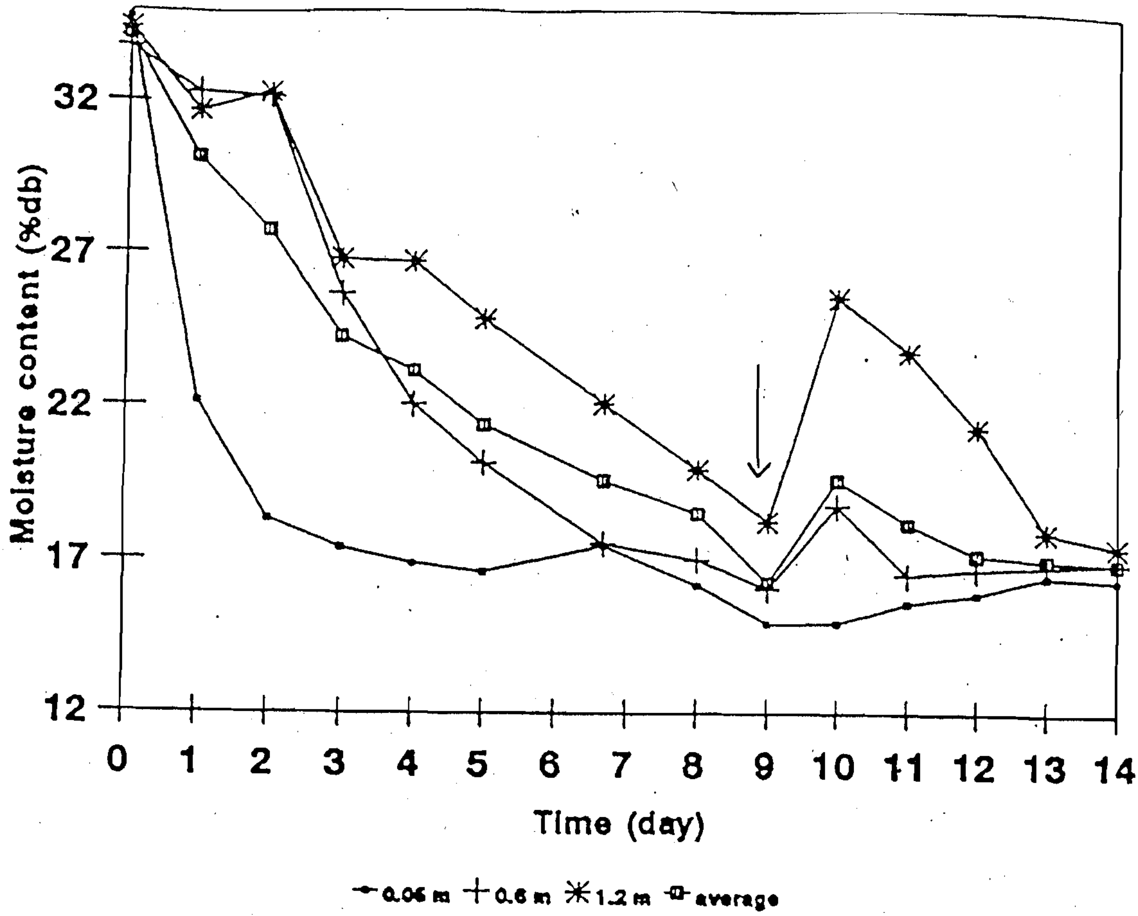


Figure 2-1 Evolution of moisture content (Test No.2)

$\dot{m} = 4.5 \ m^3/min\text{-}m^3$

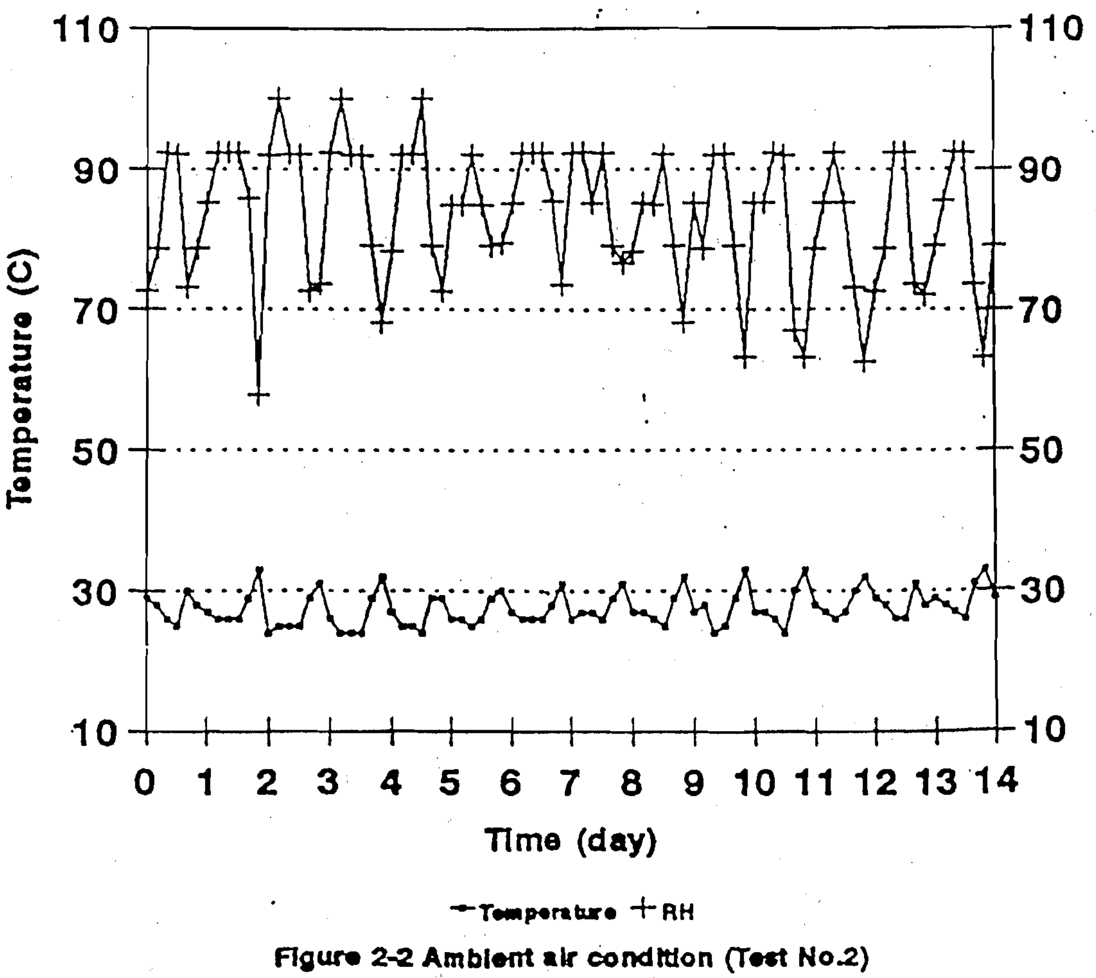


Figure 2-2 Ambient air condition (Test No.2)

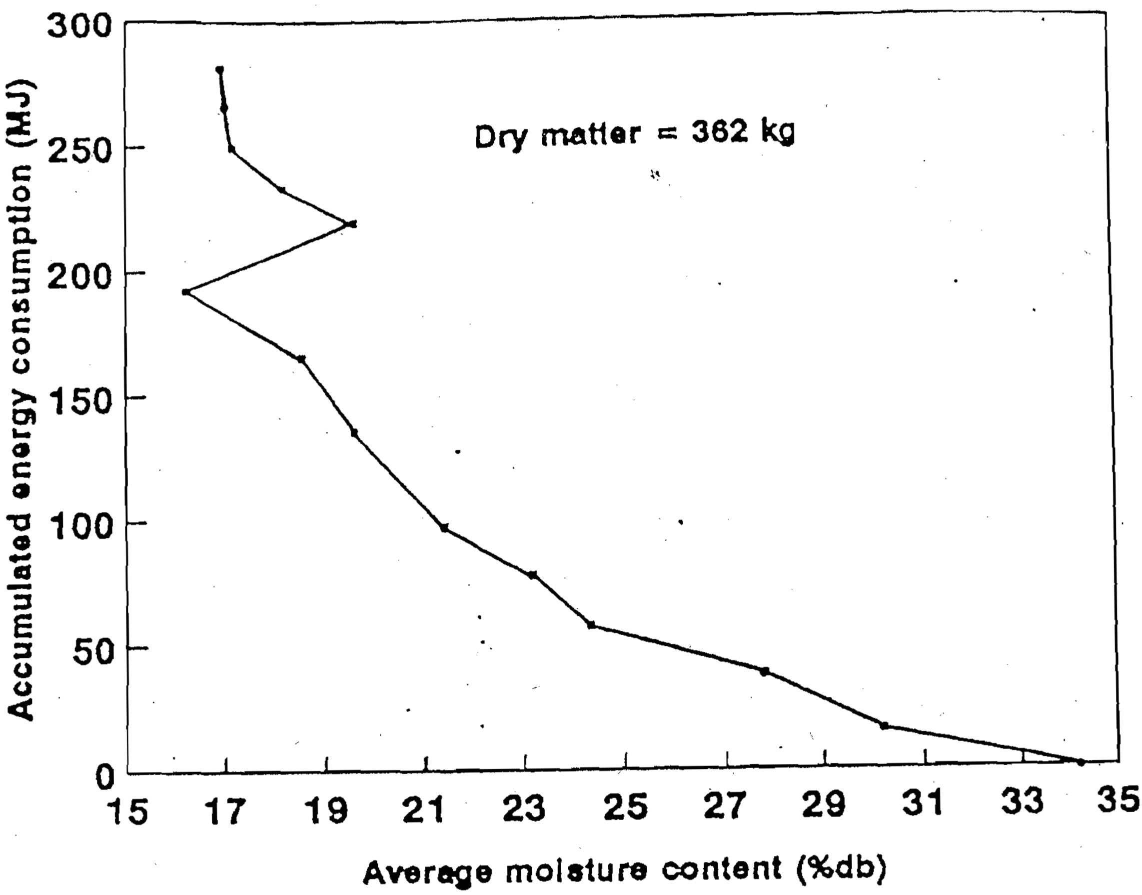


Figure 2-3 Effect of average moisture content on energy consumption (Test No.2)

2.9 MJ/kg H_2O

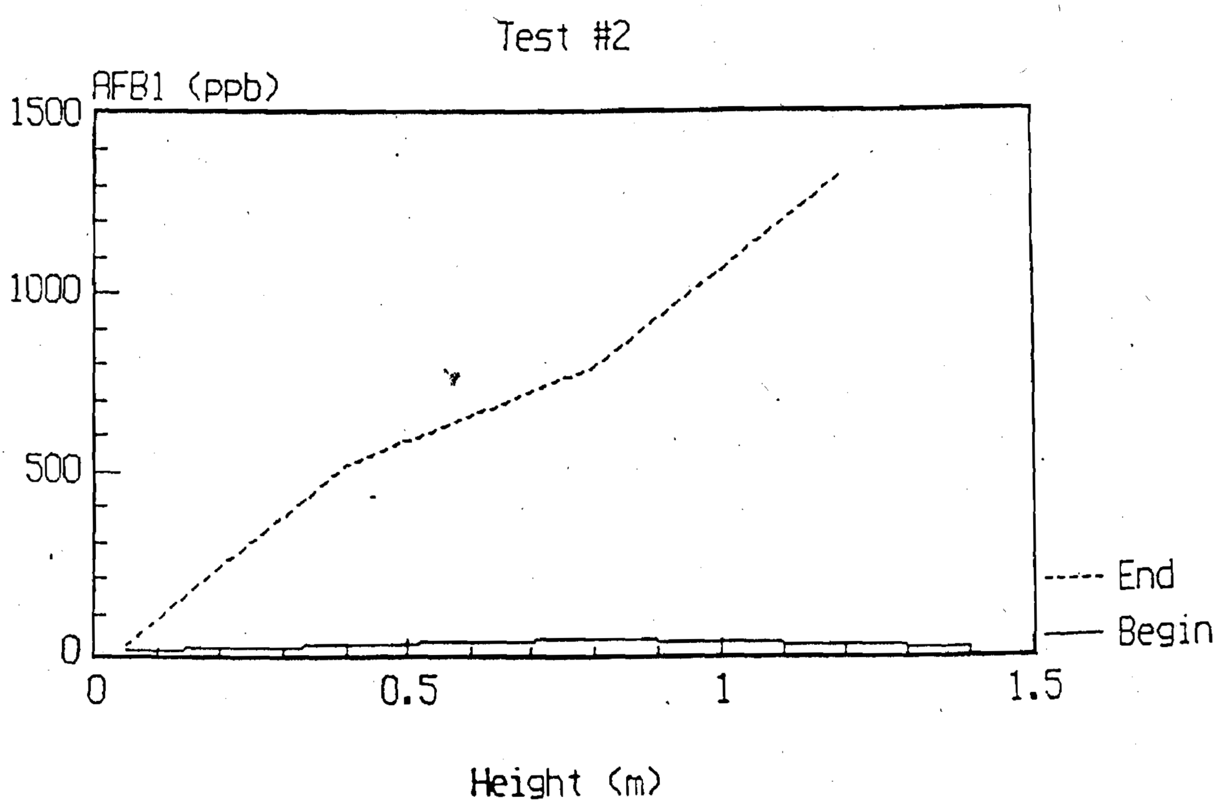


Figure 2-4 Aflatoxin in grain bed, (Test No.2)

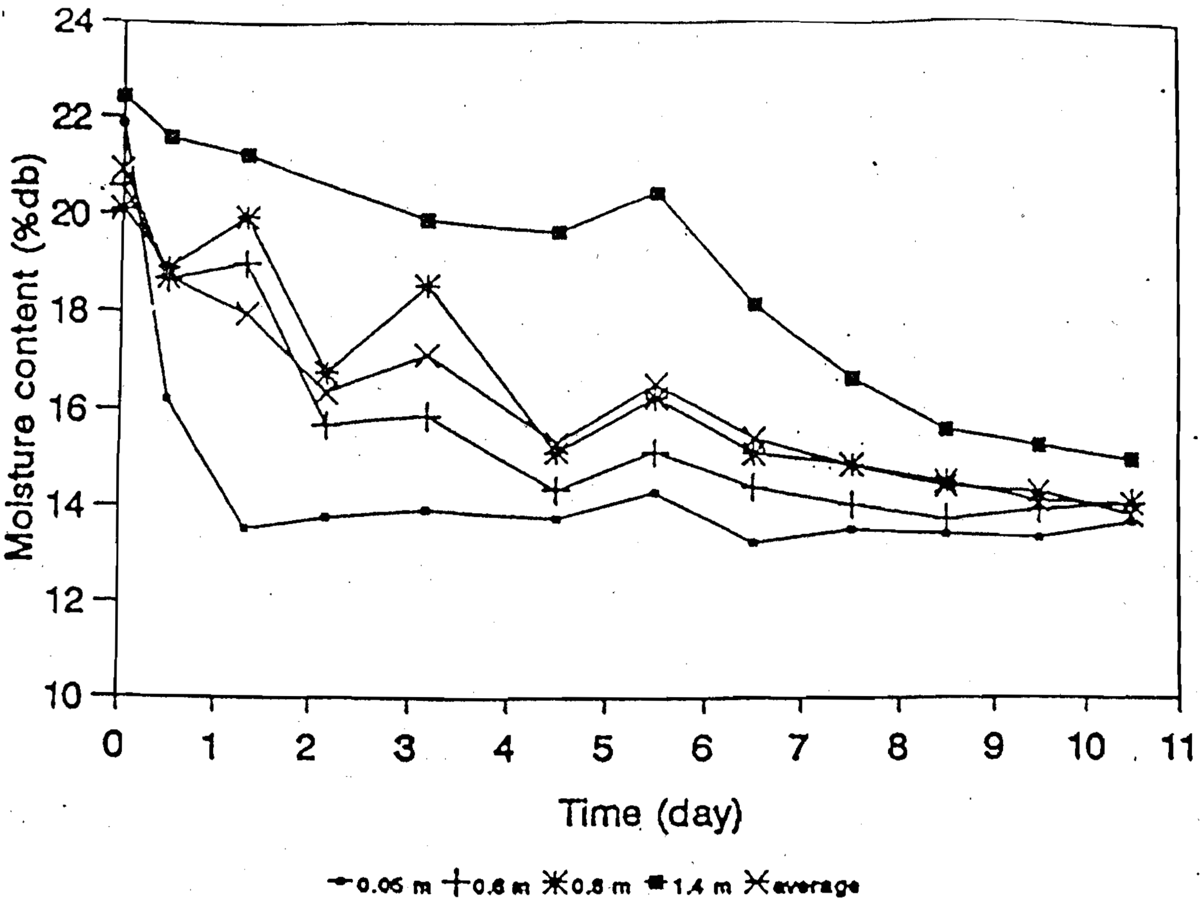


Figure 3-1 Evolution of moisture content (Test No.3)

$\dot{m}$ = 4 m^3/min-m^3

12h ventilation on

12h ventilation off

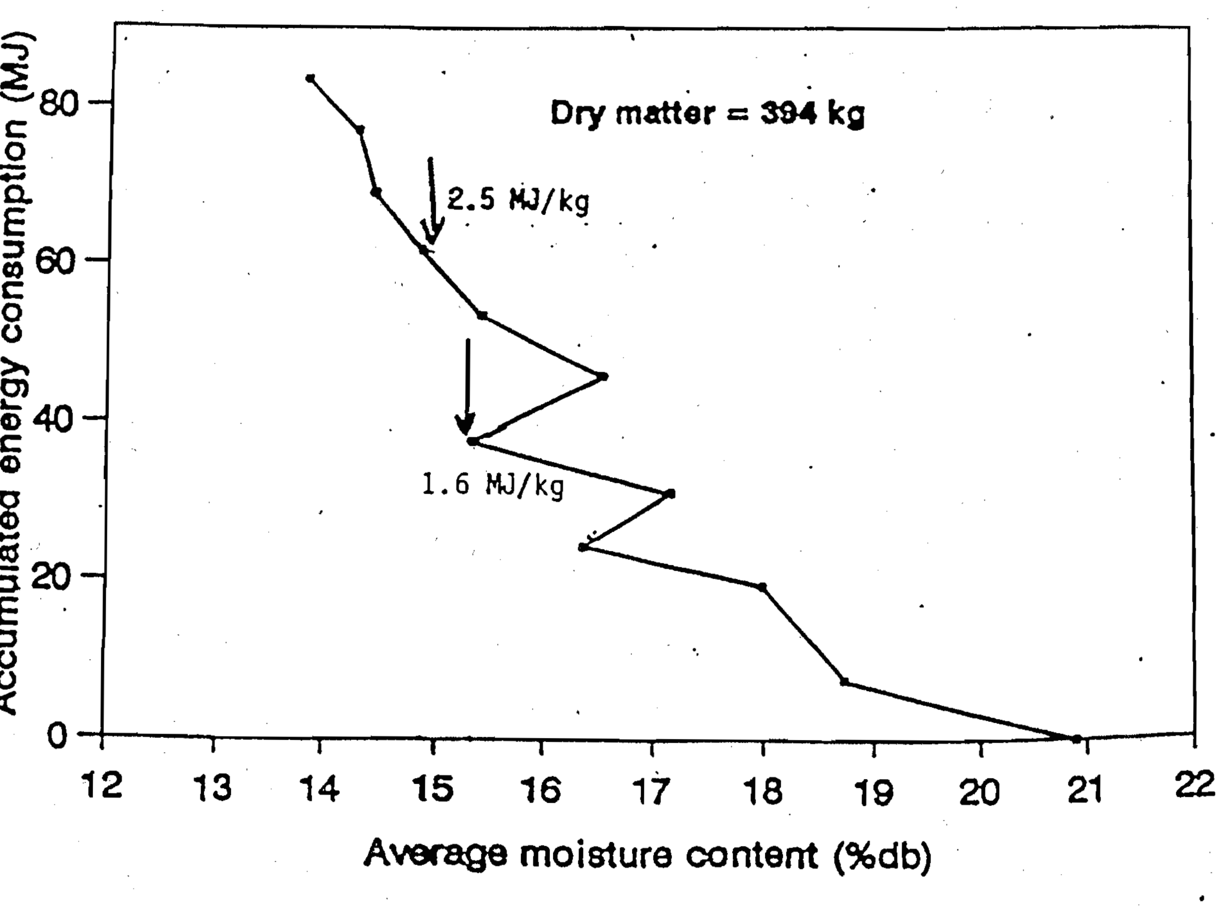


Figure 3-2 Effect of average moisture on energy consumption (Test No.3)

1.6 MJ/kg H_2O

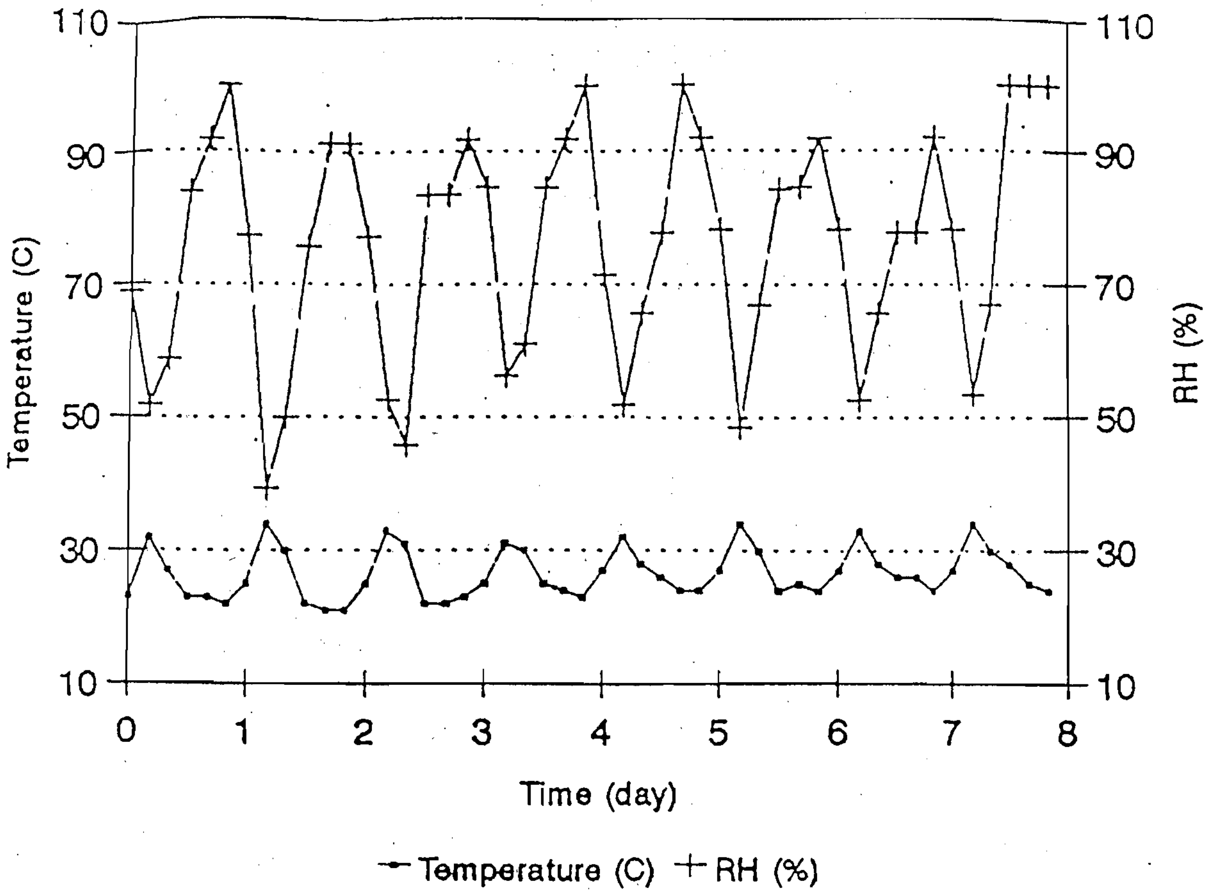


Figure 3-3 Ambient air condition (Test No.3)

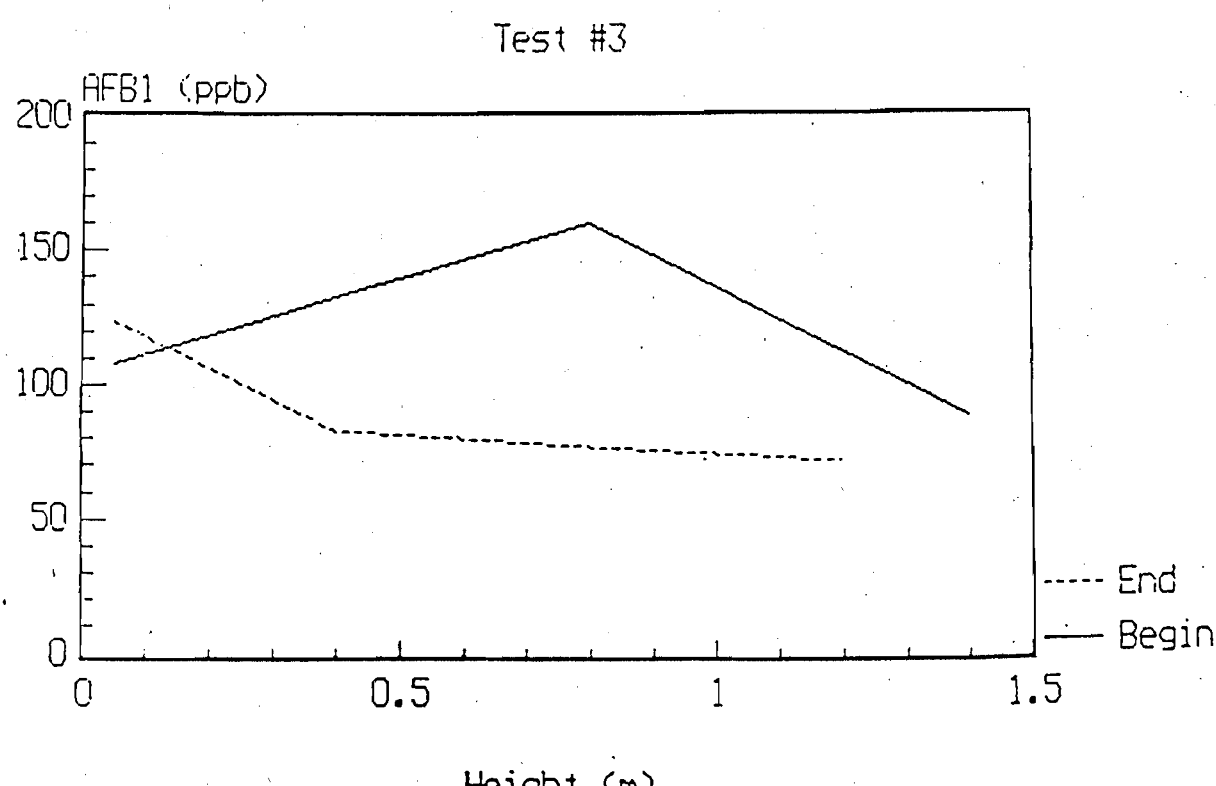


Figure 3-4 Aflatoxin in grain bed, (Test No.3)