The role of leaving maize unharvested in the field after field maturity (field-drying) in controlling aflatoxin contamination

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SUMMARY

Studies in Thailand involving field-drying trials at two agricultural research stations, and 35 grain drying trials in two provinces, strongly indicate that field-

drying for between 2 to 4 weeks may have a significant role in controlling levels of aflatoxin in Thai maize.

The field-drying trials were monitored weekly over a 6-week period (7 treatments) in randomised replicates of 4 using the Suwan 1 variety of maize. Fifty plants were used in each replicate and the trials were carried out in both the dry and rainy seasons. No trend towards an increase in aflatoxin contamination was found as field-drying time increased, and levels of aflatoxin were low at harvest (< 20 ppb). There was also no significant increase in the occurrence of kernels damaged by mould or insects. In the rainy season, standing maize having a moisture content of 27 to 30% at field maturity, was found to have dried to 18 to 22% after. 2 weeks of field-drying. These results were consistent with those obtained during 35 mechanical drying trials. In these, maize with a field-drying history of 1 to 4 weeks was shelled within 48 hours of harvest, put in a drier within 12 hours of shelling, and dried to a moisture content of 14% or 16% in less than 48 hours. The resulting maize had a total aflatoxin content which averaged less than 5 ppb, at a time when controls averaged over 100 ppb.

The advantages of field-drying were found to be: 1) it reduced moisture content to 18-22% which would make aflatoxin control by subsequent 1 - stage mechanical drying to 14% m.c. more economic, 2) it should reduce shelling damage, 3) it reduced initial onfarm aflatoxin contamination of cobs, and may reduce further contamination during long-term storage of cobs. The disadvantages would be: 1) planting of a second crop would be delayed, 2) there would be an increased risk of losses due to storm or rodent, 3) the farmer stands to lose financially unless he is adequately compensated for weight loss.

Feed-mills, and some exporters, are willing to pay a premium for maize having a low level of aflatoxin. If field-drying is used as part of a system to produce low aflatoxin maize at 14% m.c., then part of the premium can be used to compensate the farmer for weight loss, and to encourage him to cooperate with a new system of maize handling.

INTRODUCTION

Mechanical drying of maize to a moisture content of 14%, commencing within 2.5 days of harvest, has been shown (Nagler, M., et al, 1986) to effectively control the level of aflatoxin in maize produced in Thailand during the rainy season. In order to make the mechanical drying more practical and less costly, as well as to reduce shelling damage, it was found necessary to use maize cobs that had been partially dried to a moisture content of less than 22% by natural "field-drying". This is a process whereby maize is left standing unharvested in the field for a period after field maturity which allows the cob to dry as it attains equilibrium with the average relative humidity in the air. Thirty-five drying trials carried out in 2 provinces of Thailand during the rainy season in 1985 indicated that field-drying for between 1 to 4 weeks was effective in reducing levels of moisture from)26% to the range 18 to 22%, whilst maintaining physical quality and controlling levels of aflatoxin to an average of 3 ppb, see Figure 1.

The present studies were undertaken in order to provide further evidence as to the efficacy and advisability of incorporating field-drying in aflatoxin control procedures.

METHODS AND MATERIALS.

Field trials to evaluate the effect of extended fielddrying on maize quality as determined by level of aflatoxin, moisture content, and physical appearance, were carried out at two locations within Thailand. These were at Kasetsart University's "Farm Suwan" in Nakorn Ratchasima Province, and the Department of Agriculture's "Agronomy Centre", Tak Fah in Nakhon Sawan Province.

A randomised complete block design, with 4 replicates of 7 treatments comprising monitoring at field maturity, t = 0 (110 days), and t = 1, 2, 3, 4, 5, and 6 weeks, was used. Fifty maize plants of the most widely planted variety, "Suwan 1", were used for each replicate. Both the rainy season crop, planted in the third week of May 1986, and the dry season crop, planted on the 24 July at the Agronomy Centre, and 4 August at Farm Suwan were studied at each location. At the harvest time for a treatment, The 4 replicates were harvested on the same day and the number of cobs in each replicate was recorded. The number of cobs damaged by mould, insect, rat, or by other means, was also recorded. The cobs were shelled on the day of harvest and the moisture content of the grain was measured using a "Steinlite" moisture meter.

The replicated samples were then dried to a moisture content of < 12% by use of a forced-air oven at Farm Suwan and by sun-drying at the Agronomy Centre. Dried maize was sealed in a plastic bag and stored temporarily in a cold room at the

Department of Agriculture awaiting analysis. The bulk samples were divided to give a representative 2009 or 500 9 sample of kernels for physical and mycological studies. The remaining sample, in the order of 5 to 10 kg, was coarse-ground using a hammer mill (Christy-Hunt Essex Minor powered by a lister LT1 diesel engine) fitted with a 6mm screen. The ground sample was divided to give a 2.5 kg subsample which was fine ground using a 1 mm screen in the hammer mill. A 1.25 kg. sub-sample of the fine-ground material was formed into a slurry with water, ratio meal: water 1: 1.25, using a 4 litre Waring blender for 3 minutes, Fifty gramme aliquotes of this slurry were used to determine the level of aflatoxin using a method employing High Performance Thin Layer Chromatography (HPTLC) developed at the Tropical Development and Research Institute, London. The method uses a novel "BondElut" phenyl-bonded clean-up column (Analytichem International). A Camag Scan 2 densitometer controlled by a Hewlett Packard HP 6201 computer was used for quantification and confirmation was by formation of the hemi-acetal derivative by trifluoroacetic acid on a TLC plate.

RESULTS AND DISCUSSION

Effect of Extended Field-Drying on Level of Aflatoxin Contamination

a. Rainy Season.

No increase in levels of aflatoxin was observed, at either location, with increasing length of field-drying over the 6 week monitoring period, see Table 1. At Farm Suwan only 1 out of the 28 samples contained a detectable level of aflatoxin, but this was at the relatively high level of 75 ppb. This sample was one of the replicates taken after just 1 week of field-drying and resulted in an anomalous mean aflatoxin level of 19 ppb for this treatment. At the Agronomy Centre 5 out of 28 samples contained detectable levels of aflatoxin, but ail were less than or equal to 5 ppb. Hence, not only was there no increase in levels of aflatoxin during fielddrying, but also the degree of aflatoxin contamination was very low, being less than 3 ppb at Farm Suwan and less than 1 ppb at the Agronomy Centre. These results provide further evidence that extended field drying can be safely used as part of an aflatoxin control procedure for Thai maize produced during the rainy season.

b. Dry Season

There was no trend towards an increase in levels of aflatoxin contamination with increasing lengths of fielddrying at either location during the dry season trials, see Table 1. At the Agronomy Centre 50% of the samples contained detectable levels of aflatoxin, but the overall mean was still only 5ppb. Field-drying was studied over a 4 week period, instead of over 6 weeks, at Farm Suwan. No aflatoxin was detected in any of the samples from this location.

Levels of aflatoxin in dry season maize are generally considered to be low in Thailand and problems with aflatoxin prior to storage are rare. This study indicates that field-drying, which is already practised in some growing areas, is unlikely to cause an increase in aflatoxin contamination, but production of other mycotoxins cannot be ruled out.

Effect of Field-Drying on Moisture Content of Cobs

a. Rainy Season

The results are presented graphically in Figure 2. It can be seen that drying to a moisture content of <22% was achieved at both locations within 2 weeks. At the Agronomy Centre maize at field maturity had a moisture content of 29.2%. After 2 weeks of field-drying this had dropped to 21.3%. Moisture content continued to decrease and after 3 weeds of field-drying it was less than 20%, and after 6 weeks it was down to 15.2%. At Farm Suwan the moisture content was below 22% after just 1 week, and after 2 weeks of field-drying it was at 19.4%. The moisture content seemed to stabilise at about 17% after the fourth week.

This data strongly indicates that field-drying can be effective even during the rainy season in Thailand. It is thought that drying is possible because the sheath adequately protects the cob from free water during rain, and the cob can equilibriate with the Average relative humidity of 80 to 85%.

b. Dry Season

Field-drying was very effective during the dry season, as would be expected. At Farm Suwan maize had already dried to a moisture content of 14.4% after 2 weeks, and was down to 13.1% after 4 weeks. At the Agronomy Centre moisture content had reduced from 28.3% at field maturity to 14.8% after field-drying for 3 weeks. Moisture content continued to decrease and reached 10.9% after 6 weeks.

Many Thai farmers already take advantage of fielddrying and this may contribute to the low levels of aflatoxin found in the second crop.

Effect of Field-Drying on Physical Quality of Maize

There was no discernable trend towards an increase in either damaged cobs or damaged grains as length of field-drying was increased up to 6 weeks. At Farm Suwan there appeared to be a dramatic increase in damage during the first week, both in terms of damaged cobs and grain, see Table 2. The percentage of damaged cobs increased from 4.5% to 20.8%, and the percentage of damaged grains increased from 2.8 to 5.9%. As field-drying time increased the percentage of damaged cobs and grains oscillated about the mean and did not trend upwards. There was no corresponding increase in damage during the first week of field-dryintg at the Agronomy Centre. The initial increase in damage at Farm Suwan remains unexplained, but could have been due to some unrecorded environmental factor.

The major form of damage to grain was discolouration which was attributed to mould. There was very little evidence of insect damage to grain during the rainy season. Cobs from the rainy season trial at Farm Suwan were found to be, on average,11.3% mould damaged, 4.6% insect damaged and 1.8% rodent damaged.

These studies indicate that field-drying does not cause an increase in physical damage to grain. In fact the process may well result in better quality grain because damage during mechanical shelling of maize after field-drying, when the moisture content is less than 22%, should be less than that of very wet maize at field maturity. Extended field-drying may not be applicable everywhere. If an area is particularly susceptible to some hazard, such as large-scale bird or rodent attack, or frequent high winds, then it would be advisable to limit field-drying to, say, 2 weeks maximum.

CONCLUSIONS

1. Field-drying was found to be effective in reducing the moisture content of cobs to less than 22% in 2 weeks during the rainy season in Thailand.

2. No trend towards an increase in levels of aflatoxin contamination of maize was found over a 6 week period of field-drying in trials conducted at 2 Agricultural Research Stations.
3. Physical quality of maize was found to be maintained during field-drying, and the percentage of grains damaged during mechanical shelling of such maize would be expected to be reduced relative to that of maize harvested at field maturity.
4. Field-drying is seen as a major factor in controlling aflatoxin contamination of Thai maize during the rainy season. It is an essential step in the UK-Thai Project (UTP) System for the production of low-aflatoxin maize, because it reduces the cost of subsequent mechanical drying and allows drying to be completed in one pass of a continuous-flow drier. Field-drying may also reduce aflatoxin contamination during any subsequent farm storage of cobs, but further studies are needed to confirm this.
5. Disadvantages of field-drying are:

    i. The planting of a second crop would be delayed, and may no longer be possible.

ii. The farmer may lose financially unless he is adequately compensated for weight loss.
iii. There may be an increased risk of losses due to storm or other natural hazard in some areas.

6. Field-drying was found to be extremely effective as a means of reducing moisture content of maize during the dry season, without damaging grain or causing aflatoxin contamination.
7. Feed-mills and some export silos in Thailand are willing to pay a premium for maize having a low level of aflatoxin. If field-drying is used as part of a system to produce low aflatoxin maize at 14% m.c., then part of the premium could be used to compensate the farmer for weight loss, and to encourage him to cooperate with a new system of maize handling.

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Table 1. Effect of Field-Drying on the Level of Aflatoxin In Maize Cobs from Farm Suwan and the Agronomy Centre In a. Rainy Season and Dry Season.

Table 2. Effect of Field-Drying on the Physical Quality of Maize Cobs and Shelled Grain from the Trials at Farm Suwan and the Agronomy Centre in Rainy Season

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CORN SHELLER

INTRODUCTION

As the ear of corn reaches maturity, the individual grains swell and then harden to form a closely-packed cylindrical cob. The kernels on the cob are within the husks which endow some degree of protection from damage caused by insects, fungi and the ambient climate. Recovery of the grains requires the removal of the husks, a reduction in the field moisture content to a safe storage and processing level and removal of the grains from the cob (shelling). Shelling is, therefore, one of the essential processes in corn production

On a large scale, mechanized corn shellers are extensively used on previously harvested and dried cobs, and most farmers in the corn belt area of Thailand use a mechanized corn shelling. Alternatively, grain corn can be recovered directly from the field using a suitable corn picker, picker sheller, or combine harvester, but these kinds of machines have not yet been introduced in Thailand. The large size of corn grains renders them rather vulnerable to mechanical damage.

Shelled corn occupies less storage space on the farm, but because of greater resistance to air circulation, the safe moisture content for storage might be lower than that of ear corn.

HAND-OPERATED CORN SHELLERS

There is a wide variety of hand-operated corn shelling devices and designs available which seek to improve upon manual shelling. However, shellers are often required in the more remote and less prosperous rural areas where factory-made machines may be unattainable. There is seldom a choice of models available to a potential consumer. In these circumstances it may be appropriate to consider construction of a sheller using local materials in a published design.

Pinson and Walker (1984)1 described four basic styles of manual shellers as shown in Table 1. Each style is named as (1) traditional hand methods, (11) hand-held devices, (111) small rotary shellers, and (IV) large hand shellers. Illustrations of typical models are shown in Fig.2. Each style of sheller caters for different economic conditions, such as for, domestic purposes, ownership by one or two small scale farmers, use by labourers on a larger farm, and use by independent farmers on a daily hire basis. There are wide differences in machine performance and operator acceptability, much of which is due to variations in detailed engineering quality.

MECHANIZED CORN SHELLERS

(1) Principles and Types of Mechanized Corn Sheller.

Table 1. Maize shellers and shelling techniques evaluated in laboratory trials

"Spring sheller" works on this same principle, feeding the ears endways into an opening bounded by a rotating flute cylinder, a rotating toothed disk, and a spring pressure plate. The cylinder shells the ears as the disk revolves them. The cob passes through undamaged after the kernels are removed.

The *"cylinder sheller"* has largely replaced the spring sheller because of its greater capacity, its ability to shell corn, and its simplicity, although more power is required because more cob is broken and crushed. The cylinder sheller consists of a cylinder with spiral flutes or paddles which turns inside a cage with longitudinal bars. The cylinder clears the bars by approximately 5 cm, and the bars are spaced apart enough to let kernels fall through but retain cobs. The ears are fed into an opening at one end of the cage. The spiral flutes feed them through the cage and at the same time shell the ears by rolling and crushing action against the cage and each other. In some machines the cage bars are slightly flexible to reduce crushing of cobs and kernels. An adjustable cob gate serves to control the flow of corn through the cylinder, and it is adjusted to hold the corn in the cylinder long enough to be completely shelled.

For the cylinder sheller, many different types and configurations of shelling devices exist, but very few have reached the stage of even limited field use. The three types generally employed in present day combines are cross-flow rasp-bar cylinders, axial-flow rasp-bar cylinders, and spike-tooth cylinders. Spiketooth cylinders were used almost exclusively in both combines and corn shellers prior to about 1930, but most combines now produced have rasp-bar cylinders. Spike-tooth cylinders are now used to a limited extent in OS or European countries, but in Thailand spiketooth cylinders are most abundantly used.

Most cross-flow, rasp-bar cylinders have opengrate concaves with rectangular bars paralled to the cylinder axis. The clearance between the concave bars and the corrugated cylinder bars is adjustable. High speed motion pictures have shown that in cereals the main shelling effect results from the impact or shattering action of the cylinder bars hitting the head at high speed. Although rubbing undoubtedly contributes to the shelling action, the primary function of the concave appears to be holding or bringing the material into the cylinder-bar path for repeated impacts.

Axial-flow (helical-flow), rasp-bar cylinders are similar to conventional cross-flow cylinders except for the number and arrangement of rasp-bars on the rotor. Each of the 2 rotors has 2 pairs of rasp bars 180 apart, instead of 8 to 10 uniformly spaced bars. Another arrangement, on single-rotor machines, has three equally spaced, helical rasp-bars (that move the material along the rotor) and a staggered arrangement of short, axial sections between the helical bars.

The open-grate concaves on axial-flow cylinders are of the same general type as those used with crossflow rasp-bar cylinders and are adjustable in a similar manner to change cylinder-concave clearances. A major functional difference is that the material passes through the shelling zone between the axial-flow cylinder and concave several times as it moves rearward in a helical path, rather than making a single pass as with a cross-flow cylinder.

The arrangement of a spike-tooth cylinder and concave is such that the cylinder teeth pass midway between staggered teeth on the concave, thus producing a combining action in addition to the highspeed impacts upon the heads. The concave assembly is adjusted laterally to give equal clearances on both sides of the cylinder teeth.

The teeth in the spike-tooth concave are mounted on perforated, removable sections, usually with two rows of teeth per section. The total number of rows of teeth needed in the concave (usually 2,4 or 6) depends on the shelling conditions. Perforated blank sections, or grid-type grates are added to fill the concave space.

A spike-tooth cylinder has a more positive feeding action than a rasp-bar cylinder, with added advantages that it does not plug as easily, and requires less power. Rasp-bar cylinders are readily adaptable to a wide variety of crop conditions, are easy to adjust and maintain, and are relatively simple and durable. A raspbar cylinder with an open-grate concave has greater seed separating capacity than a spike-tooth cylinder.

Rubber Roller Shellers.

In the conventional cylinder shellers, the corn kernels are subjected to mechanical damage while passing through the shelling section, which consist of the steel cylinder and steel concave. Pickard4 and USDA engineers5 studied the use of a relatively soft material, like rubber, instead of steel for the rasp-bar and for the cylinder. This is similar to the groundnut rubber roll sheller developed by Khon Kaen University.

EFFECT OF OPERATING CONDITIONS ON CYLINDER LOSS AND SEED DAMAGE

The shelling efficiency will be evaluated by the amount of corn left unshelled on the cob (called cylinder loss) and damage on the kernels.

Shelling effectiveness is related to (a) the peripheral speed of the cylinder, (b) the cylinder-concave clearance, (c) the number of times the material passes the concave (e g., axial-flow cylinder), (d) the number of rows of concave teeth used with a spike-tooth cylinder, (e) the condition of the crop in terms of moisture content, maturity, etc., and (f) the rate at which material is fed into the machine.

Cylinder Loss

Such factors as cob moisture content, kernel cylinder-concave clearance Infuence the performance for cross-flow cylinder shellers, and these factors plus the restriction at the cob gate influence the performance of the axial-flow sheller. (18.75 mm) for rasp-bar cylinders.

Johnson et al indicated the relationship of cylinder loss as influenced by kernel moisture content. In this case a range of loss was proposed which represented the values occurring from both types of shelling cylinders, various reasonable adjustments, and several operating conditions (Fig. 8 The range of cylinder loss which comes about because of cylinder adjustments).

Goss et al8, report similar data on cylinder loss versus moisture content. These data are presented in Fig.9 (see Fig. 9 Cylinder loss and its relation to kernel moisture content. Self-propelled unit-cylinder-concave clearances were 314 to 1-inch at front, 5/8 to 314-inch rear; cylinder speed was 2760 to 2905 fpm; feed-rate not including corn, was 190 to 370 lb per minute. Combine with snapping roll-clearances were 1 114-inch at front and 9/16-inch at rear; cylinder speed was 2750 to 2865 fpm; feed-rate, not including corn, was 37 to 85 lb per minute.) show that a difference in loss level exists. Important is that cylinder loss tends to increase with kernel moisture but with careful adjustment this loss can be maintained below 1%.

Some workers reported that kernel moisture does not correlate as well to cylinder loss as does cob moisture. Burrough and Harbage concluded that when the cob moisture was high, considerable cob breakage occurred because the cob was too "spongy" for good shelling.15 Their results, presented in Fig.10 (see Fig. 10 Effect of cob moisture content on the loss of unshelled kernels by an axial-flow shelling unit), were from a picker-sheller travelling at 4.0 km/hr.

Morrison, in making comparative tests between a combine and a conventional sheller, presented information on the effect of several crop and machine factors on the cylinder loss.

Fig. 11 Cylinder loss, combine with rasp-bar cylinder compared to a conventional stationary sheller.

Effect of Adjustment and Design

Packard conducted tests of crop and machine variables on the influence of cylinder loss. His data are presented in Fig.12 and 13 (see Fig. 12 Comparison of results for various bars with respect to shelling and crackage and Fig. 13 Effect of cylinder-concave clearance, kernel moisture, cylinder speed, and ear orientation upon shelling efficiency and kernel crackage). From this work he concluded:

- Rasp-bar cylinders appeared to be superior to angle-bar cylinders in shelling efficiency.
- Rubber on the cylinder or concave appeared to have little effect on shelling
- Cylinder-concave clearance of 5/8-inch (15.5 mm), rear, is more desirable than 314-inch (18.5 mm) for rasp-bar cylinders.
- Cylinder loss appeared to be excessive at 30% kernel moisture content.
- Cylinder speed of 800 rpm (15.7 m/s) is more desirable than 600 rpm (11.9 m/s).
- Orientation of ears entering the cylinder is not important.

Kernel Damage by Cylinder Actions.

Breakage is of concern because unless the fines are screened out they interfere with drying and increase the possibility of grain spoiling in storage.

Damage from a rasp-bar cylinder increases with peripheral speed, especially at speed above 15.2 m/s. 11.12 Laboratory studies have indicated that damage is considerably less when the ears are fed into the cylinder with their axes parallel to the cylinder axis, rather than longitudinally or In random orientation.13 Kernel moisture content has a significant effect on damage from either a combine cylinder or a cage-type sheller. Results from various studies 13,44 indicate that crackage increases as the moisture content is changed in either direction from a minimum crackage zone of about 20 to 22% (Fig. 14 Effect of kernel moisture content upon grain crackage from two types of shelling units, as determined with a 4.8-mm (12164-in.) screen.).

Shelling actions can be obtained by machine adjustment that will remove all kernels. However, any adjustment must also be considered in terms of the kernel crackage which results. The more severe the shelling action, the greater will be the crackage.

Crackage or damaged kernel ratio is determined by (a) visually separated, (b) screening by 16/64 (6.25 mm) and 12164 (4.80 mm) round hole sieves, or (c) a colorimetric technique.

The visual separation method is reliable for determining broken kernel ratio, however, it takes a lot of time, and also for the determination of injured kernel or slightly cracked kernels, it greatly depends on the person's skill.

The sieving method was developed for grading corn into a certain grade depending on the ratio of crackage and impurities. This method is good for determining marketing value of a certain lot of corn, but for evaluation of corn sheller especially in the ease of fungus infection concerns, this method might not be suitable.

A calorimetric technique was developed by Chowdhury 6,18 to provide a fast and reliable system of grain damage evaluation. The technique is based on determining the amount of surface area of the corn kernel that is damaged. The starch molecule of damaged tissues and cells are reacted with a fast green FCF dye, and subsequently, the amount of dye absorbed by the exposed starch molecules is established by extracting the dye with a dye-recovery solution. The concentration of the dye in the recovery solution is determined by measuring the percentage transmission of light through the solution by using a spectrophotometer.

The influence of moisture content on crackage are shown in Fig.13 and 15 (see Fig. 15 Effect of kernel moisture on the percentage of kernels cracked by the sheller.). 10,16 In all cases, crackage significantly increased as kernel moisture increased.

The data presented thus far have related crackage to kernel moisture content mainly at moisture contents above 20%. Barkstorm 17 and Gross 8 reported on tests where crackage was observed for moisture contents below 20% (Fig. 16 Crackage as influenced by kernel moisture and cylinder speed.). The trend in these data is one of increased crackage with decreasing kernel moisture content. There is no inconsistency between these data and those presented before. Crackage appears to reach a minimum in the 18-19% moisture range. At kernel moistures above 20%, the soft kernels are easily crushed from an impact loading. At the low moistures the kernel becomes hard and brittle. In this condition it again becomes easily fractured under the impact loading of the cylinder.

Fig. 17 Kernel crackage as related to moisture content using the 22-inch rasp-bar cylinder

Besides influencing the kernel crackage, the shelling mechanism also affects the cob breakage. The size of the cob discharged from the cylinder affects the resulting separating characteristics of corn from the cob. Table 2 presents the size distribution of cob parts resulting from a combine cylinder operated at 670 rpm and a 5/8-inch (15.63 mm) cylinder-concave clearance (rear).

THE STUDY ON CORN SHELLER IMPROVEMENT IN THE MQIRC

In 1988, a Study on the relation between types of corn sheller, operational conditions and aflatoxin contamination was done by the Post-Harvest Section Maize Quality and Improvement Centre, DOA, Thailand.

This study was intended to clarify the relation between type of mechanized corn sheller, kernel moisture content, occurrence of mechanical damage to kernels and aflatoxin contamination, and then to contribute to corn sheller improvement.

Methods and Procedures.

Four types of corn sheller; namely, the rasp-bar cylinder sheller with special rubber attached on the spiral bars (ALVAN BRANCH Model AB/MS/8000S, England), the spike-tooth cylinder sheller (NIPPON SHARYO Model "NCR-1200': Japan), the plate-tooth cylinder sheller (a variation of the spike-tooth cylinder sheller: "LOTUS 77' Thailand), and the two row, spring sheller (CHIKUMA, Japan), were tested. All the cylinder shellers tested were of the axial-flow type.

Variable factors were the periphral speed of the cylinder or shelling disc and the kernel moisture content. Factors other than these two remained constant. The peripheral speed of the cylinder was set at three or four levels according to the results of performance tests and the standard cylinder speed of each machine prescribed by the manufacturers. Intervals of the speed was varied based on rpm, and each interval was 50 rpm. Proposed moisture contents were 32, 27, 23 and 18% (wb). It was intended that preparation of these was to be accomplished in the field from which the sample came.

Samples were harvested divided into four times at Koktum district in Lopburi Province, than the middle of August to early September. After harvest, ear corn was put in gunny sacks and kept one night underneath the farmer's house. On the next morning of the harvest day, the corn was delivered from Lopburi to the MQIRC, Bangkhen, Bangkok. The variety of corn was "Suwan 1".

To estimate suitable rpm levels for this trial and to fix feeding rate (Kg ear maize/min), performance test for each corn sheller was conducted prior to the shelling experiments. In this test, measurements of machine elements were also done.

Occurence of kernel damage and contamination of foreign material were investigated using samples extracted from corn kernels produced from approximately 400 kg of ear corn for the cylinder shellers, and 40 kg of ear corn for the spring sheller. In 1988, these procedures were done by the visual separation method.

Shelling efficiency was evaluated using samples extracted from the second and third outlet. All the kernels remained on the cobs were shelled manually, and both fractions were weighed to calculate the cylinder loss.

For four consecutive weeks after shelling, shelled corn samples each around 80 kg for the cylinder shellers and 20 kg for the spring sheller were stored under ambient air conditions, and during the storage period, samples for quantitative analysis of aflatoxin content were extracted on the 0, 1, 3, 7, 14, 21 and 28th day. Kernel moisture contents of the samples were determined by a calibrated single kernel moisture meter.

Results and Discussions

In the case of rasp-bar cylinder sheller, usually the rasp-bars are on the cylinder but in this sheller the raspbars are attached inside the concave drum.

In the spike-tooth sheller the cylinder teeth are columnar shape while traditional spike-tooth cylinder has rectangular teeth. This sheller does not have a blower, only a sieve. All the fine foreign materials and crackage were mixed with the whole kernel fractions.

The plate-tooth sheller is the most common type in Thailand, and is considered as a variation of the spiketooth cylinder sheller. The other type is the rectanglar spike-tooth closed cylinder sheller.

The spring sheller showed the lowest brakage in all moisture contents tested, but capacity is extreamly low because of its shelling mechanism. Also shelling efficiency of this sheller was extremely low to high moisture corn. For example, it was not able to shell about 41% of kernels by weight in the case of 32% m.c. while cylinder loss of the cylinder sheller was 0.5 to 5.0% at the same m.c.. (Table 3. Mechanical Damage on Kernels and Shelling Efficiency and continued)

Moisture content of kernels was deeply correlated with the broken kernel ratio.

(Fig.33) For the plate-tooth cylinder and the spike-tooth cylinder sheller, an inflection point of the broken kernel ratio appeared at around 23% moisture content. (Table 3) As with Similar results before, the rubber attached on the cylinder was not effective in decreasing the damage kernel ratio.

Aflatoxin contents decreased as the initial moisture contents of samples decreased except in the case of 23% m.c.. The relation between the damaged kernel ratio and aflatoxin contamination was not clear for each moisture content. Evaluation method of crackage we took was the visual separation method. Determination amount of this method for slightly injured kernels was fluctuated largely depending on the operaters' skill. However, exposed starch molecule from the slightly injured parts is also attacked by A. flavus, and have possibilities to produce aflatoxin. Then in 1989 alternative evaluation method such as the fast dye method is necessary to take.

To introduce an improved machinery into users, improvement based on to the established and popular model might be a fast way. In 1988, the spike-tooth cylinder sheller performed a low breakage level among the cylinder shellers. Then the following years the studies on improvement of corn sheller is focused on the spike-tooth cylinder sheller and its variation in Thailand.

From the results in 1988 and also the results by Azuma (1988, unpublished and not shown), it is suggested that the length of the shelling part of the spike-tooth and plate-tooth cylinder sheller is too long, so duration of impact loading becomes unnecessarily too long. In 1989, the effects of the range of the teeth placed on the cylinder, the shape of the teeth, and arrangement of the teeth on crackage were examined.

MOISTURE METERS

INTRODUCTION

Moisture content is one of the most important factors in quality control of grain especially in controlling fungus infestation. Products with a high moisture content will not keep for extended periods in storage, so it is important, therefore, that equipment be available for accurate determination of the moisture content. As aflatoxin contamination in corn is of major concern in Thailand, the necessity for suitable methods to determine moisture content with less time and higher accuracy assumes greater importance. The same equipment might also be used for determining the optimal time of harvest.

From our survey results, most of the farmers in Thailand do not own any devices to determine grain moisture content. In most cases, the farmers rely on visual and sensory grading techniques to estimate the moisture content. For grain, this might entail biting, rattling, feeling, estimating from the planting date or duration, and observation.

The moisture content is an index of the probable keeping quality of the product and can be expressed on either the wet or dry basis. Moisture meters for grain are generally designed to give percentage moisture content on a wet basis.

The method of determining the moisture content of products may be divided into two broad classifications: (1) direct and (2) indirect.

The direct methods are usually accepted as standards for calibration for and comparison with the indirect methods.

Regardless of the method used for determining the moisture content, there are possibilities of errors in making the determination. The major problem is that of securing a sample which is representative of the entire lot of material. To reduce the possibilities of error, several samples should be obtained from different locations in the bin or field. Usually a large sample is obtained which is taken to the laboratory for determining the moisture content. If the sample which is taken to the laboratory is not properly divided, errors may again occur. The sample can be divided equally into two parts with a suitable sample divider. These can be further subdivided for a suitable size of working samples.

The standard deviation of the moisture content of individual kernels in a sample taken from a bin of grain of uniform moisture content critically depends on the measuring device

Direct Methods

Several national and international organizations have developed standard air-oven methods for testing moisture content. These are organizations that deal primarily in cereals and cereal products.

1) International Association for Cereal Chemistry (ICC).

ICC Standard No. 110/1 specifies drying the ground seed of wheat, rice, barley, millet, rye and oats for two hours at 130-133 C. Ground maize seed is dried fore hours at 130-133 C.

2) International Organization for Standardization (ISO).

ISO adopted its moisture testing procedures from the ICC. The crops, and drying times in ISO Standard 712-1985 (E) are the same as in ICC Standard No.110/1.

3) International Seed Testing Association (ISTA).

ISTA procedures for cereals and maize described in Chapter 9 of the rules (Seed Science and Technology, vol.13, p.338-341, 493-495) conform to those of ISO. The procedures in detail are described in Appendix II.

4) European Economic Commission (EEC).

The EEC has also adopted ICC Standard No.110/1 as its procedure.

5) American Association of Cereal Chemists (AACC).

AACC Method 44-15A specifies that soybeans, rice, peas, lentils and grain are to be ground and dried one hour at 130 + 1 C. Whole seed of maize and beans are dried 72 hours at 103 + 1 C. Whole seed of flax are dried four hours at 130 + 1 C.

6) Association of Official Analytical Chemists (AOAC).

AOAC Method 14.063 prescribes a drying period of one hour at 130 + 3 C for ground wheat, rye, oats, maize, buck wheat, rice and barley.

7) Official Grain Standard of USDA.

The Official Grain Standard specify the same methods and crops as AACC.

8) American Society of Agricultural Engineers (ASAE).

ASAE Standard S352 lists oven temperatures and heating times for whole seeds of 31 kinds of agricultural crops. Most of these methods were developed by Hart, Feinstein and Golumbic and published in USDA Marketing Research Report 304 in 1959. The procedures in detail are described Appendix I.

BASIC REFERENCE METHODS

Direct methods that are widely accepted are called basic methods. Basic methods do not require calibration against some other methods and are themselves used in calibrations. Several basic methods have been used for cereals, oil seeds and edible legumes, but there is no general agreement among countries as to which method is best. Several basic methods that have been used in developing air-oven methods for grain are described here.

1) Air-Oven Methods

Air-oven methods are widely used and have been officially adopted by numerous governmental agencies and international organizations. They are relatively simple and inexpensive to conduct and give reproducible results between laboratories. Most technique development has been with cereals, oil seeds and edible legumes, and these methods are often assumed to be adequate for other seeds.

In performing the air-oven method, a weighed quantity of seed is heated at a certain temperature for a specific period of time. The loss in weight during heating is considered to be the moisture content of the sample. However, no single air-oven procedure can be used with the same accuracy on al kinds of seed. Results vary depending on the time and temperature used. Drying to constant weight is not satisfactory because different constant weights are obtained at different temperatures. In many cases, however, temperature and time of heating appear to have been established empirically, based on attainment of constant weight.

Water exists in seeds as "free" water, which is loosely held by capillary forces, and as "bound" water, which is more tightly held. It is difficult to remove all the water without also removing other volatile materials, or causing chemical decomposition that may produce more water, or increasing dry weight through oxidation. The apparent moisture content at any drying temperature is thus a balance of all these factors. Although oven methods are considered basic, they are in fact rather empirical, with results depending on the testing conditions. Proper testing conditions for greatest accuracy must be determined by calibration with another primary method that does not depend on drying temperature and time.

2) Vacuum-Oven Methods

In vacuum-oven methods, seeds are dried a temperatures lower than 100 C in a partial vacuum to reduce the amount of other volatiles released. Temperature still plays a role in determining the apparent moisture content at constant weight, even under vacuum. Non-aqueous volatiles may still be lost because they are released at lower temperatures under vacuum. Since all oven methods are empirical, accurate air-oven methods may not necessary be established by comparison with drying to constant weight in a vacuum-oven.

Air-oven methods developed by the ICC for cereals correspond to the results obtained with the vacuumP2O5 method. In this method, phosphorus pentoxide is placed in the drying tubes to absorb the moisture released from the seeds. ICC Standard No.109/1 specifies drying ground seed to constant weight at 50C, a procedure requiring approximately 150 hours or more.

ISO has adopted the basic method of ICC. The crops, temperature and times in ISO Standard 7111985 (E) are the same as in ICC Standard No.109/1.

The air-oven methods of the AACC were developed to correspond with the results obtained after drying to constant weight (more than five hours) at 98 C -100C in a vacuum-oven (AACC Method 44-40).

The AOAC methods appear to be identical to those of the AACC. The vacuum-oven method is described in AOAC Method 14.003.

3) Distillation Methods

In distillation methods, seeds are placed in a distilling liquid and distilled until no more water is given off. The water is collected and measured by volume. The results obtained depend on the boiling temperature of the liquid used. Toluene is most commonly used and gives satisfactory results in most cases.

Table 4. Caracteristics of Dessicants

Dessicants	Amount of Water Vapour in the Dry Air (g/m)	Drying Temperature for Reclamation
Anndrous calcium chloride	0.2	300
Anhydrous	0.004	230 ~ 250

calcium sulfate		
Phosphrous pent-oxide	0.00002	unable
Molecule sieve	0.0001	200 ~ 400
Activated alumina	00018	180
Silica gel	0.006	150

4) Karl-Fischer Methods

The Karl-Fischer procedure is frequently used as a basic reference method for other procedures. It is useful in measuring moisture content of solids, liquids and gases, and is appropriate for use on seeds. Both "free" and "bound" water are measured. A major advantage is that results are not dependent on temperature or duration of drying. In this procedure, moisture is extracted from a ground sample of seed with methanol and kept with Karl-Fischer reagent to determine the amount. The method is superior to oven methods because the reagents are specific for determination of water, and prolonged heating at high temperature is avoided.

The air-oven methods of the ASAE for whole seeds of 31 kinds of crops were taken from USDA Marketing Research Report 304 and are all calibrated against the Karl-Fischer methods.

5) Other Basic Methods

Near-infrared spectrometry, gas chromatography (GC), neutron technology moisture analysers nuclear magnetic resonance (NMR) and other basic methods for determining moisture content have been developed. Their use on grain has been limited and they still do not have played an important role in moisture determination.

INDIRECT METHODS (SECONDARY METHODS)

Indirect methods involve the measurement of a property of the material including mechanical, electrical, or thermal property, which is related to the moisture content. One of the direct means is required to calibrate the indirect

method. The moisture content is usually expressed on a wet basis for the indirect methods.

1) Electrical Resistance Methods

The electrical resistance or conductivity of a material depends on its moisture content. This principle is used as a basis for a number of moisture meters. These moisture meters must be calibrated for each grain against a standard method. In as much as temperature affects the electrical resistance of a material, corrections for variations in temperature must be made for tests conducted at temperatures other than those at which the calibration is reported. The electrical resistance units are rather simple in design and require only a few seconds for making a moisture determination. The resistance of grain is measured between two steel rolls or plates which serve as electrodes. A different spacing of rolls or plates can be made. One of the problems with the meter is the difficulty of maintaining calibration because wear of the bearings, rolls or springs changes the spacing between the electrodes and gives a lower moisture content. By proper maintenance, however, improper moisture content value due to spacing can be minimised.

The relationship between moisture content and resistance is indicated in the following equation;

log p = — am + c or log (log 1/p) = bm

where a, b and c are constants; m is moisture content; p is resistance.

The pressure exerted on the sample with the electrical resistance method affects the resistance of the product. A straight line must result when moisture content determinations are plotted against oven determinations, so calibration consists only of determining the compression data which will give a straight line on a 45 slope.

The electrical resistance of grain decreases when the pressure is increased.

Above 17% moisture content, there is a parabolic relationship between the moisture content and the logarithm of the electrical resistance. Most meters do not give readings below 7% moisture, because there is very little change in the electrical conductivity. Grain that has been recently dried with heated air

gives lower readings than the actual moisture content. This occurs because the tendency of these meters is to measure the resistance on the surface. If moisture has been added to the grain, the readings are higher than the actual moisture content of the product.

The characteristics of the resistance type moisture meter are summarised:

- **The circuit is simple and cheap, also easy to handle.**
- **Density of the samples does not give much effect on determination.**
- **Temperature affects determination.**
- **There is a tendency to indicate moisture content of the higher part on the electrodes.**
- **Most of the meters require groupe samples. Very low moisture is difficult to measure. place here from opposite page!**

2) Dielectric Methods (Capacitance)

The dielectric properties of products depend on the moisture content. The capacity of a condenser is affected by the dielectric properties of the material

placed between the condenser plates. Wet materials have a high dielectric constant, and dry materials have a low dielectric constant. Water has a dielectric constant of 80 at 20C Most grains have a value less than 5, and air in a vacuum has a value of 1.

The characteristics of the capacitance type moisture meter are summarised:

- **The circuit and handling is rather complicated, also the price is relatively higher than the resistance types.**
- **Sample density greatly affects determination.**
- **Temperature affects determination.**
- **Easy to get an average moisture content of a whole sample.**
- **Samples are not destroyed**

Dielectric constant (capacitance) gauges consist of a pair of electrodes that set up a radio frequency field. As product the space containing the electrodes, dielectric properties of the process material change the radio frequency field. These changes are measured, and the moisture content is inferred, because the dielectric properties of water are different from most dry substances.

The dielectric constant principle was the first reasonable approach to moisture measurement in the grain industry. Such manufacturers as Motomco and DICKEY-john were pioneers in grain industry moisture measurement.

Cost of this technology is moderate, but the main disadvantage is its sensitivity to composition and particle size changes. Fat content variations, protein content variations, or slight changes in product formulation have a very noticeable effect on moisture accuracy. In grain industries, where these gauges are frequently used, almost every hybrid variety of the grain needs its own calibration curve. The measurement is sensitive to temperature and bulk density changes. Freshly wetted products or products with surface moisture are not suitable for measurement with this technology. The relationship between dielectric constant and moisture content is not linear.

Details of Some Available Proprietary Moisture Meters

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Mobile maize dryer development at farm and cooperative/collector levels

by Kriang-Krai Mekvanich

INTRODUCTION

Maize has been one of the major cash crops of Thailand. About 65-70 per cent of the 4-5 million tons annual production has been exported to other Asian countries. The remaining produce was utilised by the domestic feed industry. Maize production is increasing due to the utilisation of hybrid seed and high market demand from the feed industry.

Harvesting of maize is usually done in two periods: July to October and December to January. Wet maize harvesting and storage practiced commonly in the first period has posed serious problems especially due to the high incidence. of aflatoxin. There is therefore an urgent need for improvements in both on-farm handling practices, and cooperative/collector drying. Traditionally farmers shell their maize at the time of selling to cooperative/collector. It is also a critical time for drying shelled maize to avoid hazards associated with microorganism development. Recommendations have been issued to dry freshly shelled maize to a safe moisture content, within a 24-48 hour period.

Considering numbers of advantage of local drying at farm and cooperative/collector levels such as

- **Excessive moisture reduction at selling to collector, end user or exporter can be avoided. Additional income generated from selling maize at 14-15 per cent moisture content (m.c.) instead of at 18-20 per cent m.c. (w.b.) considerable.**
- **Storage losses in both quantity and quality as well as cost incurred in**

storage can also be reduced.

- The possibility of long-term storage is enhanced. Maize prices are generally higher towards the end of the harvesting period especially during the off-season period.
- High quality maize in terms reduced of aflatoxin content will command better prices or premiums from the feed industry.
- Transportation costs from production area to silo complexes are lower due to lighter weight of dry maize.

From these advantages various types of mobile dryers have been tested/developed. In this paper two types of mobile dryer will be presented: the DAK mobile heater and the US mobile dryer.

THEORY OF DRYING

Drying has two basic stages: (1) diffusion of internal moisture to the surface of the kernel, and (2) removal of external moisture by air flowing around the

kernel. Vapour pressure is increased internally within the kernel which causes moisture to diffuse through the micropores of the seed coat. The grain temperature largely establishes the rate of diffusion, and therefore must be controlled in order not exceed a maximum rate which would result in damage. Removal of the exterior moisture for a given air flow is also dependent upon the air temperature. These two stages must be balanced to produce high quality uniformly dried grain.

In addition to varieted characteristics of the grain, the drying rate is also allected by atmospheric conditions. Hard and fast rules cannot be set due to these variables. It will be necessary to dry several batches to determine the exact dryer settings in a specific area.

Grain matures at 30% to 35% moisture. While some grain may be harvested easily at 30%, others do not harvest well above 20%. Therefore, grain should be harvested as soon as possible after maturity, as long as grain damage is at a minimum and gleaning is thorough.

To properly store grain, the grain moisture content must be compatible with

the length of time the grain will be in storage, and with the grains intended end use. This moisture content will vary due to locality.

Grain type	**1 year storage (% moisture)**
Corn	13%
Wheat	13-14 %
Barley	13%
Rice	12%
Grain Sorghum	12%
Soybeans	11 %
Edible Beans	14-16%

For long-term storage up to 5 years, or for grain stored for seed, moisture levels should be 2% lower than shown in the above Table.

The Storage and Processing Research Centre, Agricultural Engineering Division, Department of Agriculture. Thailand, with support from the ASEANEEC R1 Project, has designed and developed a mobile heater for drying maize on the cob in the farmer's storage.

Two models were tested at the collectors and farmers level. Both prototypes are mobile heat source units consisting of a corn cob furnace, a heat exchanger, and a blower mounted on a mobile frame.

The first prototype has a capacity of 5,100 megajoules or 2 tonnes capacity to dry maize from 25% to 16%. The corn cob furnace is constructed from bricks and cement and has a 1.22x1.52 main fire grate placed at 45 angle with a horizontal plane, and a 15x61 cm small auxiliary grate also at 45 but, in the opposite direction of the main fire grate (see Figure 1). The back wall of the furnace is connected to the fire tube of the heat exchanger. The furnace is designed to burn 300 kg corn cob per hour.

The heat exchanger is a parallel flow baffle type with 36 fire tubes of 7.62 cm diameter enclosed in a 122 cm diameter outer shell. The heat exchanger is 2.4

m long with a 30 cm diameter smoke stack of 10 m height. The flame and smoke produced by the furnace passes through the fire tubes of the heat exchanger and the smoke stack on the opposite side of the furnace. Cold air enters the heat exchanger at the opening toward the furnace end, and hot air leaves the heat exchanger at the far end of the furnace by means of a blower driven by a 7.5 Hp electric motor.

The blower which draws hot air from the heat exchanger and forces heated air through the grain mass is a forward curve centrifugal type rotor. The rotor is 53.5 cm in diameter capable of delivering 140 cubic meters per minute (c.m.m.) of 33 mm static pressure art 980 rpm.

The second prototype (see figure 2) is a smaller scale model. The furnace (0.7 cubic meters) has a 65x85 cm main fire grate and 65x15 cm auxiliary grate designed to burn 60 kg corn cob per hour. The heat exchanger has 20 fire tubes of 8.89 cm diameter. The blower is driven by an 8 Hp Diesel engine.

RESULTS:

Results of development work and field testing of the two prototype mobile heater units have shown the following:

- **Drying maize on the cob in the farmer's crib, to a moisture content that is safe for temporary storage (18-16% mc) by the use of a small mobile heater unit (second prototype) is a technically and economically viable system for resolving the drying problem of maize in the wet season.**
- **The introduction of the in-crib drying system described in (a) above is capable of integration, without changes, into the present system of onfarm shelling by collectors and marketing the shelled maize in the normal manner after the wet season has allowed entry of vehicles into the farm lands.**
- **The in-crib drying system, developed by the project, which dries the maize to a moisture content of about 18-16% followed by storage in the crib for about 2 months is compatible with both the current maize pricing system. This offers considerable premiums to dry maize down to 18%,**

and the market price level attains, or is close to, its maximum value 2 months after the wet

- **Season harvest.**
- **A small mobile LSU-type, batch dryer for shelled maize is feasible and economical for on-farm operations. However, it has been superceded by in-crib drying which also eliminates the problems associated with shelling high moisture cob maize. The daily throughput of this small dryer has been found however to be too small for main use at the collectors level. It was shown to have promise as an auxiliary dryer at this level for handling small deliveries of maize at different conditions after the main intake which is handled by large capacity drying units.**
- **When testing the first prototype it was found that a larger non-mobile LSU type dryer for shelled maize was a technically and economically viable system at the collectors level for drying the shelled, partially dried, maize collected and shelled from the farmer's crib store.**
- **The combination of the mobile heater for in-crib drying which is suitable for small groups of farmers and the shelled maize LSU type dryers at Agricultural Cooperatives form a combination that will meet the**

objective of the project to design and develop a mobile maize dryer suitable for farmer's groups.

US MOBILE DRYER

The dryers described in this paper are radial heat flow, recirculating batch type mobile dryers. The three imported dryers have been trialed at Petchaboon and Nakom Sawan provinces, the main maize growing area under USAID "Appropriate Technology Transfer Project". One 12 tonne unit was manufactured by GT Inc., U.S.A., utilising diesel oil as the burner fuel and two 2 tonne units were made by Morridge Company., U.S.A, utilising LPG as burner fuel. The dryers utilise either tractor Power Take off (PTO) or an electric motor as the prime mover. The structure can be divided into 6 main components (see figure 3);

- **Hot air supplying unit comprising of and axial fan, oil vapourizer and ring burner**

- **Holding bin made of perforated, polyestercoated galvanised steel cylindrical sheet. The bin is fixed on a steel-frame trailer.**
- **Hot air chamber, located at the middle of the holding bin, made of the same steel sheet. Grain wall thickness is 45.7 cm. to provide uniform and throughly drying**
- **Grain circulating system consisting of 3 vertical screw conveyors: lower, main and upper. The upper one is attached with and unloading head so the grain can be transferred directly to the grain storage or truck.**
- **Grain loading system comprising of a loading hopper and horizontal screw conveyor which brings the grain to the bottom of the bin.**
- **Control system. The GT dryer has an applied micro-processor to set, control and check the preparation and operation of the dryer, as follows:**

Battery voltage supply which must be in the range of 11-18 volts.

Tractor PTO speed in the ranged 440-540 rpm.

Seed/grain type selection such as maize seed, maize grain, rice seed, rice

grain etc.

Maximum hot air temperature.

Maximum grain temperature.

Difference between the operating hot air temp and the setting.

Difference between the operating grain temp and the setting.

Specification of Mobile GT dryer (GT 580)

1. **Recirculating batch type**
2. **Drying capacity (20.5-15.5%) :8.5 tons/hr.**
3. **Operating height :5.58 m.**
4. **Transport height :4.11 m**
5. **Bin diameter: 3.4 m.**
6. **Grain wall thickness :45.7 cm**
7. **Size of burner: 982,300 Kcal./hr.**

8. **Type of fuel: Diesel oil**
9. **Fan size and type :81.3 cm Axial**
10. **Fan rating: 16,000 CFM at 374 Pa.**
11. **PTO speed :525 RPM**
12. **Vertical auger diameter: 30.5 cm.**
13. **Loading auger diameter: 20.3 cm.**
14. **Recirculating time: 12-15 min.**
15. **Holding capacity :12.7 tons**
16. **Loading rate :846 kg./min.**
17. **Unloading rate :846 kg./min**

There are four steps in operating the dryer from loading to unloading. Maize grain is loaded either from the grain sack or dump truck through loading hopper, loading auger and vertical auger to holding bin. After completion of loading, the loading auger clutch is disengaged. The grain will be circulated within the bin by vertical auger (see figure 4)

Once the bin almost filled with the grain, the ring burner can be started.

Drying components can be set and controlled manually in Morridge dryer, or by microprocessor in the GT dryer. Hot air is forced by fan to the hot air chamber, then though the grain wall to bin outside. Drying is continued until the grain moisture content reaches 15.5% (see Figure 5).

In general, the maximum grain temperature is set at 45.5 for seed and 60 for grain.

After the completion of drying, the burner is shut off. However, the fan is still operating to cool the grain down until the temperature difference of the grain to the ambient temperature is less than 5C to avoid condensation in storage At this stage, the moisture content of the grain is decreased 1-2%, with the grain outloaded of 14-14.5% mc (see Figure 6).

By pulling the unloading head to the unloading position, all the dried grain is conveyed out of the dryer. (see Figure 7).

From actual operations under humid tropic conditions (ambient temp 30-37 and ambient relative humidity 65-85%) from August to November in the years

1987 and 1988, it was found to dry maize from average 21-22% to 15%,

- **Drying rate during drying period was 2-3% The higher the initial grain moisture content, the higher the drying rate;**
- **Drying rate during the tempering period was 1.2%;**
- **Drying time (hot air forcing) was 1 hr. 50 min. and total operating time was 3 furs. 10 mini**
- **Total drying cost was 130 per tonne. Considering the present maize purchasing system, the use of the maize dryer is encouraging and profitable provided that the maize volume to be dried is large enough. Mechanical maize drying has high potential of being successful with large farmers groups or cooperatives, as well as local collectors.**

Drying and chemical treatment of grains to prevent mycotoxin contamination during storage

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Athapol Noomhorm and Tomas D. Cardona

INTRODUCTION

Mycotoxins are toxic compounds produced by fungi. Mycotoxicosis is the result of ingesting toxincontaminated diets by animals and humans. The first outbreak of mycotoxicosis was ergotism before 1700 and the cause and effect was found to be associated by the consumption of ergot. The second, was the outbreak of stachybotryotoxicosis in horses and of alimentary toxic aleukia in humans in the USSR in the 1930's. The third was the outbreak of aflatoxicosis of turkeys in England in 1960 which was caused by feeding aflatoxin

contaminated peanut meal from Brazil. Since then, aflatoxin and aflatoxicoses and other mycotoxins and mycotoxicoses have received extensive study.

1). Aflatoxins.

These are a group of bis-furano-isocoumarin derivatives produced by fungi from Aspergillus group. These have various derivatives, the most important being aflatoxin B. B: produced by Aspergillus flavus and isolated often from maize and Aflatoxin G1 and G2 produced by Aspergillus parasiticus commonly isolated from peanut. Of these aflatoxins, B. and G1 are most frequently encountered in quantities sufficient to be toxic. From the standpoint of public health, the derivative M, was found in bovine milk after cows ingested feeds contaminated with aflatoxin B.. The aflatoxin level of 20 ppb is permitted in feed grains and feeds in the USA but for food intended for human consumption, the tolerance is zero. For maize export, an acceptable aflatoxin level is 50 ppb during loads.

2). Zearalenones

Zearalenone or its derivatives when ingested by animals can cause either serious injury (Zearalenone and zearalenols consumed by swine); have little or no effect (zearalenone consumed by laying hens, broiler and turkeys); promote growth (zearalanol when slowly absorbed from ear implant in beef cattle and sheep) or serve as a benefical drug (zearalanol taken to alleviate post-menopausal distress in women). The most serious effects of zearalenone occur in swine ingesting Fusarium infected cereal grain such as maize, wheat and barley. Such cereals, ingested alone or mixed into a feed formulation, will cause hyperestrogenisn and infertility. Other animals affected are chickens, turkey poults, rats, mice, guinea pigs, monkeys, lambs and man.

3). Trichothecenes.

Trichothecenes are responsible for feed refusal, emesis, and poor growth in swine and are associated with the hemorrhagic syndrome in poultry and with a variety of symptoms and lesions in other animals. Some of the trichothecenes are extremely toxic when consumed or even when in contact with the skin. This toxin was produced by fungus Trichothecium roseum and various Fusarium species.

4). Ochratoxin.

This was first isolated and characterised by Van der Merwe in 1965 during a routine laboratory screening tests designed to detect toxic fungal products in foodstuffs in South Africa It was found out that Ochratoxin A, B and C were found to be extremely toxic to ducklings. This toxin is predominantly produced by Aspergillus ochraceus, Penicillin viridicatum and other Penicillium species.

MYCOTOXIN PREVENTION

The major factors that determine whether grain in storage would be invaded sufficiently by fungi are the following: (a) moisture content to the grain, (b) temperature of the grain, (c) relative humidity, (d) amount of broken grains and foreign materials present, (e) degree to which the grain already has been invaded by fungi before it arrives at a given site, (f) presence of insects and mites and (9) length of time it is stored. All of these factors interact with one another to some extent, but the major determinants are moisture content,

relative humidity, temperature and time.

Precautionary measures must be done on newly harvested grains so that losses in quality and quantity could be avoided. A recommended and proven method is to reduce the moisture content as early as possible. This can be accomplish by drying (sun drying, air drying, etc) and subsequently controlling the relative humidity and temperature during storage. In addition, chemical application prior to storage and during storage will be administered.

A. Drying

Field drying of most grain has been an accepted practice since commercial farming began. However, sun and wind are the primary drying agents and may not be available when most needed. As the demand for higher quality farm products grow, mechanical drying has become popular. Drying of crops in the field allowed farmers to follow a more predictable schedule in harvesting and, in some cases, produce a second crop on the same land because of early removal of the first crop. After harvest, the moisture content of the produce must be dried to 12-14% w.b. for safe storage with minimal deterioration.

Now, drying and curing costs are rising rapidly because the prices of commonly used fossil fuels and electricity are increasing faster than the general inflation rate. Integration of solar energy into conventional systems may replace or reduce the demand for depletable energy sources.

1). Sundrying

Sundrying is probably the oldest and most common way of reducing the moisture content of any crop. It utilises solar energy from the sun directly. Sundrying has been practiced while the crops are still in the field. It probably hastens maturation of crops. As the crops mature, the moisture content ranges from 26 to 35% w.b. This moisture range should be reduced immediately prior to storage by direct sundrying by spreading the grains on mat or cement surfaces. In sunny days, the drying process will take 2 to 3 days depending upon the spreading density and the prevailing atmospheric conditions. This is the cheapest process. However, product contaminations could not be avoided. Morever, the process is laborious and time consuming for large scale use.

2). Mechanical driers

Mechanical driers are equipment where the drying medium (air) is moved artificially into the product by means of force (usually fan driven by motor). The air is normally heated to reduce its relative humidity and increase its moisture absorbing capacity. This results in greater drying capacity and faster drying rates. Mechanical driers are divided into three types: (a) static batch drier, (b) recirculating batch drier and (c) continuous flow driers (11).

Static driers are used where grains are either placed in bags or in a container through which the drying air is blown. Recirculating batch drier, as the name implied, grains are recirculated through the drying chamber. This method would continuously mix the grains which is necessary to have an even drying and no grain is being continuously subjected to high drying air temperature thereby minimising damage. Continuous drier is the most common design used in large installations. The grain is fed into the top and flows vertically through the drier at a rate which is designed to extract the required moisture from the grain. Drying is achieved by passing heated air through the grain. The flow of heated air can either be cross, counter, concurrent and mixed with the grains. However, high power consumption is required for recirculting large amount of grain. Furthermore, elevators/augers are needed.

3). Solar drying

With the oil crisis in the 1970s, non-conventional energy sources has been resorted to in drying farm crops. Solar energy is tapped by the use of a collector and converted to a more convenient form of energy and either directly use or store it for later delivery to the point of use. In solar drier, solar radiation would be allowed to pass through a transparent sheet where heat absorbent (stones, black sheets) are placed and in turn heat the air. The heated air is conveyed into the drying platforms where grain drying is taking placed. Simple, single-glazed solar collection systems have been used to slightly raise the temperature of drying intake air, thus speed up the drying process. Solar drying systems are categorised as passive or active.

A passive system depends on natural convention, conduction, or radiation to transfer thermal energy from the point of collection to the storage component and to the point of use. Many agricultural applications such as greenhouses, field drying of crops use passive solar systems. While an active system has a mechanical mean such as pump or fan to drive a heat-transfer fluid from one part of the system to another. Active solar systems have been used for

decades and proven feasible in many parts of the world. However, more development is necessary before large scale application can become a reality. Effective use of solar energy for grain and crop drying depends on:

1) Geographical location

This will affect on the availability of solar radiation at harvest time and also the relative humidity at that location.

2) Crop type

Different grain crops are harvested at different seasons and have the different physical properties which the will affect the drying rate.

3) Size of operation

The size of the drying operation must accommodate the size of the crop so that the harvest can proceed in an orderly manner.

4) Government policy

The solar drying systems are not readily accepted by potential users because of the investment cost when comparied with the conventional method. A governmentfinanced economic trade-off program may be necessary to encourage greater use of solar energy.

The, Asian Institute of Technology (AIT) has developed a low cost solar dryer for paddy. It consisted of a solar air heater, a box for the grain bed, and a chimney giving a tall column of warm air to increase the convection effect. Clear plastic sheet covering the grain bed allows it to be heated from above by the sun while protecting it from rain. Black plastic sheet is used to cover the ground and serves as heat absorber (Fig. 1. Design concept of a solar dryer). The construction cost of AIT solar dryer ranges from 4,000-5,000 baht dependent on the availability of the materials in each location. The dryer is capable of drying one metric ton of paddy. The drying period depends on the availability of sunlight. Life expectancy of the dryer is one year.

CROP DRYING SYSTEMS

Corn Drying.

Corn at harvesting stage has a high moisture content and should be mechanically dried to reduce its moisture content as early as possible to prevent grain quality deterioration by fungal invasion. A combination of initial, short-time, high temperature drying and extended, lower-temperature, final drying can save energy and maintain higher grain quality. During sunny days, solar drier can be used for corn drying.

Field-shelled high moisture yellow corn was dried in 5.5 m (18 ft) diameter low temperature drying bins (Fig. 2. Solar collector units and the 5.49 m (18 ft) diameter grain drying bins). One bin had two solar collector units positioned such that the fan inlet caused airflow through the collectors; the second bin fan is used for ambient air only. Axial fans provided high airflow rates in grain depths of about 2 to 3 m. When the corn in the tops of the bins reached about 16 percent moisture, the bins were emptied and the corn was transferred to another storage bin. The increase in the solar-assisted drying system compared to the ambient air system ranged from 8 percent during 5 days of favorable drying weather to 13 percent during 5 days of less favorable

weather. The transfer strategy reduced the drying time, reduced overdrying, and allowed the system to be reloaded about each week. Micro-flora activity was minimized by shorter drying time and by the mixing of lower and higher moisture corn during the transfer to other storage bins.

Peanut Drying

Peanuts are a valuable source of protein and oil and must be harvested at quite moist state to preserve quality and minimize field losses due to shattering. The nuts are exposed by digging and then usually dried for a short-time in the windrow before being picked. Edible peanuts require careful drying because continuous exposure to temperatures above 35C cause an offtaste and may split a high percentage of kernels. On the other hand, low-temperature drying or interruption of a high temperature drying cycle encourages mould growth and increases the risk of mycotoxin development.

General recommendations for peanut drying include limiting drying air temperature to 8C above the ambient temperature as minimum to 25C maximum and maintaining a minimum airflow rate of 12.5 m /min per m of

peanuts in dryer.

Several feasibility studies of solar-assisted peanut drying units have been conducted as shown in Figure 3 (see Fig 3 Peanut dryer with solar heated water and solar-heated air). Troeger and Butler (5) compared a water and an air solar systems with a conventional LPG dryer. The result reveals that the greater the percentage of split kernels, the greater chance of fungal penetration. Both water and air systems performed well. This systems equipped with a 70 m collection and a 7570 lifer water storage, can supply 75% of the energy needed to dry 4080 kg of peanuts from an initial moisture content of 20% to a desired 10% level in 24 hours. As with other types of grain and crop drying, its economic feasibility will be greatly enhanced by multiple use.

B) Chemical Treatment

Drying has been proven effective for preventing mycotoxin contamination of

crops. However, drying equipment may not be always available in the farm due to its cost and the lack of technical know-how on the farmers to operate such facilities. Besides, climatic conditions in the tropics are unpredictable and mostly harvesting seasons coincide with the onset of the wet season. The high moisture crops especially corn will be contaminated with aflatoxin within 48 hours. Therefore, chemical treatment is imperative.

It has been reported that 10% of the harvested foods are destroyed in storage by insect pest thus, protecting our harvested crops from insect pests can significantly increase availability of food resources. Damage done by insects are often followed by moulds because the insect produce heat and water that move the microclimate into a high deterioration environment. Thus, preventing insect infestation by chemical application may provide adequate grain protection aside from good storage structure and storage hygienes. Chemicals are applied as preventive and control measures. Preventive is when chemicals are applied before insect infestation and control when infestation has occurred.

Thorough sanitation is the first and most effective step toward preventing

insect infestation. Storage areas should be clean and tight enough to keep out insects and to keep in fumigant gasses if such treatment becomes necessary. The insecticides should be sprayed to the point of "run-off". All parts of the storage structure must be sprayed to kill most indigenous insects and to prevent insects from establishing an infestation. The persistence of adequate insecticide residues applied to the surface of storage structures is an important factor in combating storage insects. The chemicals recommended as grain protectants are malathion, prevent moulds and bacterial activity. The name of pyrifos methyl, fenitrothion, methyl phoxin and pirimiphos methyl (9).

The BP Chemicals of England has developed chemicals which when applied to moist grains prevent molds and bacterial activity. The name of the chemical is propcorn which is 100% active liquid preservative based on feed grade propionic acid. Propcorn prevents deterioration, loss of dry matter, nutrition loss and removes the associated health hazard to grain handlers, livestock and the end user. It has been found out that propcom treated moist grain could be stored and transported with its condition retained for up to 12 months without the use of specialised storage. Moreover, the addition of propcorn adds the energy value of the grain. One ton of propcorn on 100 tonnes of grain gives

and additional calculated energy value equivalent to 1 1/2 tonnes of barley. Another chemical is Nilspor, a propionic acid based chemical which similar to propcorn but the propionic acid content is higher. It is more effective than propcorn but it is corrosive.

Kemin Industries in US has also produced a mould inhibitor called Myco Curb. It is a non-corrosive liquid mould inhibitor non-toxic and non-volatile. It contains propionic acid, acetic acid, sorbic acid, benzoic acid, mono- and all-esters of 1,2 propanediol, hydrated ammonium phosphate, propyl benzoate, porpyl acetate, butylated hydroxyanisole (13).

Inspite of the grain protectant applied, a possibility for insect infestation may occur during storage. When this happens, chemicals may be applied again depending on whether insect population and infestation reached or exceeded the economic threshold level. An appropriate measure is to apply fumigants. A fumigant is a chemical that exists as a gas at ambient temperatures and pressures or produces a gas from solids or liquid. As a gas, it diffuses through air, permeates products and enters the respiratory system of insects. However, fumigation is recommended for an enclosed space with or without

facilities for recirculating the gas to aid in achieving homogenous gas concentrations or removing the gas after fumigation. The common fumigants used are methyl bromide, phosphine, carbon tetrachloride, chloropicrin, carbon disulfide, ethylene dibromide and dichlorvos.

The effectivity of fumigation is influenced by the following factors: temperature, moisture, time, fumigant formulation, dosage and application procedure, storage structure and aeration. Of course, safety procedures should be observed because fumigants will ham non-target organisms, including man. Manufacturers safety recommendations for applying certain fumigants should be strictly followed.

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CHEMICAL APPLICATOR FOR FRESHLY HARVESTED MAIZE

Maize in Thailand is usually harvested in the wet season. Sundrying is not possible as well as mechanical dryer due to the low financial capability and the lack of technical know-how for the farmers. Therefore, chemical treatment is an alternative. Chemical control has been reported to be a successful alternative to prevent fungal infestation which lead to aflatoxin contamination during subsequent storage. Dipping and spraying have already been studied end' the former has provided a good control of fungus growth. However, this method consumes a large quantity of chemicals and is, therefore, not economical and also laborious. Spraying by batch gave promising results but still capacity is low. So, a chemical applicator was developed.

A pedal-driven chemical applicator (Fig 6 A pedal-driven Chemical applicator for freshly harvested maize cobs) consists of a hopper, spraying-mixing chamber, a collecting chute, pedal driven mechanism, cam-plunger assembly, spraying system (knapsack sprayer) and a frame. The hopper is a wedge-shaped type flow bin with an opening on the side and the hopper bottom was made movable so that maize cobs would flow continuously into the spraying-mixing chamber. The spraying-mixing chamber is made of an empty plastic drum with 4 helical rubber flights. The cob collecting chute is made of a

perforated G.l. sheet for the spray solution and cobs to separate systematically and the frame was made of G.l. pipes and angle bars with two 25-cm wheels.

The applicator has a capacity of 0.6, 0.72 and 0.84 ton/hr at 25,35 and 45 RPM, respectively. Using a knapsack sprayer, the spray discharge varies from 21.36,28.72 and 36.27 at 25, 35 and 45 RPM, respectively. However, 45 RPM is an appropriate pedal drive speed since spray nozzles did not form a cone spray at lower RPMs.

The operation of the applicator starts with the loading of the freshly harvested maize cobs and the preparation of the spray solution based on the recommended chemical application rates. The pressure in the sprayer tank can be built up initially by running the pedal drive without opening the discharge control valve for 1 minute. After this, the control valve will be opened to impound spray solution in the sprayingmixing chamber for another 2 minutes or until the spray solution will start dripping into the collecting chute. Then, the hopper will be opened and the spraying operation will start. Clogging on the hopper opining can be avoided by a 10 mm diameter rod

inserted into a hole at the side of the hopper.

The applicator can be operated by a single person. However, two persons were found to be suitable so that the total operation will be continuous thus, improving the capacity. One person will drive the pedal while the other will load the maize cobs and remove the sprayed cobs from the collecting chute.

Laboratory trials indicated that aflatoxin contamination could be prevented on the stored maize cobs during subsequent storage. However, extensive farm trials be conducted before introducing this machine for farmers' use. Moreover, further modifications should be made after the farm trials to incorporate the feedbacks of the farmers regarding the design and operation of the applicator.

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Batch and continuous drying

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by Maitri Naewbanij and Viboon Thepent

INTRODUCTION

Drying is one of the crucial steps in food processing and preservation. It is the means of providing grain at optimum moisture content for processing, such as rice milling and wheat milling processes, as well as rendering grain moisture content at stage where moisture is unavailable for mould growth. In preserving grain without deterioration, drying is the cheapest among other methods, ie, chemical application and controlled atmosphere storage. Drying methods and operation are rather specific for each kind of grain and its use. Skilled operators are often required for the drying operation.

PRINCIPLE OF DRYING

Drying is the process of moisture removal from the product, or grain in this case. Since grain is a hydroscopic material which can either absorb or desorb moisture from the air or its surroundings depending on the difference in vapour pressure, moisture transferred from a higher vapour pressure, to the lower one. In the sundrying process, grain is heated by solar radiation thus creating a higher vapour pressure in grain than the surrounding air. In the same manner, the heated air drying process starts when the grain is heated (by conduction) when it comes in contact with the air. Higher velocity air flow in heated air drying has the advantage of reducing the boundary layer of the grain, thereby increasing the heat transfer coefficient of the grain, as well as increasing the rate of moisture movement from grain to the surrounding air. Therefore, the drying rate of a specific kind of grain is dependent on both air temperature and air flow rate.

MOISTURE MOVEMENT

When the heated air is forced through the grain mass, the vapour pressure of the grain increases as the temperature of the grain increases. The vapour pressure at the grain surface increase rapidly, since the surface of grain is heated first during the initial stage of drying. Center grain temperatures rise slowly as the moisture at the center of grain slowly migrates to the drying air. Drying rates of grain, therefore, can be characterised into four stages (Fig. 1 Illustration of constant rate and falling-rate drying periods.), the heating period (AB), the constant rate period (BC), the first falling rate period (CD), and the second falling rate period (DE).

The constant rate period occurs during the drying of the surface moisture. In this period, the grain temperature does not increase appreciably due to the effect of evapourative cooling. Removal of moisture from the grain is fastest during this period.

The falling rate periods occur after the removal of the surface moisture or during the removal of moisture from within the grain. During this period of

drying, grain temperature is slowly by the incoming hot air, thus, the vapour pressure within the kernel increases and slowly moves out to the drying air. Drying at this stage is dependent on grain characteristics, temperature of the kernel, and the vapour pressure of the hot air.

CALCULATION OF MOISTURE CONTENT

Grain moisture content may be expressed as percentage moisture on dry matter and percentage moisture of wet grain depending on the purpose for its use. In research or scientific purpose, the moisture content of grain is usually expressed as percentage of moisture on dry matter basis, which is expressed as in equation (1)

$$M_{(db)} = \frac{\text{Wt. of Water} \times 100}{\text{Wt. of dry matter}} \quad \ldots(1)$$

Where:

$M_{(db)}$ = moisture content, % dry basis.

For commercial purposes, the grain moisture content is expressed as percentage moisture on wet grain basis. This is so because most of the moisture meters can only measure the grain moisture content accurately in percentage moisture on wet grain basis. Mathematically, A can be expressed as :

$$M = \frac{[\text{Wt. of Water}] \times 100}{\text{Wt. of water} + \text{Wt. of dry matter}]} \quad ...(2)$$

or

$$M = \frac{\text{Wt. of water} \times 100}{\text{initial grain Wt.}} \quad ...(2a)$$

Calculation of moisture reduction or weight of water removed from grain is one of the many important requirements in designing a grain dryer. It gives the rough idea of how much air, fuel and power are needed to dry a certain

kind of grain.

If initial moisture content of grain (M1), initial weight (W1) and desired moisture content (M2) are determined, then final grain weight (W2) is calculated by the following equation:

$$W2 = \frac{100 - M1 \times w1}{100 - M2} \quad ...(3)$$

EXAMPLE

Determine the heat requirement to dry 2 tonnes of corn if the initial moisture content is 25% and is to be dried down to 15%. Assuming the heat utilisation factor of the drying system is 80% with the air at temperature remaining constant at 90C. Ambient air conditions may be taken as 30C, 7.0% R.H, and air is supplied at the rate of 0.33 cu.m/s/cu.m of grain.

SOLUTION

Amount of water needed to evaporate from corn can be calculated as;

Method A:

$$M = \frac{\text{Wt. of water}}{\text{Wt. of corn}} \times 100$$

$$\frac{25}{100} = \frac{\text{Wt. of water}}{\text{Wt. of corn at 25\% MC}}$$

Wt. of water at 25% MC = 0.25 x 2000 kg = 500 kg

Therefore:

Wt of dry matter = 200 - 500 = 1500 kg

$$M = \frac{\text{Wt. of water}}{\text{Wt. of water + dry matter}} \times 100$$

$$\frac{15}{100} = \frac{\text{Wt. of water}}{\text{Wt. of water + dry matter}}$$

0.15 (Wt. of water + 1500) = Wt. of water

Wt. of water 15% = $\frac{0.15 \times 1500}{(1-0.15)}\text{kg}$ **= 264.71 kg**

Thus, amount of water to be removed from corn is,

500 - 264.71 = 235.29 kg

Method B: Using equation (3) to determine final weight

$$W2 = \frac{(100-25)}{(100-15)} \times 2000$$

Amount of water to be removed = W1 - W2 = 2000 -1764.71 = 235.29 kg

Calculation for the drying air requirement to evapourate 235.29 kg of water

from corn requires the knowledge of psychrometrics.

The psychrometric chart tells the property of air at any given air condition. It contains five types of lines having the vertical axis of absolute humidity (ratio of moisture contain in a unit weight of air), the horizontal axis of air temperature. The curved line upward from left to right is the relative humidity line (percentage of moisture to the potential moisture holding capacity of a specific moisture holding capacity of a specific volume of air at given condition), the slanted line is the wet bulb temperature which is consiged with the constant enthalpy (constant heat energy) line, and the incline upward from left to right line is the specific volume line. To be able to use this chart, we must know the characteristic of processes described on the chart and two properties of air at a given condition. That is when a point is located, then a line can be drawn according to the process specified. The processes discribed on the psychrometric chart are shown in Figure (see Fig.2 A skeleton psychrometric chart) (2).

Thus given the ambient air condition, 30C or 86F and 70% R.H., the initial point (1) can be located on the psychometric chart (Fig 3 Psychromatric chart:

high temperature). Point (2) is determined by the heating process or air temperature raised to 90C (194F). Point (3) is determined by following the wet bulb temperature line up to the temperature of the exhaust air. Temperature of the exhaust air (air temperature leaving the grain mass) can be determined from the given heat utilisation factor (HUF) and the air temperature at point (1) and point (2) as follows:

$$HUF = \frac{T2}{T2 -} - \frac{T3}{T1}$$

$$0.8 = \frac{90}{90 -} - \frac{T3}{30}$$

$$T3 = 90 - 48 = 42 \text{ deg. C}$$

The amount of air required can, therefore, be calculated by dividing the amount of water to be removed form corn by the difference in reading of the absolute humidity values between point (3) and point (2), that is:

$$\text{air requiremen t} = \frac{235.29}{(.038 - 0.19)} = 12{,}383.68 \text{ kg of air} = 10{,}897.64 \text{ cu.m}$$

(sp.vol.of air = 0.88 cu. M/kg)

The heat requirement can be calculated by multiplying the total weight of air requirement by the different in readings of enthalpy of point (2) and point (1), or calculated

Total heat required 12,383.68 (143.5 78) = 811,131.04 kj

In the case where air is supplied at the rate of 0.33 cu.m/sec per cu.m of grain then the burner capacity can be computed as;

for shelled corn, the specific volume = 720 kg/cu.m

volume of 2 tonnes corn = $\frac{2000}{720}$ **= 2.78 cu.m**

Total air folw = 0.33 x 2.78 = 0.9174 cu.m/s = 3300 cu. m/hr

Drying time requited $= \frac{10,897.64}{3,300}$ **= 3.3 hr**

3,300

and burner capacity $= \frac{811,131.04}{3.3} = 245,797.28\ kJ/hr$ or $= 68.28\ kW$

BATCH DRYING

Batch drying is a system at which a certain volume of grain is being dried at a time. The volume is fixed by the holding capacity of a dryer, and dried to required moisture. After unloading the dried grain from the dryer, then drying for the next batch of grain can be performed. Batch drying, therefore, requires loading and unloading time for each batch of grain needed to be dried.

CONFIGURATION OF BATCH DRYING BINS

Several configurations and designs of batch drying bin have been manufactured and are widely used in many countries around the world. They may be stationary bins or portable bins. However, the batch drying bins can be classified into two groups; (a) static grain dryer, and (b) mixing - grain dryer.

The static - grain dryer has many configurations as shown in Figure (see Fig. 4 Principle of static - batch grain dryers)(4). They may be a thin layer bed, thick layer bed, vertical column thin layer, and round structure radial dryers. The static - grain dryer has a disadvantage of over-drying the grain nearest to the wall of the incoming hot air. Grain nearest to the wall of the incoming hot air loses its moisture first to the hot air, while temperature of the air dropped, at the same time the air absorbs moisture given off from the grain. Thus, the hot air reduces its temperature and capacity while moving through the grain bed. The difference in grain moistures between the layer nearest to the hot air and the outer layer varies with grain thickness, temperature of hot air, and airflow rate.

The mixing - grain batch dryer is designed to come over this drying problem of the static grain dryer. Design of the dryers usually is of a tall vertical drying column to facilitate the mixing operation. Mixing is achieved by recycling the discharged grain back to the dryer 3-4 cycles before its moisture reduced to the desire level. A fairly uniform grain moisture content may be obtained by this dryer if the recycling time is short. Figure (5) shows various designs of the mixed grain batch dryer.

CONTINUOUS DRYING

The term continuous drying is where grain is continuously flowing though a dryer without stopping. The dryer itself has the same features as that of the mixed grain dryer. However, it requires several buffer bins for holding the discharged gram. The operator for the continuous flow dryer must have knowledge of grain drying management to programme the dryer to operate at its maximum efficiency. The continuous drying system offers the lowest operating costs as compared to batch drying systens Furthermore, a uniform

grain moisture content after drying is obtained, and the drying capacity of the continuous flow dryer is higher than that of the mixing grain batch dyer if the same dryer and drying conditions are used.

Continuous flow drying is usually employed in relatively large grain complexes. The system can handle a large quantity of grain, and offer greater flexibility for drying operations. Figure 6 shows the typical operation pattern of the continuous drying system. Wet grain after being cleaned is put into the continuous dryer which continuously discharges grain into the buffer bins. Moisture content of the grain after passing the dryer may be reduced 2 to 4% depending on the grain moisture content at intake, drying air temperature and the air flow rate. The grain is held in the buffer bins 6 hours or more allowing for the equalisation of moisture within the kernel. For rice drying, the reduction of grain moisture should not go beyond 2% for each pass. Higher rates of moisture reduction causes crack or fissure development within the kernel. The partially dried grain after being tempered in the buffer bin is recycled into the dryer until the desired moisture is reached. The final pass before moving grain into storage is the cooling phase. This is to bring down the grain temperature to that of the surrounding ambient air temperature. Grain

continues giving off moisture until the surrounding air reaches equilibrium conditions with the vapour pressure inside the grain. Cooling down of the inter stitial air causes condensation to occur on the grain surface, thus, a favourable condition for mould growth.

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Insect pests of stored products

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Chuwit Sukprakarn

Thailand is one of rice growing countries in the world, the cultivation is about

10 million hectares and annual production is 19.5 million tons. Rice is grown in all parts of the country from the Southern border with Malaysia to the Northern border with Laos and Burma with a distance of about 1,600 kilometres. Most of the rice varieties are irrigated rice and depended upon rainfall, very few are upland rice. About 20 percents are floating rice which may grow in water at several metres deep. Rainfall is the most variable climatic factor affecting rice cultivation. The average annual amounts of rainfall for the whole country is 1,500 mm (about 60 inches) per year. In the Northeastern Region, only 1,000 mm are common while in the Southern Region the usuall rainfall are about 2,000 mm and may reach up to 2,500 mm.

Besides rice production, Thailand also producing maize, sorghum, mungbean, soybean, groundnut, cassava etc.

Most of the farmers do not store the grain for a longer period except for replanting. They generally sell the grain either before harvesting or during threshing for the rent or money requirement. Nearly all of the grain and other agricultural products therefore are kept in the mills, godowns or even silos ready to be exported or distributed to the local markets. For this reason, those

who operate storage facilities must know how to protect the grain from insect infestation. Government organizations as well as the farmers do not emphasise much research on stored grain insects. Very few research works on stored grain insects have been undertaken during the recent years, most of the works were confined on the insect pest attacked in the field rather than the pests of stored grain.

Losses due to insect infestation

The percentage of losses is very difficult to determine and the figures vary from 1 % to as much as 25%. The official figures however, released by the five ASEAN countries stated that the member nations lost about 25% of their paddy crop during harvesting and other post-harvest practices including storage and transportation, and the loss represents 10.5 million tons of paddy whereas FAO reported in 1977, the loss of rice within the postharvest system for Thailand ranged from 8-14%. In Thailand itself, there is no official report on losses due to insect infestation. The estimation of losses is based only upon

experiments. For paddy, some investigators reported that the loss in weight for 8 months was at 1.14-3.41% when in farm and more than 5% for commercial storage while the author reported that grain loss was from 0.05-10.48% for one year storage. The report recently from the Rice Institute, 20 varieties of paddy seed when stored untreatment for 10 months, the losses varied from 2.06 to 24.30% with an average 4.54%. Other grain crops eg. maize, sorghum and pulses, these crops have already been infested by the insects from the fields and also from the poor storage condition. When the grain has no protection, the insect population will build up rapidly. Therefore, the losses and damages by insect pests are related to the storage duration. Unfortunately, there is no record on losses of these crops but it has been observed that the severe damage will occur within a few months of storage and may reach upto 50% for 6 months storage. This is one of the reasons why the farmers need not keep the grain in large quantity and longer periods.

Presently, quantity loss is not as important factor as the loss of goodwill in the international trade. The loss of goodwill between traders and farmers or between importers and exporters in the international trade could be a serious matter in future marketing. In the past, some major exporters experienced

the embarrassment of some shipments being declared distressed cargoes. This was due to the presence of some quantity of insecticide on grain which may cause health hazards to human beings. Commercial losses can also occur due to the reduction of quality through adulteration or insect attacks.

The major insect pests can be grouped according to feeding behavior as follows:

Paddy:	Rice weevil (Sitophilus oryzae (Linnaeus))
	Angoumois grain moth (Sitotroga cerealella (Olivier))
	Lesser grain borer (Bhyzopertha dominica (Fabricius))
	Siamese grain beetle (Lophocateres pusillus (Klug))
	Flat grain beetle (Cryptolestes pusillus (Schonherr))
Rice:	Maize weevil (Sitophilus zeamais Motschulsky)
	Rice weevil (S. oryzae (Linnaeus))

	Red flour beetle (Tribolium castaneum (Herbst))
	Rice moth (Corcyra cephalonica Stainton)
	Saw-toothed grain beetle (Oryzaephilus surinamensis (Linnaeus))
	Flat grain beetle (Cryptolestes pusillus (Schonherr))
Maize & sorghum:	Maize weevil (Sitophilus zeamais Motschulsky)
	Red flour beetle (Tribolium castaneum (Herbst))
	Corn-sap beetle (Carpophilus dimidiatus (Fabricius))
	Rice moth (Corcyra cephalonica Stainton)
	Tropical warehouse moth (Ephestia cautella (Walker))
Pulses:	Cowpea beetle (Callosobruchus maculatus (Fabricius))
	Southern cowpea beetle (C. chinensis (Linnaeus))
	Tropical warehouse moth (Ephestia cautella (Walker))
Cassava:	Coffee bean weevil (Araecurus fasciculatus (Degeer))
	Lesser grain borer (Rhyzopertha dominica (Fabricius))

	Cigarette beetle (Lasioderrna serricorne (Fabricius))

Biology of Storage Insects

Insects development take place between 17C and 35C The optimum temperature for most storage insects is around 30C at 75% relative humidity The insects are more critical in their response to high temperatures. Most insect pests are killed by temperatures above 40C. Whereas most stored grain insects are able to withstand temperatures below freezing for several days but when exposed to 65C for a few minutes all the insects are killed.

The number of important storage insects is rather small, being about 30. Most species have a short life cycle of 4-6 weeks and are universal in their taste.

A number of storage insects lay their eggs in or near produce. After hatching the larvae into the produce and develop there till after pupal stage. Other pests develop and pupate on or between the produce.

Adults of storage insects can be long or short living. Bruchids and moths are short living (up to 3 weeks). They lay most of their eggs during the first week of adulthood. Other species like Sitophilus and Tribolium can live for 6 to 12 months. Egg deposition takes place over a prolonged period.

Important parameters in the development and reproduction of storage pests, besides climate, are the kind and condition of the produce and its moisture content. So at 25C and 70% relative humidity the development of Ephestia cautella takes about 30 days on grains, 43 days on groundnuts and 53 days on cocoa beans. Storage pests can be divided into primary and secondary pests. Primary pests like Sitophilus or Ephestia species are able to develop on undamaged produce, while secondary pests will develop only on produce which was previously damaged by other insects or mechanically. So in stored produce a certain succession of pests may occur.

In this section only the biology of some major insect pests will be briefly discussed.

1. The rice weevil (Sitophilus oryzae L.)

Order Coleoptera, Family Curculionidae

The weevil is brown to black with two paler reddishbrown patches on each elytra, 2-3 mm long. The female lays about 200 eggs in the grain and the larva feeds and pupates in the grain. The incubation period lasts 36 days, the larval and pupal period is 20-30 and 3-7 days respectively. The life cycle is completed in 30-40 days.

2. the red flour beetle (Tribolium castaneum Hbst.)

Order Coleoptera, Family Tenebrionidae

The beetle is 2.3-4.4 mm long, reddish-brown and flat. Eyes large, emaginate; antennae clavate, 11 segmented. The egg, white, oblong or pear-shaped. A female lays 15-72 eggs in rice and the incubation period takes 3-7 days. The larva is whitish, worm-like. There are 6-7 larval instars and the larval period ranges 21-40 days. The pupal period is 3-7 days and the life cycle completed in 26-48 days.

3. The Angoumois grain moth (Sitotroga cerealella Oliv.)

Order Lepidoptera, Family Gelechiidae

A small moth with a wing span of approximately 1/2 inch which can be distinquished by its pale brown colour and the elongate sharply pointed apices of the hind wings. A female lays 30-78 white, oblong shaped eggs, singly or in small groups. After hatching the whitish larva bores into and spends its complete life cycle wishing a single grain, eventually pupating there. It takes 4-6 days for incubation period and 26-35 days for larval period. The pupal period takes 3-6 days and the moth can live for 3-7 days.

4. The almond moth (Ephestia cautella W.)

Order Lepidoptera, Family Phycitidae

The moth is greyish or pale grey with two zigzag lines on forewing with a wing span of about 12-16 mm. A female lays upto 205 eggs in cracks or crevices on grain after which the female dies soon after. The eggs hatch within 3-6 days.

The whitish larvae molt 3 times and complete their life cycle in 27-83 days.

5. The rice moth (Corcyra cephalonica Staint.)

Order Lepidoptera, Family Galleriidae

A medium-sized moth with a wing span of 20-25 mm, the forewings are uniformly pale brown with the veins slightly darkened. A female lays 44-364 whitish eggs with incubation of 4-5 days. The larva is white to whitish-grey. The larval period takes 2841 days with 5-7 larval instars. The pupal period is 6-13 days and the moth can survive for 4-6 days.

6. The Cowpea beetle and Southern cowpea beetle (Callosobruchus chinensis L. & C. maculatus F.)

Order Coleoptera, Family Bruchidae

These two species are resemble in appearance and they occasionally feed on food together. The size of the Cowpea beetle is little smaller than the

Southern Cowpea beetle (2.0-3.5 mm.: 3.0-4.5 mm). It is small, oval brown beetle with or without black markings on the elytrae. A female lays more than 10 yellowish eggs (average 50 eggs) on grain with the incubation period 36 days. The larva feeds and pupates inside the grain then emerges as adult. The larval and pupal period is 1820 and 3-7 days respectively. The life cycle completed in 18-33 days and the beetle can survive up to 12 days.

Prevention and control of storage insects

The principal means of prevention is to select a place and method of storing, that suit best the produce and local conditions. Many products like maize, sorghum, groundnuts etc. can either be stored as unshelled or as shelled produce.

Unshelled produce such as maize and sorghum can be stored on the cob or in the ear in rectangular or round cribs constructed from poles, bricks and chickenwire. Because of good ventilation mould problems are few, but

protection against insects and rodents needs use of pesticides.

Shelled produce can be stored in bags in warehouses or in bulk in silos.

In all cases, strict hygiene is very Important. Warehouses and silos must be cleaned thoroughly of old infested produce before the new harvest is brought in. Bags should be stacked on pallets and stand free of walls and celling. Different products should be stacked separately. Food stores should be swept out every week and the sweepings must be burned immediately. The storage structures should be closed off to prevent entry by pests, airtight silos with good thermal insulation offer the best protection.

Admixture the grain or seed with inert substances such as dust or plant parts could prevent maize and sorghum from insect damage for some period, while in oil seeds and pulses the admixture the grain with edible oil like palm oil, rice bran oil or peanut oil are recommended to control the Bruchids.

Temperature Control: Since most stored product insects cannot tolerate extreme temperature, heating and cooling are logical approaches to insect

control. To some extent it has been a common practice to superheat some comodities for insect control. The temperatures of 55-60C maintained for 10 to 12 hours are effective. Actually, these temperatures kill most insects very quickly but when the grain and materials are involved, the certain temperature must be kept for several hours to ensure complete penetration.

Low temperature is probably the most important single factor in making long term storage possible and economical. The insects become inactive and eventually die at a temperature below 12C. Freezing quickly kills many insects. Low temperature is also important in maintaining seed viability.

Moisture Control: Most of the stored grain insects are unable to survive and reproduce in grain whose moisture content is below 9 per cent. Most favorable grain moistures for insect development ranges from 12 to 15 per cent. If, by various means, it is possible to reduce and maintain the moisture below than favorable for reproduction and development, then we have in effect, controlled the insects.

All agricultural products should be well dried before storage especially for

storing in silos. A high moisture content tends to increase insect and mould development; to bacterial deterioration, and chemical changes in the produce. When the crop is ripe it still has a high moisture content. Under dry weather conditions the crop is usually left in the field to dry, but in the humid tropics artificial drying is often necessary.

Produce should not be stored at moisture contents higher than indicated below.

paddy	15%
rice, maize, wheat, sorghum	13%
millet	16%
cowpeas, beans	15%
groundnuts, cocoa beans	7%

Chemical Control: For the protection of stored produce against the insects the following groups of pesticides are used:

a) insecticides
b) fumigants

For the protection of store produce, pesticides are often applied shortly before use or mixed with the produce, which limits the choice of pesticides which can be used and rates of application. It will be obvious that, for the protection of stored produce, only pesticides can be used with a rather low mammalian toxicity whose residues easily degrade to innoxious compounds which can be excreted. Insecticides which are accumulated in the human body e.g. DDT are of course completely unsuitable for use on stored produce.

Insecticides may be used for spraying wall, floors and ceilings of warehouses or storerooms in order to kill a residual infestation. The insecticides can also be sprayed directly on bagged produce. This may prevent or delay reinfestation of insect-free produce. Insecticides may be mixed with the produce. This can give complete protection for a long period and may also kill

pests which have already infested the produce. The best way however to disinfect produce, warehouses or storerooms, is by means of fumigation. The fumigants used penetrate into the grain or compressed products like tobacco and kill all insects. Some fumigants kill also micro-organisms. After fumigation, reinfestation must be prevented by insecticides or by storing the produce in an insect proof silo or container.

Resistance to pesticides is developing fast in storage pests. If this occurs the best way of protection if probably a combination of fumigation with storage in insect proof containers or silos.

Insecticides

For the protection of stored products only a few insecticides are in common use.

a) Malathion: This is a safe insecticide which can be admixed to or sprayed on

shelled (threshed) or unshelled (unthreshed) grains. On stored produce only premium grade malathion must be used. (LD50 = 1400 mg; tolerance 8 ppm for raw cereals (FAO/WHO) The general recommendation is to mix 100150 9 2% with 100 kg produce.

Malathion dust has some limitations.

1) The product must be dry, (moisture content not higher than 13.5%) otherwise the malathion breaks down very fast.

2) The formulated malathion dust mostly has a rather short shelf life (not more than 6 months).

Malathion can also be used for spraying walls, floors or the outside of stacks (1000 mg a.i./m).

b) Ryrethrins: This is a very safe botanical insecticide but costs are high (LD50 = 1500 mg; tolerance 3 ppm for raw cereals) (FAO/WHO).

Pyrethrins are mostly admixed with a synergist to increase their effectiveness and stability and to reduce costs. The shelf life of dust formulations is rather short. Rates of application are:

100 g 0.2% pyrethrins + piperonyl butoxide (1:5) per 90 kg cereals and 100 9 0.1% pyrethrins + piperonyl butoxide (1:5) per 90 kg beans.

c) Other insecticides

During the past years a number of other insecticides have become available, the use of which is permitted in several countries.

The most important are the following:

bioresmethrin
bromephos
chlorpyrifos-methyl
fenitrothion
pirimiphos-methyl

tetrachlorvinphos

Rates of application are indicated in the table below.

	Grain g.a.i./100 kg dusts	Bags g.a.i./m WP	Warehouses g.a.i./m WP
bicresmethrin	0.3		
bromophos	0.6.08	1.0-1.25	0.51.0
chlorpyrifos methyl	0.4-.06	—	—
fenitrothion	0.8-1.0	0.5	0.5-1.0
pirimiphos-methyl	0.40.6	0.5	0.5
tetrachlorvinphos	1.0-1.5	1.0 2.0	1.0-2.0

Fumigants

A fumigant is a chemical which at the required temperature and pressure can exist in the gaseous state in sufficient concentration to be lethal to a given pest organism.

Many fumigants are available and several are commonly used throughout the world. Any confined space which can be made airtight, may be used for fumigations, e.g. silos, railway, trucks, shipholds, plastic bags, etc. Bagged produce is mostly fumigated under gasproof sheets.

After fumigation a small amount of unchanged fumigant may remain as a residue.

The following fumigants are commonly in use:

a) Methylbromide. It penetrates easily in large stacks of bagged produce but, without a special circulation system its use in large silos is limited because of unsatisfactory distribution of the gas in the grain bulk.

In flat storage, for instance in barges, this does not play a role. Under atmospheric conditions a fumigation takes 24 hours. Under vacuum conditions only several hours are needed.

Methylbromide is highly toxic and rather sophisticated equipment such as gas cylinders piping systems, gas masks and gas detectors are necessary. The fumigation has to be carried out by trained personnel.

Rates of application under atmospheric pressure are 16-32 g/m for 24 hrs depending on temperature, commodity and the insect or mite species to be controlled.

b) Phosphine. This fumigant is available in the form of tablets (pellets or sachets). Moisture absorption liberates phosphine which is very toxic to insects. The tablets must be evenly distributed through the grain by adding them to the grain flow when a bin is filled.

The tablets can also be inserted in or between bags which then must be covered by air-tight sheets. Since the development of phosphine starts some

hours after application, the use of phosphine is easy, but gas masks are necessary when aerating large stacks.

Rates of application are 1-1 1/2 tablet per m for bagged produce under plastic sheets or 2-5 tablets per ton for grain in silos. A fumigation with phosphine takes 5-7 days, besides the ease in application phosphine has some other advantages. There is less chance of affecting the germination capacity than with other fumigants like methylbromide. However, a preliminary test is always useful. The penetration of phosphine is probably better than that of methylbromide and costs of fumigation are usually less. Till now phosphine has not caused residue problems.

c) Liquid fumigants like carbon tetrachloride or mixtures of carbon disulphide, ethylene dibromide or ethylene dichloride and carbon tetrachloride are easier to handle as they are less toxic to man. The liquid is poured on the produce or left in trays to evaporate. Such a fumigation takes several days depending on the temperature and quantity of fumigant used.

Airtight storages

When grains are stored in an airtight container, the oxygen content in this container will decrease slowly due to the metabolism of the grains, insects and microorganisms until there will not be enough oxygen for any insect development. Airtight storage is an attractive way to protect produce against insects without pesticides, but often the costs of constructing suitable silos prevent their general use. For airtight storage on a small scale, oildrums or plastic bags may be used.

The lowest O_2 concentration below which insects cannot survive is about 2%. On the other hand a high CO_2 concentration (36%) together with a high O_2 concentration (15-21%) is lethal to storage pests too. The relative humidity has a strong influence on the effect of the gas concentrations. In general, a low relative humidity increases the mortality cause by low O_2 or high CO_2 concentrations. A new development is the use of CO_2 for long-term preservation and fumigation of cereal grains which has been found more effective and easier to apply than to decrease O_2 concentrations.

Table

Sieves

Hand-held sieves

Hand-held sieves are commonly used for assessing the foreign matter content of small samples of grain. Round-framed sieves with a diameter of 300 to 310 mm are preferred, although square-framed sieves with sides 300 to 310 mm long may be used. Each set of sieves should be provided with a bottom pan (receiver), for the collection of material passing through the screens, and a lid to prevent spillage during the sieving.

Comparability of the results of using hand-held sieves depends primarily on uniformity in their manufacture and it is essential to use sieves made by a factory whose products are approved by a standards organisation.

Hand-held sieves should be used in a uniform manner if comparability of results is to be maintained. Firstly, the sieve should be held level in both hands directly in front of the body, with the elbows tucked in to the waist. Secondly, using a steady motion, the sieve should be moved approximately 25 cm to the left and back through the centre position, smoothly 25 cm to the right and returned to the centre position. This sieving operation should be repeated exactly 30 times, taking about 30 seconds to do so. No forwards and backwards or up and down movements are permitted, although a final gentle tap of the sieve will help to clear it of any material hanging from the perforations before the bottom pan is removed. When sieves with slotted screens are being used, it is important to ensure that the long sides of the slots are parallel with the movement of the sieve.

Sack sieves

The foreign matter content of grain is more accurately assessed when the contents of whole sacks are screened, although this is obviously more time consuming than the hand-sieving of small samples.

A sack sieve should possess two essential features a hopper for feeding grain gradually on to the screen and a screen and a screen that moves during the sieving operation. The slope of a moving screen should ensure that the grain is kept in motion towards the discharge end. Lateral movement of the screen, as in a rotary type of sieve, is more efficient in separating out foreign matter than the end-to-end movement of other kinds of mechanical sieve.

Some standard stove sizes for cereal grains

Locally produced varieties of grain may require sieves to have screens with specifications significantly different from those indicated in Table 20. Samples of grain should be checked against standard sieves of different specifications before quantities of sieves are purchased for grain quality assessment.

Care and maintenance

Sieves of standard quality are precision instruments that should be used and handled with care, and always kept clean and dry. A proper sieve brush should be used for removing dust and other material from a sieve after it has been

used. Pieces of material stuck in the perforations should never be pushed through from the top surface of the screen. This can distort the holes and affect the accuracy of the sieve. Instead, the screen should be tweed upside down and tapped sharply or the material should be pushed out of blacked perforations with the finger tip.

Newly manufactured sieves are often coated with a thin film of oil or wax. This must be removed with warm water and detergent before the sieves are used.

If a sieve is not going to be used for some time, it should be thoroughly cleaned and coated with oil before storage to prevent possible deterioration. it must be cleaned before reuse.

Sieves are subject to wear and tear despite due care and attention and they should be checked periodically for accuracy, by comparing them with standard sieves. This is normally the responsibility of a national standards organisation or central laboratory in control of all grain quality matters.

International rules for seed testing 1985

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Adopted at the Twentieth International Seed Testing Congress, Canada 1983, to become effective on 1 July 1985. International Seed Testing Association, Seed Sci. & Tech., 13: 299-355,(1985)

Chapter 9: DETERMINATION OF MOISTURE CONTENT

9.1. Object

The object is to determine the moisture content of seed by methods suitable

for routine use.

9.2. Definition

The moisture contents of a sample is the loss in weight when it is dried in accordance with these rules. It is expressed as a percentage of the weight of the original sample.

9.3. Principle

The methods prescribed are designed to reduce oxidation, decomposition or the loss of the other volatile substances while ensuring the removal of as much moisture as possible.

9.4. Apparatus

The following apparatus is necessary, depending on the method used:

(a) An adjustable grinding mill;

(b) Constant temperature oven and accessories which shall include containers and a desiccator;

(c) Analytical balance;

(d) Sieves

Suitable apparatus is described in the Annex.

9.5. Procedure

9.5.1. Precautions

The submitted sample shall be accepted for moisture determination only if it is in an intact, moisture-proof container from which as much air as possible has been excluded. The determination shall be started as soon as possible after receipt. During the determination, exposure of the sample to the atmosphere of the laboratory shall be reduced to the absolute minimum. For species that do not require grinding no more than two minutes may elapse from the time

the sample is removed from the container in which it was received until the working sample is enclosed in the drying container and weighed.

9.5.2. Weighing

Weighing shall be in grams to three decimal places.

9.5.3. Working sample

The determination shall be carried out in duplicate on two independently drawn working samples each of the following weight, depending on the diameter of the containers used:

Less than 8 cm diameter-- 4 to 5 9. 8 cm diameter or larger-- 10 9.

Before the working sample is drawn, the submitted sample shall be thoroughly mixed by one of the following methods:

Either, (a) Stir the sample in its container with a spoon, or, (b) Place the opening of the original container against the opening of a similar container and

pour the seed back and forth between the two containers.

Each working sample shall be drawn by a method prescribed in Rule 2.7.2 in such a manner that the sample is not exposed to the air for more than 30 seconds.

9.5.4. Grinding

Large seed must be ground before drying unless their high oil content makes them difficult to grind or liable to gain in weight through oxidation.

It is obligatory to grind seed of the species indicated in Table 9A.

The grinding shall be done on a sub-sample before drawing the working sample. The required fineness of grinding is indicated in the Annex.

9.5.5. Pre-drying.

If the species is one for which grinding is necessary and the moisture content is more than 17% (or, 10% in the case of Glycine max (Soybean) and 13% in

the case of Oriza saliva (Rice)), pre-drying is obligatory. Two sub-samples, each weighing at least 259 to the nearest 2.0 mg, are placed in weighed containers. The two sub-samples, in their containers, are then dried to reduce the moisture content to less than 17% (or, 10% in the ease of Glycine max (Soybean) and 13% in the case of Oriza sativa (Rice)). Pre-drying methods are indicated in the Annex.

After pre-drying, the sub-samples are reweighed in their containers to determine the loss in weight. Immediately thereafter the two partly dried sub-samples are separated ground and the ground material subjected to the procedure prescribed in Rule 9.5.7. or 9.5.8. as appropriate.

9.5.6. Prescribed methods.

1. The Low Constant Temperature Oven method as prescribed in Rule 9.5.7. shall be used for seed of the species indicated in Table 9B.

2. The High Constant Temperature Oven methods as prescribed in Rule 9.5.8. shall be used for seed of the species indicated in Table 9C.

9.5.7. Low constant temperature oven metho.

The working sample, drawn according to Rule 9.5.3., must be evenly distributed over the surface of the container. Weigh the container and its cover before and after filling. Place the container rapidly, on top of its cover, in an oven maintained at a temperature of 103 2C and dry for 17 1 hours. The drying period begins at the time the oven returns to the required temperature. At the end of the prescribed period cover the container and place it in a desiccator to cool for 30 45 minutes.

After cooling weigh the container with its cover and contents. The relative humidity of the ambient air in the laboratory must be less than 70% when the determination is carried out.

9.5.8. High constant temperature oven method.

The procedure is same as described in 9.5.7., except that the oven is maintained at a temperature of 130 -133 C, the sample is dried for a period of four hours for Zea mays (Maize), two hours for other cereals, and one hour

for other species and no special requirement pertains to the relative humidity of the ambient air in the laboratory during determination.

9.6. Calculation of results.

9.6.1. Constant temperature oven methods

The moisture content as a percentage by weight shall be calculated to one decimal place by means of the following formula:

$$(M_2 - M_3) \times \frac{100}{M_2 - M_1}$$

M_1 — is the weight in grams of the container and its cover,

M_2 — is the weight in grams of the container, its cover and its contents before drying, and

M_3 — is the weight in grams of the container cover and contents after drying.

If the material is pre-dried, the moisture content is calculated from the results obtained in the first (predrying) and second stages of the procedure. If S. is the moisture lost in the first stage, and S2 is the moisture lost in the second stage, each calculated as above and expressed as a percentage, then the original moisture content of the sample calculated as a percentage is:

$$S_1 + S_2 - \frac{S_1 \times S_2}{100}$$

9.6.2. Tolerances

Take as the result the arithmetic mean of the dupilcate determinations carried out on a sample if the difference between the two determinations does not exceed 0.2%. Otherwise, repeat the determination in duplicate.

9.6.3. Reporting results (omitted)

Annex to chapter 9

9.4.A. Apparatus

9.4.A.1. Grinding mill

The mill used for grinding must meet the following requirements:

(a) Be constructed of non-absorbent material.

(b) Be so constructed that both the seeds to be ground and the resulting ground material are protected from ambient air during grinding, to the maximum extent possible.

(c) Grind evenly at a speed that does not cause heating of the ground material, and minimises air currents that might cause loss of moisture.

(d) Be adjustable so as to obtain particles of dimensions indicated in Annex 9.5.4.A.

9.4.A.2. Constant temperature oven and accessories

The oven may be of gravity-convection or mechanical-convection (forced draught) type. It should be electrically heated with thermostatic control, well insulated and capable of maintaining a reasonably uniform temperature throughout the chamber and the specified temperature at shelf level. It should be equipped with removable perforated or wire shelves with a thermometer which has been tested to be accurate to 0.5C placed near the upper shelf in the vicinity of the samples. The heating capacity should be such that after preheating to the required temperature, followed by opening and loading with containers the oven will again reach the required temperature within 15 minutes.

Containers must be made of non-corrosive metal or glass of approximately 0.5

mm thickness, and have snug fitting covers to minimise gain or loss of moisture, and should have sides rounded at the base, a flat bottom and level edges. Both the container and its cover should be identified by the same number. Before using, dry the container for one hour at 130C, or by an equivalent drying procedure, and cool in a desiccator.

The effective surface must enable the working sample to be distributed so as to give not more than 0.3 9/ cm.

The desiccator should be fitted with a thick metal plate to promote rapid cooling of the containers and contain a suitable desiccant such as phosphorus pentoxide, activated alumina, or molecular sieves type 4A, 1/16 (11) pellets.

9.4.A.3. Analytical balance

The analytical balance must be quick weighing and capable of weighing to 0.001 9.

9.4.A.4 Sieves

Wire sieves are required with meshes of 0.50 mm, 1.00 mm. and 4.00 mm.

9.5.4.A. Grinding

For cereal and cotton seeds fine grinding is necessary; at least 50% of the ground material shall pass through a wire sieve with meshes of 0.50 mm and not more than 10% remain on a wire sieve with meshes of 1.00 mm. For leguminous and tree seeds coarse grinding is necessary; at least 50% of the ground material shall pass through a sieve with meshes of 4.00 mm.

Adjust the grinding mill to obtain particles of the required dimensions, grind a small quantity of the sample and reject it. Then grind an amount of the samples slightly greater than that required for the test.

9.5.5.A. Predrying

In the case of very moist seed of Zea mays (= Maize) (above 25% moisture content) the seed is spread in a layer not deeper than 20 mm and dried at 70C for 2-5 hours, depending on the initial water content.

In the case of other species with a moisture content exceeding 30%, samples should be dried overnignt in a warm place such as the top of a heated oven.

In other cases, the samples should be pre-dried in a constant temperature oven at 130C for 5-10 minutes, depending on the moisture content. The partly dried material is then kept in the laboratory for two hours.

Festuca spp.

Holcus lanatus

Hordeum vulgare (all vars)

Lactuca sativa

Lathyrus spp.

Lepidium sativum

Lolium spp.

Lotus spp.

Lupinus spp.

Lycopersicon Iycopersicum

Table 9D. Tolerance levels for differences between two determinations of moisture content of tree and shrub seeds

Class	Seed size Number of pure seeds/kg	Initial moisture content%	Tolerance %
Small seeds	> 5000	< 12	0.3
Small seeds	> 5000	> 12	0.5
Large seeds	< 5000	< 12	0.4
Large seeds	< 5000	12-25	0.8
Large seeds	< 5000	> 25	2.5

KARL FISCHER METHOD

In recent years considerable attention has been given to the method of Karl Fischer for determining the moisture content of a wide variety of materials. The method depends upon the reaction of iodine with water in the presence of sulfur dioxide and pyridine to form hydrolic acid and sulfuric acid. Since the method is strictly stoichiometric it is, theoretically at least, one of the most accurate methods for determining moisture content. In applying the method to grain, the grain must be finely ground and the moisture extracted with anhydrous methyl alcohol. Because of certain practical difficulties in its application, the Karl Fischer method has been used only infrequently in determining moisture content in grain, although Fosnot and Haman (1945) applied the method to wheat and barley. Hart and Neustadt (1957) have adopted the method to all cereal grains and have used it to test the accuracy of official oven methods. The technical skill required and the time-consuming nature of this analytical method make its usefulness likely to remain limited.

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FOSNOT, R.H. and R.W. HAMAN, A Preliminary Investigation of the Application of the Karl Fischer Reagent to the Determination of Moisture in Cereals and Cereal Products., Cereal Chem., 22:41-49 (1945)

HART, J.R. and M.H. NEUSTADT, Application of the Karl Fischer Method to Grain Moisture Determination., Cereal Chem., 34:26-37 (1957) (Cited from "Storage of Cereal Grain and Their Products".)

Table 9A. Species for which grinding is obligatory

Arachis hypogaea	Oryzasative
Avenaspp.	Phaseolusspp.
Cicer arietinum	Pisum sativum (a/l vars)

Citrullus lanatus	Quercus spp.
Fagopyrum esculentum	Ricinus communis
Fagus spp.	Secale cereale
Glycune max	Sorghum spp.
Gossypium spp.	Triticum spp.
Lathyrus spp.	Zeamays
Luminus spp.	

Table9B. Species for which the /ow constant temperature oven method shall be used

Allium spp.	Raphanus sativus
Arachis hypogaca	Ricinus communis
Brassica spp.	Sesamum indicum
Camelina sative	Sinapis spp.
Capsicum spp.	Solanum melongea

Glycine max	All tree species
Gossypium spp.	
Linum usitatissimum	

Table9C. Species for which high constant temperature oven method shall be used.

Agrostis spp.	Medicago spa
Alopecurus pratensis	Melilotus spp.
Anethum graveolens	Nicotiana tabacum
Anthoxanthum odoratum	Onobrychis viciifolia
Anthriscus spp.	Ornithopus sativus
Apium graveolens	Oryza sativa
Arrhenatherum spp.	Panicum spp.
Asparagus officinalis	Papaver somniferum

Avena spp.	Paspalum dilatatum
Beta vulgaris (all vars)	Pastinaca sativa
Bromus spp.	Petroselinum crispum
Cannabis sativa	Phalaris spp.
Carum carvi	Phaseolus spp.
Chloris gayana	Phleum spp.
Ciccr arietinum	Pisum sativum (all vars)
Cichorium spp.	Poa spp.
Citrullus lanatus	Scorzonera hispanica
Cucumis spp.	Secale cereale
Cucurbita spp.	Sorghum spp.
Cuminum cyminum	Spinacia oleracea
Cynodon doctylon	Trifolium spp.
Cynosurus cristatus	Trisetum flavescens

Dactylis glomerata Daucus carota	Triticum spp. Valerianella locusta
Deschampsia spp.	Vicia spp.
Fagopyrum esculentum	Zeamays

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Basic principles of grain drying

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by Prof. F.W. Bakker-Arkema

ABSTRACT

A thorough understanding is required of the principles of drying and the fundamentals of grain deterioration in order for the agricultural engineer to adequately design a grain drying system. The topics of psychrometrics, equilibrium moisture content, grain quality, air movement, and drying theory are reviewed at the technical level required to fully comprehend subsequent papers to be presented at the grain drying seminar in Nanjing, China. This review closely follows six chapters from the standard book on grain drying by Brooker et al. (1974), which in the Chinese translation, is used as a text during the seminar. The author's five papers along with the Brooker textbook should aid in acquainting Chinese engineers with the latest designs and operations of grain dryers for small-scale and largescale installations, and in transferring up-to-date drying technology from abroad into China.

INTRODUCTION

Cereal grains and legumes are usually harvested at moisture contents too high for safe storage. Thus, drying is a necessity. A large amount of water (103.5

kg per tonne of wet material) has to be removed in drying wet grain from 22 to 13% (w.b.)*. Sufficient drying air has to be provided to the grain to assure that drying to safe-storage moisture contents is completed before microbial deterioration of the grain commences. This is the main objective of all sun and mechanical grain drying systems.

Although much grain in the world is still sun. dried, this review of drying principles will stress the mechanical drying of the crop in bulk. The paper can be considered a synopsis of the book "Drying Cereal Grains" by Brooker, Bakker-Arkema and Hall. Each section represents one Chapter in this text.

Proper understanding of the fundamentals of grain drying requires a basic understanding of the topics of psychrometrics, grain deterioration, grain moisture equilibrium, air movement, and drying theory. Each of these topics will be reviewed.

MOIST AIR PROPERTIES

This section is covered in detail in Chapter 2 of Brooker et al. (1974).

The air to be used in grain drying can be considered a mixture of dry air and water vapor. Psychrometrics refers to the thermodynamic relationships between dry air and water vapor.

There are three air humidity terms which need to be understood by grain dryer operators: vapor pressure, relative humidity, and absolute humidity. The water vapor pressure is the partial pressure exerted by the water vapor molecules in moist air; at saturation it is called the saturated vapor pressure. The relative humidity is the ratio of the actual water vapor pressure in the air to the water vapor pressure in saturated air; the relative humidity is expressed as a decimal or percentage. The absolute humidity is the weight of water vapor in the air per unit weight of dry air; absolute humidity values of drying air range from 0.005 to 0.1 kg/kg. Each of the three air humidity terms is used frequently in grain drying calculations.

Three air temperature terms require consideration in dryer design. dry-bulb, wet-bulb, and dew-point temperature. The dry-bulb temperature is the value

registered by an ordinary thermometer. The wetbulb temperature is the temperature indicated by a wetwick covered thermometer with air passing over the wick at a speed of at least 5 m/s. The dewpoint temperature is the temperature at which condensation occurs if moist air is cooled at constant absolute humidity. The three temperature terms are of significance in understanding grain drying principles.

Two additional thermodynamic terms of the drying air are required in grain drying calculations: enthalpy and specific volume. The enthalpy of moist air is the heat content of the air per unit weight of dry air above a certain reference temperature. The specific volume of moist air is defined as the volume per unit weight of dry air. Note that both of these thermodynamic properties are defined in terms of dry air; the same is true for the absolute humidity.

In Chapter 2 of Brooker et al. (1974), equations are given for calculating each of the eight thermodynamic properties of moist air defined in the previous paragraphs. Because the thermodynamic properties of air are so frequently needed in analyzing grain-drying calculations, charts have been constructed, for various dry-bulb temperature ranges and atmospheric pressures, of the

values calculated from the Brooker psychrometric equations. These charts are called psychrometric charts.

The vertical axis of the psychrometric chart usually represents the absolute humidity (and the vapor pressure), the horizontal axis the dry-bulb temperature. Diagonal lines represent constant enthalpy (and wetbulb) values. The relative humidity lines are curved. The specific volume lines are drawn obliquely to the horizontal axis. If two of the thermodynamic values of the air are known, the other properties can be read directly from the psychrometric chart.

Several processes in grain drying can be followed directly on the psychrometric chart. These include: heating, humidifying, condensing and drying.

GRAIN QUALITY

This material is covered in more detail in Chapter 3 of Brooker at al. (1974).

The objective of post-harvest drying is to maintain the desired qualities of the grain. It depends on the enduser of the grain which grain quality factor is most essential. Desirable properties of the dried grain to be considered by the grain dryer designer might include: (1) appropriately low and uniform final moisture content, (2) low moldcount of the dried kernels, (3) low percentage of broken and damaged kernels, (4) high viability (seed), (5) high head-yield (rice), (6) high bakingquality (wheat), (7) high oil-recovery (soybeans), (8) high starch-yield (sorghum), (9) high protein-content (wheat), and (10) high test-weight (maize).

Many countries have official grain standards under which grain is traded; unfortunately, no international standards have as yet been adopted. Few of the properties listed in the previous paragraph are contained in the grain standards. In the United States, the standards for the six grades of paddy includes maximum limits of heat damaged, chalky and physically damaged kernels, and specified color requirements; moisture content is not part of the grades. In the Philippines, the five standard grade requirements for paddy

include maximum limits of nine factors, including foreign matter, moisture content, and cracked kernels. The United States standard for the six grades of maize includes the factors of moisture content, test weight, broken kernels and foreign material, and damaged kernels.

The drying-air temperature can have a significant effect on grain-quality although it should be emphasized that the kernel-temperature rather than the drying-air temperature should be considered in assessing kerneldamage. In many grain dryers, there is no significant difference between the air and kernel temperatures (e.g. in in-store dryers), but in some dryer designs the maximum kernel-temperature is far below the inlet airtemperature (e.g. in concurrent-flow dryers). The maximum allowable grain-temperature depends on (1) the use to be made of the grain, (2) the moisture content of the grain, and (3) the type of grain. For seed grain above 24% (w.b.) moisture content the safe dryingtemperature is 43C, and below 24% (w.b.) is 49C; for milling-wheat above 25% (w.b.) the maximum temperature is 60C, while at moistures below that level 66C drying air can be used. In feedgrain, kerneltemperatures in the 100-120C range do not affect the nutritive value of the grain but may increase the susceptibility of the kernels to breakage.

Research is being conducted to quantify the grainquality deterioration during the drying process. First order reaction equations have been developed for the decrease during drying in seed-viability of wheat and the increase in breakage susceptibility of maize. A somewhat different set of equations has been developed for the dry-matter loss and mold development during lowtemperature in-store drying.

GRAIN EQUILIBRIUM MOISTURE CONTENT

Chapter 4 in Brooker et al. (1974) should be consulted for additional information on the topic

The concept of equilibrium moisture content (EMC) is important in grain drying because the EMC determines the minimum moisture content to which a grain is dried under a given set of drying conditions. The EMC is defined as the moisture content of a biological product after it has been exposed to a particular environment for an infinity long period of time. The EMC of grain is

dependent upon the humidity and temperature of the air, and on the grain-type, grainvariety, grain-maturity, and grain-history.

As an example of the effect of grain-type, consider 16% (w.b.) moisture content wheat and oats stored at 30C and 75% relative humidity. Because of the difference in the equilibrium moisture contents of the two crops at 30C-75% RH, the wheat will absorb moisture while the oats will lose water.

EMC values of different grains have been determined over a wide range of temperatures and relative humidities. These values are available in the literature in table and in graph form. The graphs are known as EMC isotherms, and are plots at a particular temperature of the percent moisture content (on the coordinate) versus the percent relative humidity (on the abscissa).

To facilitate dryer design calculations, equations have been developed for the sigmoid-shaped EMC isotherms. International agreement appears to have been reached to recommend the theoretically-based Guggenhein-Anderson-de Boer (GAB) isotherm for the calculation of the EMC values of all food

products including grains. The empirical isotherm equation developed specifically for grains by Chung-Pfost has been used extensively in the past for grain dryer design.

EMC data allow calculation of the heat of vaporization of moisture from the grain. This value is a measure of the energy requirement to dry grain at different moisture contents and temperatures. Knowledge of the heat of vaporisation of a grain is essential for the calculation of the fuel consumption of the crop during the drying process.

AIR MOVEMENT

The topic of air movement is discussed in more detail in Chapter 5 in Brooker et al. (1974).

Drying air fulfills two functions in a mechanical grain drying system: (1) to carry the necessary energy to the grain to evaporate the moisture, and (2) to

carry the evaporated water out of the grain mass. When air is forced through a bed of grain, resistance to the flow develops because of friction and turbulence. The resistance, called the pressure drop, is overcome by providing an excess pressure on the air entrance side of the grain mass, or by providing a vacuum on the air exit side. The pressure drop through the layer of grain depends on the rate of airflow, the physical characteristics of the grain kernels, the bed porosity, the thickness of the layer, the percentage of impurities in the grain, and the method of filling the dryer.

Pressure drop data for grains and legumes have been determined experimentally over a wide range of airflow rate. The data is usually plotted on log-log paper in terms of mm of water column (or Pascal) per meter of bed depth versus airflow rate in m per sec per m of bed area Equations are available in the literature expressing the pressure drop through a grain mass in terms of airflow rate, percentage of fines, moisture content, and bed depth.

In addition to the resistance in the grain, the drying air can encounter resistance in the air-ducting system of the dryer. The sum of the grain and ducting resistances represents the system resistance of the dryer.

The air-moving device used in grain drying systems is the fan; it should be able to deliver the specified volume of air at the correct pressure Two types of fans are in use in grain-drying installations, the axial-flow and the centrifugal. Axial-flow fans have one or more impellers (with radial blades) rotating within a cylindrical casing; air flows parallel to the axis of the fan shaft. Centrifugal fans have an impeller (with blades around its periphery) rotating within a scroll-shaped casing; the air enters parallel to the impeller shaft and is fumed 90 before discharge Axial fans are noisier than centrifugal fans, operate at lower pressures, require less space, and are in general less expensive in delivering a certain air volume.

The performance of geometrically similar fans is governed by a series of fan laws which express the effect of speed of rotation of a fan on the volume of air delivered, the pressure developed and the power required. Proper matching of the pressure drop versus airflow curve of a fan rotating at a certain speed with that of a drying system results in the operation of the fan at the desired characteristic pressure and airflow rate of the dryer. If the match between fan and drying system is correct, the fan will operate close to the optimum efficiency range of the fan, and near the rated horsepower.

GRAIN DRYING CALCULATIONS

This section parallels Chapter 8 in Brooker et al. (1974).

Drying is a process of simultaneous heat and moisture transfer. A number of biological products, when drying as single particles under constant external conditions, exhibits a constant-rate moisture loss during the initial drying period, followed by a falling-rate drying period. Grains and legumes, however, dry entirely within the falling-rate period.

In order to model the drying of a grain dryer, the drying-rate characteristics of the individual kernels have to be known in terms of the moisture and temperature changes occurring at different drying conditions. The drying rate equation fulfills this purpose.

Due to the complexity of the falling-rate graindrying process, engineers prefer to lump the effects of the different physical drying-transport mechanisms (ie.

liquid diffusion, capillary flow thermal diffusion, vapor diffusion) into a simplified semi-theoretical diffusion equation with a concentration and temperature dependent diffusion-coefficient. Values for the effective diffusion-coefficient have been published for most grains including paddy and maize. A purely empirical dryingrate expression, the so-called "thin-layer" equation, is frequently used by grain dryer designers; values for the "drying constant" of cereals and legumes are available in the literature.

Thin-layer (or diffusion) equations describing the drying-rate of individual grains are an essential part of deep-bed grain-drying models of in-store and continuous-flow dryers. There are basically two types of drying models, the differential-equation type and the heat-mass balance type. Each can be divided into nonequilibrium and equilibrium models. The nonequilibrium/differential-equation grain-drying models are the most fundamental and general in nature, and give the most accurate predictions of the dryingrate, the moisture content distribution, and the energy consumption of a particular dryer-type, regardles of its configuration or grain-type.

REFERENCES

Brooker, D B., Bakker-Arkema, F.W., and Hall, C.W. 1974. Drying Cereal Grains. AVI Publishing Co., West port, CT. U.S.A. Available in Chinese Translation.

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Present state of small-scale grain drying in the USA

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by Prof. F.W. Bakker-Arkema

ABSTRACT

Small-scale, on-farm drying of grain in the USA takes place in high-temperature, high-capacity dryers, or in low-temperature; low-capacity units. A new category, combination dryers, combines the two systems. High-temperature batch dryers are flexible, but are energy inefficient and often cause grain damage. Low temperature dryers require skill on the part of the operator and are limited to the drying of grains at moisture contents below 22% (w.b.); the units have the potential to produce excellent quality grain at minimum energy consumption.

Combination grain drying systems combine the advantages of the high-temperature and lowtemperature drying. All grain can be dried in combination drying systems regardless of the initial moisture content of the grain or the local weather conditions. It produces grain of superior quality, minimises fuel consumption, and has great flexibility. It appears suitable to Chinese conditions.

1. INTRODUCTION

This paper parallels Chapter 6 and part of Chapter 7 in the book on grain drying by Brooker et al. (1974).

On-farm grain drying systems in the USA are considered to have a capacity of less than 10 tonnes per hour in removing five percentage points of moisture from wet grain. The systems include batch drying, natural air drying, supplemental-heat drying, solar drying, combination drying, and in-bin counterflow drying. Each system is able to dry any type of grain and legume, although some cannot dry material with initial moisture content over 21 - 22% (w.b.).

Cleaning of the grain before drying is strongly recommended regardless of the drying system employed because it enhances the air flow rate and the subsequent grain storability.

2. HIGH-TEMPERATURE SYSTEMS

Drying wet grain in batches in a bin from harvest to safe-storage moisture content is called batch-in-bin drying. Relatively large airflow rates (up to 20 m/mintonne) and high air-temperatures (40 - 70C) are used; the grain depth in the bin is limited to 0.6 -1.2 m to minimize overdrying of the bottom grain dryers. Dryingtime varies from 4 - 8 hours depending on the harvest moisture content, drying air-temperature, and the airflow rate. Automatic batch dryers are molecule units fulfilling the same purpose as batch-in-bin dryers.

The grain-quality and energy-efficiency of batchtype drying systems are marginal; their advantages are the high drying capacity and simplicity of operation.

3. LOW-TEMPERATURE SYSTEMS

Natural-air and supplemental-heat drying are similar processes. The grain is

dried and stored in the same storage in on-floor flat warehouses or in metal bins. The distinction between the two drying methods is that no heat (except fan energy) is added in natural-air drying, while in the case of supplemental-heat drying, the air-temperature is increased 1 - 5C (usually with electric heaters) to decrease the relative humidity of the drying air to below 55%. Natural-air and supplementalheat drying have for a long time been used in the USA to dry small grains harvested during the summer months at moisture contents below 18% (w.b.). Now both systems have been adapted to dry maize and paddy at moisture contents up to 24% (w.b.). The recommended minimum airflow rates and maximum grain depths depend on the environmental conditions. For instance, natural air drying requires 0.6 m mine, t(1) in the more southern state of Indiana. Thus, before these two in-store drying techniques can be transferred to the different provinces in China, the minimum airflow rates have to be established for those regions.

Solar grain drying (not to be confused with sundrying which does not require a mechanical air movement device) has been researched extensively in the USA during the past decade. The solar energy available at a particular location depends on the latitude and the local weather conditions. The price of solar

collection depends on the labor costs and construction materials. These factors have contributed to the wide diversity in opinion about the value of solar grain drying systems. It is the opinion of the author that solar heat can replace significant amounts of energy in some grain drying systems, and is technically feasible; however, it will not become economically feasible in the USA until the fossil fuel prices have at least doubled.

Other recent developments in small-scale, lowtemperature grain drying include trickle-ammonia drying, heat pump drying, and stir-drying.

Low-temperature grain drying systems are lowcapacity systems but are able to produce higher quality grain at decreased energy consumption than hightemperature dryers. Considerable expertise is required of the dryer operators of low-temperature systems to ensure that the grain has dried before microbiological deterioration of the grain occurs.

4. COMBINATION DRYING

Combination drying is defined as a system in which high-temperature, high-capacity drying is followed by in-store low-temperature, low-capacity drying. The high-temperature phase of combination drying can be a batch-in-bin dryer or a mobile automatic-batch unit. The heat grain (usually maize) is harvested at 28 - 32% (w.b.), partially dried with high-temperature air to 18 22% (w.b.), and subsequently moved to a natural-air, or supplemental-heat in-store drying system for tempering and final drying/cooling. The low-temperature part of combination drying may require from 2 days to 2 months, depending on the moisture content of the grain placed in the low-temperature bin and on the airflow rate and temperature of the drying air. Combination drying systems produce grain of improved quality and require about half as much energy as high-temperature batch drying. Drieration is the best known of the combination drying system.

In-bin counterflow drying is a relative new combination drying system which has rapidly gained popularity because of its exceptional flexibility. This system also lends itself well to the use of biomass furnaces.

5. REFERENCES

Brooker, D. B., Bakker-Arkema, F. W., Hall, G. W. 1974. Drying Cereal Grains. AVI Publishing Company, Westport, Connecticut, USA. Available in Chinese Translation.

SMALL-SCALE U.S. GRAIN DRYERS

1. IN-STORE DRYING

- **AMBIENT AIR FULL-BIN DRYING**
- **LAYER DRYING**
- **AMMONIA DRYING**
- **SOLAR DRYING**
- **SUPPLEMENTAL HEAT DRYING**
- **STIR-DRYING**
- **BATCH-IN-BIN DRYING**

- **IN-BIN COUNTERFLOW DRYING**

2. COLUMN BATCH AND CONTINUOUS FLOW DRYING

- **CROSSFLOW DRYING**
- **CONCURRENT-FLOW DRYING**

3. COMBINATION DRYING

- **DRYERATION**
- **MODIFIED DRYERATION**

IN-STORE (IN-BIN) DRYING OF MAIZE)

1. FULL-BIN DRYING (LOW TEMP. SYSTEM)

- **AMBIENT AIR OR SUPPLEMENTAL HEAT - (+ 1-5C)**

- **LIMITED INITIAL MOISTURE CONTENT - (20-21%)**
- **LIMITED BED DEPTH - (3-5 M)**
- **EXTENDED DRYING PERIOD - (5-90 DAYS)**
- **MODERATE AIRFLOW RATE - (13 M/MIN TON)**
- **LOCATION DEPENDENT**
- **HUMIDISTAT OR THERMOSTAT CONTROL**
- **INTERMITTENT STIRRING**

2. BATCH-IN-BIN DRYING (HIGH TEMP. SYSTEM)

- **HEATED AIR - (45-55 C),**
- **UNLIMITED INITIAL MOISTURE CONTENT - (16-35%)**
- **VERY LIMITED BED DEPTH - (1-1.2 M)**
- **SHORT DRYING PERIOD - (6-12 HRS)**
- **HIGH AIRFLOW RATE - (1015 M/MIN TON)**
- **LOCATION INDEPENDENT**

3. IN-BIN COUNTERFLOW DRYING (COMBINATION SYSTEM)

- **HEATED AIR - (70-90C)**
- **UNLIMITED INITIAL MOISTURE CONTENT - (16-35%)**
- **UNRESTRICTED BED DEPTH - (0.3-4.5 M)**
- **SHORT DRYING PERIOD - (0.5-2 HRS)**
- **VARYING AIRFLOW RATE - (125 M/MIN TON)**
- **LOCATION INDEPENDENT**

SMALL-SCALE HIGH-TEMPERATURE MAIZE DRYERS

1. COMUN-BATCH DRYERS

- **SHALLoW GRAIN DEPTH - (0.34/4 M)**
- **HEATED AIR - (85-110C)**
- **HIGH AIRFLOW RATE - (75-100 M/MIN TONI**
- **UNLIMITED INITIAL MC - (16-35%)**
- **SHORT DRYING PERIOD - (0.5-1.5 HRS)**
- **SHORT COOLING PERIOD - (0.44.6 HRS)**

- **THERMOSTATIC CONTROL**
- **INTERMITTENT DRYING/COOLING**

2. CONTINUOUS-FLOW CROSSFLOW DRYERS

- **SAME AS ABOVE EXCEPT FOR:**
- **AIR - RECYCLE OPTION**
- **CONTINUOUS DRYING/COOLING**
- **AIRFLOW PERPENDICULAR TO GRAIN FLOW**

3. CONTINUOUS-FLOW CONCURRINT-FLOW DRYERS

- **LARGE GRAIN DEPTH - (1-2 M)**
- **HIGH AIR-TEMPERATURE - (150-200C)**
- **HIGH AIRFLOW RATE - (100-120 M/MIN TON)**
- **UNLIMITED INITIAL MC - (16 35%)**
- **SHORT DRYING PERIOD - (0.34.5 HRS)**
- **CONTINUOUS DRYING/COOLING**
- **AIRFLOW CONCURRENT/COUNTERFLOW TO GRAIN FLOW**

LARGE-SCALE MAIZE DRYING IN THE USA

1. CROSSFLOW DRYERS

- **AIRFLOW PERPENDICULAR TO GRAINFLOW**
- **TEMPERATURE AND MC GRADIENT IN GRAIN COLUMN**
- **COLUMN THICKNESS - 0.34.4 M**
- **AIRLOW RATE - 4040 M/MIN M**
- **STATIC PRESSURE - 500-1000 PA**
- **DRYING AIR TEMPERATURE - 90-110C**
- **ENERGY CONSUMPTION - 4-9 MJ/KG**
- **AIR RECYCLE SAVINGS - 25-45%**

2. CONCURRENT-FLOW DRYERS

- **AIRFLOW CONCURRENT TO GRAIN FLOW**
- **TEMPERATURE AND MC OF DRIED GRAIN IS UNIFORM**

- **BED THICKNESS - 0.91.2 M**
- **AIRFLOW RATE - 15-25 M/MIN M**
- **STATIC PRESSURE - 2000-3000 PA**
- **DRYING AIR TEMPERATURE - 175-300C**
- **ENERGY CONSUMPTION - 3.0-4.5 MJ/KG**
- **AIR RECYCLE SAVINGS - 510%**

3. MIXED-FLOW DRYERS

- **AIRFLOW COMBINATION CROSSFLOW/CONCURRENT FLOW TEMPERATURE AND MC OF DRIED GRAIN RELATIVELY UNIFORM**
- **BED THICKNESS - 0.24.4 M**
- **AIRFLOW RATE - 25-45 M/MIN M**
- **STATIC PRESSURE - 500-750 PA**
- **DRYING AIR TEMPERATURE - 95-120C**
- **ENERGY CONSUMPTION - 3.54.5 MJ/KG**

AIRFLOW TERMS

- **AIRFLOW RATE (Q) - AIRVOLUME DELIVERED BY A FAN PER UNIT TIME (M/SEC).**
- **STATIC PRESSURE (P) - RESISTANCE TO AIRFLOW AS AIR FLOWS THROUGH A GRAIN COLUMN (PA).**
- **TOTAL FAN EFFICIENCY (CT} THE RATIO OF THE THEORETICAL AIR-HORSEPOWER TO THE BRAKEHORSEPOWER.**
- **FAN SHAFT POWER -**

POWER (WATTS) = $\frac{QP}{C_T}$

STATIC PRESSURE (P)

- **IS A FUNCTION OF:**
  - **TYPE OF GRAIN**
  - **MOISTURE CONTENT OF THE GRAIN**
  - **KERNEL SIZE OF THE HYBRID OR VARIETY**
  - **PACKING OF THE GRAIN**
  - **FINES IN THE GRAIN**
  - **DEPTH OF THE GRAIN**
  - **AIR FLOW RATE THROUGH THE GRAIN**
- **P- EQN:**
  - **q = APB**
  - **WHERE A AND B ARE PRODUCT CONSTANTS**

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Cereals and cereal products - Determination of moisture content (Routine method)

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1. SCOPE AND FIELD OF APPLICATION

This International Standard specifies a routine method for the determination of the moisture content of cereals and cereal products,

The method is not applicable to maize, for which a method is specified in ISO 6540, Maize - Determination of water content (on milled grains and on whole grains).2

2. REFERENCES

ISO 711, Cereals and cereal products Determination of moisture content

(Basic reference method)

ISO 950, Cereals - Sampling (as grain).

3. DEFINITION

Moisture content: The loss in mass, expressed as a percentage, undergone by the product under the conditions specified in this International Standard.

4. PRINCIPLE

Following any grinding and conditioning, drying of a test portion at a temperature between 130 and 133C, under conditions which enable a result to be obtained which is in agreement with that obtained by the basic reference method (see ISO 711).

5. APPARATUS

5.1 Analytical balance.

5.2 Grinding mill, having the following characteristics: characteristics:

a. **made of material which does not absorb moisture;**
b. **easy to clean and having as little dead space as possible;**
c. **enabling grinding to be carried out rapidly and uniformly, without appreciable development of heat and, as far as possible, without contact with the outside air;**
d. **adjustable so as to obtain particles of the dimensions indicated in 7.1.1**

5.3 Metal dish, non-corrodible under the test conditions, or, failing this, a glass dish, with a sufficiently tightfitting lid, and having an effective surface area enabling the test portion to be distributed so as to give a mass per unit area of not more than 0.3 g/cm.

5.4 Constant-temperature oven, electrically heated, controlled in such a way that, during normal working, the temperature of the air and of the shelves carrying the test portions is within the range 130 to 133C in the neighbourhood of the test portions.

The oven shall have a heat capacity such that, when initially adjusted to a temperature of 131C, it can regain this temperature in less than 45 min (preferably in less than 30 min) after insertion of the maximum number of test portions that can be dried simultaneously.

The effectiveness of the ventilation shall be determined using durum wheat semolina, of maximum particle size 1 mm, as the test material. The ventilation shall be such that after insertion of the maximum number of test portions that the oven will accommodate, and drying at a temperature of 130 to 133C, the results, after heating the same test portions for 2 hand then for a further 1 h, do not differ by more than 0, 15 g of moisture per 100 9 of sample.

5.5 Desiccator, containing an effective desiccant.

6. SAMPLING

See ISO 950.

7. PROCEDURE

7.1 Preparation of the test sample

7.1.1 Products not requiring to be ground

Products having no particles greater than 1.7 mm, less than 10% (m/m) being over 1 mm and more than 50 % (m/m) being less than 0.5 mm, do not need to be ground before the determination.

Well mix the laboratory sample before taking the test portion (7.2.1)

7.1.2 Products requiring to be ground

If the sample does not have the particle size characteristics mentioned in 7.1.1, it shall be ground either without preconditioning (7.1.2.1) or with preconditioning (7.1.2.2)

7.1.2.1 Grinding without pre-conditioning

For products which are not likely to undergo variations in moisture content in the course of grinding [in general, products with a moisture content between 7 and 17 % (m/m), (see 9.1)] carry out grinding without pre-conditioning.

Adjust the grinding mill (5.2) to obtain particles of the dimensions indicated in 7.1.1, grind a small quantity of the laboratory sample and discard this quantity.

Then quickly grind a quantity of the laboratory sample slightly greater than that required for the test portion (about 5 9), and immediately proceed in accordance with 7.2.2.

7.1.2.2 Grinding with pre-conditioning

Products which are likely to undergo changes in moisture content during the course of grinding in general, products with a moisture content more than 17 % (m/m)' or less than 7 % (m/m)] shall be preconditioned so as to bring their moisture content to between 7 and 17 % (m/m)' [preferably between 9 and

15% (m/m) (see 9.1)], before grinding.

If the moisture content is more than 17 % (m/m)', the more frequent case, weigh to the nearest 1 mg a sufficient quantity of the laboratory sample to provide a test portion slightly greater than 5 9 (see 7.2.2) and carry out a pre-drying operation according to the instructions in 7.3, except that the time of heating in the oven (5.4) shall be 7 to 10 min and the cooling of the product to laboratory temperature shall be carried out with the dish (5.3) uncovered and without a desiccator, for at least 2 furs.

In the case of products having moisture contents of less than 7 % (m/m), weigh to the nearest 1 mg, a sufficient quantity of the laboratory sample to provide a test portion slightly greater than 5 g (see 7.2.2), place it in a suitable atmosphere (generally that of the laboratory) and leave it until a moisture content within the limits indicated above is obtained.

Weigh the sample to the nearest 1 mg, immediately grind it, controlling the grinding so as to obtain particles of the dimensions indicated in 7.1.1, and immediately proceed in accordance with 7.2.2.

7.2 Test portion

7.2.1 For products not requiring to be ground, rapidly weigh, to the nearest 1 mg, a quantity slightly greater than 5 9 of the test sample (7.1.1) in the dish (5.3), previously dried and tared, together with its. lid, to the nearest 1 mg.

7.2.2 In the case of products which have had to be ground, weigh all the grindings obtained (7.1.2.1 or 7.1.2.2) to the nearest 1 mg, in the dish (5.3), previously dried and tared, together with its lid, to the nearest 1 mg.

7.3 Drying

Place the open dish containing the test portion (7.2), together with the lid, in the oven (5.4) and leave for 2 h (90 min for flours) from the moment when the oven temperature is again between 130 and 133C.

Rapidly take the dish out of the oven, cover it and place it in the desiccator (5.5); when several tests are being carried out simultaneously, never place dishes on top of one another in the desiccator.

When the dish has cooled to laboratory temperature (generally between 30 and 45 min after it has been placed in the desiccator), weigh it to the nearest 1 mg.

7.4 Number of determinations

Carry out two determinations on test portions taken from different test samples but from the same laboratory sample.

8. EXPRESSION OF RESULTS

8.1 Method of calculation and formulae

The moisture content, expressed as a percentage by mass of the product as received, is given by the following formulae:

a) without preconditioning:

$$(m_0 - m_1)\frac{100}{m^0}$$

where

m_0 is the mass, in grams, of the test portion (7.2.1 or 7.2.2);

m_1 is the maass, in grams, of the test portion after drying (7.3)

b) with preconditioning:

where

m_0 is the mass, in grams, of the test portion (7.2.1 or 7.2.2);

m_1 is the mass, in grams, of the test portion after drying (7.3);

m_2 is the mass, in grams, of sample taken before preconditioning (7.1.2.2);

m_3 is the mass, in grams, of the preconditioned sample (7.1.2.2).

Take as the result the arithmetic mean of the determinations if the requirement concerning repeatability (see 8.2) is satisfied.

Round the result to the nearest 0.05 units.

8.2 Repeatability

The difference between the values obtained from the two determinations (see 7.4) carried out simultaneously or in rapid succession by the same analyst shall not exceed 0.15 9 of moisture per 100 9 of sample. If it does so, the determinations shall be repeated.

8.3 Remarks

The results compared with those obtained by the basic reference method (see

ISO 711) generally differ by less than 0.15 9 of moisture per 100 9 of sample.

9. NOTES ON PROCEDURE

9.1 The range of moisture contents given for conditioning products before grinding corresponds approximately in the laboratory to a temperature of 20C and a relative humidity of 40 to 70 %. It should be modified for other atmospheric conditions.

9.2 Never place moist products in an oven containing test portions at the end of drying, as this will result in partial rehydration of the latter.

10. TEST REPORT

The test report shall show the method used and the result obtained. It shall also mention all operating details not specified in this International Standard,

or regarded as optional, as well as any incidents which may have influenced the result.

The report shall include all details required for the complete identification of the sample, and in particular the date on which the analysis was carried out.

Cereals and cereal products-Determination of moisture content (Routine method)

ERRATUM

Cover page

Amend the element of the title in parentheses to read:

"(Routine reference method)"

Amend the corresponding element in the French title to read:

"(Methode de reference pratique)"

Page 1

Amend the element of the title in parentheses to read:

"(Routine reference method)"

Replace the first paragraph of clause 1 by the following:

This International Standard specifies a routine reference method for the determination of the moisture content of cereals and cereal products.

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International Association for Cereal Chemistry (ICC) -

ICC-Standard No. 109/1

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Approved: 1976

1. TITLE

Determination of the Moisture Content of Cereals and Cereal Products (Basic reference method).

1.1

In the case of maize (and whole maize meal) the method for the determination of moisture content differs in some respects from the method for other cereals (and cereal products). In the Standard the variations are indicated by two columns in the description of the method; the right-hand column applies to maize and the left-hand column to other cereals and cereal products.

Cereals and cereal products (+) Maize and whole maize meal (+) For the sake of simplicity, in following paragraphs the word "product" is used to mean a cereal as well as a cereal product

2. SCOPE

This method can be taken as the standard for the development of methods which are specifically suited to the practical determination of the moisture content of wheat, rice (hulled paddy), barley, maize or whole maize meal, millet, rye and oats, as grains, ground grains, semolina and flour

It is not to be used for the settlement of commercial disputes.

3. DEFINITION

The moisture content of a product is defined as the loss in weight sustained by

the material under the conditions specified in this Standard, expressed as a percentage of the weight of the original sample.

4. PRINCIPLE

Measurement of moisture loss when the material, ground if necessary without chan ICC-Standard No. 109/1 ge of moisture content, is equilibrated in an anhydrous atmosphere at a temperature between 45 and 50C and at a pressure of 1.3... 2.7 kPa (10...20 mm Hg).

5. REAGENTS

5.1

Sulphuric acid.

5.2

Phosphorus pentoxide.

6. APPARATUS

6.1

Analytical balance (min. precision: 0.1 mg, max. load: 200 9).

6.2

Apparatus which reduces the pressure to 1.3...2.7 kPa (10...20 mm Hg) (e.g. water jet pump).

6.3

Grinding apparatus

- **made of a material which does not absorb moisture,**
- **easy to clean, with minimal dead space,**
- **rapid and uniform grinding without heating up, contact with surrounding air being prevented as far as possible,**
- **giving particle sizes in accordance with the requirements given in 8.1.1.**

6.4

Corrosion-proof metal dish watertight cover. Its utilisable surface should allow a sample distribution of 0.3 9 per square centimetre.

6.5

Glass or porcelain bowl.

6.6

Desiccation tube made of glass (2) with one end closed and the other end provided with a semi-capillary connecting tube and a tap for producing a

vacuum. Both ends are closed with a ground stopper. After drying, the sample is cooled in the desiccation tube eliminating the need for a desiccator at this stage.

6.7

Electric drying oven with temperature regulation or other apparatus which raises the temperature of the chamber containing the sample dish to between 45 and 50C.

6.8

Air-drying system: washing apparatus containing analytical grade sulphuric acid (d20 K 1830 kg/m), and connected to a tube containing analytical grade phosphorus pentoxide (P2O5) dispersed on fibreglass.

6.9

Desiccator with active drying agent (phosphorus pentoxide). Vacuum bell-jar

or desiccator large enough to cover the metal dish

7. SAMPLING

According to I.C.C. Standard Method No. 101.

8. PROCEDURE

The weighing should be carried out to a precision of 0.0002 9.

8.1

Preparation of the sample

8.1.1 Products which do not require grinding.

Products with a particle size of 1.7 mm or less, with well than 10% by weight larger than 1 mm and more than 50% by weight smaller than 0.5 mm, need not be ground before the determination.

8.1.2 Products requiring grinding.

If the particle size of the sample does not correspond to that of 8.1.1, grinding, with or without preliminary conditioning, is necessary.

8.1.2.1 Grinding without preliminary conditioning.

This is carried out in the case of products the moisture content of which does not vary during grinding; in general these are grains with a moisture content of 7...17%(7...15% for oats). 9...15%

The grinding apparatus is set up so that the particle sizes obtained correspond to those in 8.1.1. A small quantity of the products is ground and discarded. Approximately 3.5 g 30 g of the sample is then ground rapidly. The powder is quickly homogenised with a spatula.

The ground product ca.3 g of the ground product is placed in the previously dried and tared metal dish (6.4.); the dish is quickly covered and weighed (M2).

The determination is then carried out.

When using pin- or hammer-mills, the interval between sampling and weighing before drying must be less than 2 or 3 min.

8.1.2.2 Grinding with preliminary conditioning.

Products which are too dry (m.c less than 7%) or too moist (m.c. less than 9%) (m c. above 17%, or 15% for oats) (me above 15%) must be moistened or dried, respectively, before grinding. In the case of products with a moisture content below 7% below 9% the sample is moistened by being brought into an atmosphere such that the final moisture content is between 7 an 17% (for oats between between 9 and 15% 7 and 15% and for other cereals preferably between 9 and 15%)

The most frequent need is for pre-drying of grain which is carried out generally when the moisture content exceeds 17% exceeds 15% in order to bring it within the limits of 7...17% (for oats 7...15% and for 9. 15% other cereals 9...15% if possible). 3.5 9 of the sample in whole grains (Mo) is weighed accurately and the drying process carried out according to 8.3., however the drying time is 1 1/2 h to max 2 h and a renewal of the phosporus pentoxide is not necessary. 100 9 of whole grains (Mo) is accurately measured into the metal dish (6.4.); the metal dish is placed under the vacuum bell-jar (6.9.) in which there are petri dishes with phosphoric anhydride in a ca. 1 cm thick layer, the vacuum bell-jar is closed and the pressure gradually reduced to 1.3...2.7 kPa (10 to 20 mm Hg), in order to prevent spattering of the substance, (e.g. by inserting a semicapillary tube). The connection with the device producing the vacuum is closed. The sample remains at laboratory temperature until its moisture content is between 9 and 15% (usually 2..4 days). The phosphorus pentoxide is renewed each time it becomes hydrated. The atmospheric pressure in the vacuum belljar is' restored by slowly introducing the air which has passed through the drying system.

The sample must be held at laboratory atmosphere for at least 24 h.

The pre-dried sample is accurately weighed (M') and some 30 9 of it is immediately ground; the powder is homogenised rapidly with a spatula. 3 9 of it is weighed accurately into the determination dish (6.4.). The interval between the two weighings (M' and M2) should be less than 2 min.

After conditioning the. sample is accurately weighed (M') and immediately ground in the previously set up grinding apparatus (6.3.). The ground product is placed in the metal dish (6.4.). The sample is weighed again, and the interval between the two weighings (M, and M2) may not exceed 2...3 min. The determination is then carried out.

8.2

Sample for analysis

8.2.1 In the case of products not requiring grinding (see 8.1.1.) quickly

- place some 3 9 of the substance in the metal dish (6.4.) which has, after being in the srying cupboard (6.7.), been tared, and cooled to laboratory

temperature in the dessiccator (6.9);

- close the dish and weigh (Mo).

8.2.2 In the case of products which require grinding (see 8.1.2.), the ground product (see 8.1.2.1. and 8.1.2.2.) in the closed and weighed metal dish (4.4.), is used as the sample for analysis.

8.3

Determination

The open dish (6.4.) containing the sample is placed inside the glass tube (6.6.); a dish (6.5.) containing a 1 cm thick layer of phosphoric anhydride is placed next to it. The two ends of the desiccation tube are joined together; the pressure in the enclosed space is gradually reduced to between 1.3 and 2.7 kPa (10...20 mm Hg), to avoid spattering of the substance (e.g. by inserting a semi-capillary tube). The connection with the device producing the vacuum is closed. The part of the tube containing the dish is heated to 50C in the drying

oven (6.7.).

As soon as the phosphoric anhydride cakes it must be renewed, after which atmospheric pressure is restored inside the desiccation tube (6.6.) by introducing slowly, using a semi-capillary tube, air which has passed through the drying system (6.8.). The desiccation tube is closed again and vacuum drying carried out at 50C as before. After cat 100 h the tube is removed from the drying oven and cooled to laboratory temperature. Atmospheric pressure is restored inside as previously indicated. The dish is rapidly removed, covered, and weighed immediately (M3)

Dehydration is continued until constant weight is attatined (less than 0.00006 9 difference between two weighings carried out 48 h apart).

The determination must be performed at least twice.

9. PRESENTATION OF RESULTS

9.1

Calculation method and formulas

The percentage moisture content of the product is

9.1.1 without preconditioning

without grinding $(M_0 - M_3) \times \frac{100}{M_0}$

with grinding $(M_2 - M_3) \times \frac{100}{M_2}$

9.1.2 with preconditioning

$$\left[\frac{(M_2 - M_3 \times M_1)}{M_2} + M_0 - M_1\right] \times \frac{100}{M_0} = 100\left(1 - \frac{M_1 \times M_3}{M_0 \times M_2}\right)$$

when

M_0 = initial weight of the original sample in 9 (whole grains before conditioning in the case of

a determination with preliminary drying or wetting),

M_1 = weight of the original sample in 9 after conditioning,

M_2 = weight of the sample in 9 after grinding,

M_3 = weight of the sample in 9 after complete drying.

The determination must be carried out at least twice. The arithmetic mean of the determinations, if the condition for the accuracy of the determination (9.2.) is fulfilled, is taken as the result. The result is rounded off to the nearest 0.05 9 water per 100 9 sample.

9.2

Accuracy of the determination

The difference between the results of two determinations is calculated to the nearest 0.01%. The difference between the results of these determinations, which have been carried out simultaneously or in quick succession by the same person, should not exceed 0.10 9 water per 100 9 sample. If this is not the case, another duplicate determination must be performed.

Note: with some practice, differences of less than 0.05 9 water per 100 9 sample can be achieved in one laboratory.

10. EXPERIMENTAL REPORT

The experimental report should give the method used and the result obtained. In addition, all details of the procedure which are not provided for in the present ICC-Standard or are optional must be mentioned, and any incidents which might have influenced the result.

The experimental report must contain all the data necessary for complete identification of the sample.

11. REMARKS

11.1

The moisture content range given for conditioning the cereal grains before grinding is suitable for a temperature of approximately 20C and relative humidity of 40 to 70% in the laboratory. Under other atmospheric conditions the m.c. range would have to be changed.

11.2

The length of pre-drying time should only be thought of as a guideline. It is necessary to check whether the desired conditioning can be achieved in this time with the equipment and type of cereal being used.

11.3

Discolouration of the surface of the phosphorus pentoxide indicates the loss of traces of volatile organic substances from the product being tested. This phenomenon serves as a warning. If in the case of certain adulterated products the discolouration becomes very marked, the heating temperature should be reduced. The phosphorus pentoxide should be renewed as soon as it cakes at the surface.

11.4

The above-described basic reference method for the determination of moisture content in cereals and cereal products was worked out to guarantee the elimination of the entire moisture content of the product, as water addition and removal experiments show. At the same time any chemical change in the substance, especially oxidation or loss of volatile organic substances, is avoided. Given the present state of knowledge this method offers a practical way of measuring the moisture content of cereals and cereal products.

SAMPLE DISH

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International Association for Cereal Chemistry (ICC) - ICC-Standard No. 110/1

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Approved: 1976

1. TITLE

Determination of the Moisture Content of Cereals and Cereal Products (Practical method).

1.1

In the case of maize (and whole maize meal) the method of determining moisture content differs in some points from the method for other cereals (and cereal products). In the description of the method in the Standard, the variations are given side by side in two columns: the right-hand column applies to maize and the left-hand to other cereals and cereal products.

2. SCOPE

This method is applicable specifically to: wheat, rice (hulled paddy), barley, millet, rye and oats as grains, ground grains, semolina and flour. This method gives unsatisfactory results for brewing barley maize grains or flour from whole grains. Because of the very high moisture content which can be found in maize sample (sometimes more than 40%) and because of the size and structure of the grains, problems arise in the predeying and grinding of maize for moisture determination. For this reason both the practical and the basic

reference methods can in this case only be carried out by specialist laboratories.

3. DEFINITION

Moisture content is taken to be the loss in weight, expressed as a percentage of the weight of the original sample, which the product undergoes under the conditions specified in the present ICC Standard No. 110.

4. PRINCIPLE

Determination of the weight loss suffered by The sample when dried at a temperature of 130 to 133C under precisely fixed conditions so that a result is achieved which corresponds to the result obtained using the basic reference method (ICC Standard No. 109, Determination of the moisture content of

cereals and cereal products).

5. REAGENTS

6. APPARATUS

6.1

Analytical or semi-analytical balance, minimun accuracy 1 mg, maximum load 100 to 200 9.

6.2

Grinding apparatus

- **made of a material which does not adsorb any moisture**

- **easy to clean, with minimum dead-space**
- **quick, even grinding without noticeable heating, contact with surrounding air being prevent as far as possible**
- **regulation of the desired particle size in accordance with the requirements set out in 8.1.1**

6.3

Metal dish without a cover; the usable surface must permit a distribution of 100 9 grains in one layer.

6.4

Vessel made of corrosion-resistant metal, or glass, with a watertight cover; the usable surface must permit a distribution of the sample of max. 0.3 9 per cm.

6.5

Electrically heated, temperature regulated drying cabinet, set at a temperature between 75C and 85C and provided with adequate ventilation which is set so that the temperature of the air and the shelves near to the sample is between 130C and 133C under normal conditions.

- **The drying cabinet should have a heating capacity such that when the temperature had previously been set at 131C. this temperature can be regained in less than 45 minutes (if possible less than 30 minutes) after the maximum number of samples that can be dried simultaneously have been-put in.**
- **The effectiveness of the ventilation is determined using durum semolina with a maximum particle size of 1 mm as the sample material. The ventilation should be such that, when drying simultaneously as many samples as the drying cabinet will hold, at a temperature of 130C to 133C and after heating periods of 2 h and 3 h, the difference in the results does not exceed 0.15 g water per 100 9 sample.**

6.6

Desiccator with a thick, perforated metal plate, which could alternatively be porcelain. The desiccator contains analytical grade phosphorus pentoxide (P2O5) or anhydrous calcium sulphate, granulated and impregnated with cobaltous chloride indicator, or any other effective desiccant.

7. SAMPLING

According to ICC Method No.101

8. METHOD

Weighing is to be carried out with an accuracy of 0.001 9.

8.1

Preparation of the sample

8.1.1 Products not requiring grinding:

Products with a particle size smaller than or equal to 1.7 mm, with less than 10% by weight larger than 1 mm and more than 50% by weight smaller than 0.5 mm, need not be grounded before the determination.

8.1.2 Products which require grinding:

If the particle size of the sample does not correspond to that given in 8.1.1, it must be ground, with or without preliminary conditioning.

8.1.2.1 Grinding without preliminary conditioning:

This is done when there are no variations in the moisture content of the sample during grinding to be taken into account. This is in general the case with grains having a moisture content between 7 and 17% 9 and 15% (7 and 15% for oats).

The grinding apparatus (6.2) is set so that particle sizes corresponding to 8.1.1

are obtained. A sample quantity of the product is ground and discarded.

A quantity of the sample which is a little larger than the amount intended for the test, which must be at least 5 9, 30 9 of maize, which is quickly homogenised using a spatula, 8 9 of the ground product is then ground rapidly. The ground product is placed in the metal vessel (6.4) which has been dried, cooled and tared; the vessel is quickly closed and weighed (M2). The determination is then carried out.

When using pin-or hammer-mills, the interval between taking the sample and weighing before dehydration must be lest than 2 or 3 min.

8.1.2.2 Grinding with preliminary conditioning:

Products which are too dry (m.c. less than 7%) (m.c. less than 9%) or too moist (m c. above 17%, or 15% for oats) (m.c. above 15%) must be moistened or dried, as appropriate, before grinding.

In the case of products with a moisture content below 7% (below 9% for oats)

the sample is moistened by being brought into an atmosphere such that its moisture content is between 7 and 17% or between 9 and 15% in the case of oats. (for other cereals preferably between 9 and 15%).

The most frequent need is for predrying of grain, which is generally undertaken when the moisture content is over 17% (over 15% for oats) in order to bring it within the limits of 7 to 17% (between 7 and 15% 9 to 15% for oats and if possible between 9 and 15% for other cereals).

A sample of whole grains (Mo) somewhat larger than the amount intended for the test is weighted and the process described in 8.3 is continued, except that the time in the drying cabinet (6.5) is only 7 to 10 min. and cooling of the product to laboratory temperature takes place in the open vessel with 100 9 of whole grains is weighed accurately into the metal dish (6.3) (Mo)' which is placed in a drying cabinet at 80C (6.5) and remains there until the moisture content is between 9 and 15% (ca 1 to 5 h). The dish is removed from the drying cabinet and left to stand for at least 2 h under laboratory conditions, so that the grain is brought to laboratory temperature and a uniform distribution out a desiccator and takes at least 2 h.

After conditioning, the sample is weighed again (M') and immediately ground in the grinding apparatus which has been set up in advance (6.2). The ground product is placed in the test vessel (6.4) and weighed again (M2), the interval between the two weightings (M' and M2) not exceeding 2 to 3 min.

The determination is then carried out. of moisture occurs. The sample is then weighed again accurately (M,). Some 30 9 of the conditioned grains is removed and immediately ground in the grinding apparatus (6.2) the powder is quickly homogenised with the spatula. Exactly 8 9 (M2) is placed in the test vessel (6.4). The interval between the two weighings (M, and M2) must be less than 2 to 3 min.

8.2 France

Sample for analysis

8.2.1 For products which do not require grinding (see 8;1.1), the following are quickly performed:

8.2.1.1 At least 5 9 of the substance 8 9 of the substance is placed in the metal vessel (6.4) which, after standing in the drying cabinet (6.5) has been tared and cooled to laboratory temperature in the desiccator (6.6)

8.2.1.2 The vessel (6.4) is closed and weighed (Ma).

8.2.2 For products which require grinding (see 8.1.2) the ground material in the closed and weighed vessel (6.4) is used as the sample for analysis (see 8.1.2.1 and 8.1.2.2).

8.3

Determination

The open vessel (6.4) with the sample is placed in the drying cabinet (6.5) for 2 h (90 min for flour).

The time is calculated from the point when the drying cabinet has regained a temperature of 130C. The vessel is then quickly removed from the drying

cabinet, covered and placed in the desiccator (6.6); the vessel must never be placed one on top of another in the desiccator. As soon as the vessel has cooled to laboratory temperature (usually 30 to 45 min after being put into the desiccator), it is weighed (M3)

The determination must be performed at least twice.

9. PRESENTATION OF RESULTS

9.1

Method of calculation and formulae

The percentage moisture content of the product is

9.1.1 without preconditioning 100

without grinding $(M_0 - M3) \times 100/M_0$

with grinding $(M_2 - M_3) \times 100/M_2$

9.1.2.

with preconditioning $100\left(1 - \frac{M_1 \times M_3}{M_0 M_2}\right)$

when

M_0 = original weight in g of the original sample (whole grains before conditioning in the case

of a determination with preliminary drying or damping),

M_1 = weight in g of the original sample after condition,

M_2 = weight in g of the sample after girding,

M_3 = weight in g of the sample after complete drying.

The determination must be carried out at least twice. The arithmetic mean of the determinations, when the conditions for accuracy of determination (9.2) are fulfilled, is taken as the result. The result is rounded to the nearest 0.05 9 moisture per 100 9 sample.

9.2

Accuracy of the determination

The difference between the results of two determinations is calculated to an accuracy of 0.01%. The difference between the results of these determinations, which are carried out simultaneously or in quick succession by the same person, must not exceed 0.15 9 moisture per 100 9 sample. If this is not the case, a further determination must be carried out in duplicate.

9.3

Remark

In comparsion with the results of the basic reference method, these results vary in general by less than 0.15 g moisture per 100 9 sample.

10. EXPERIMENTAL REPORT

The experimental report should give the method used and the results obtained. In addition, all details of the procedure which are not provided for in the present ICC Standard or are optional must be mentioned, as well as any incidents which might have influenced the result.

The experimental repros must contain all the data necessary for complete identification of the sample.

11. REMARKS

11.1

The moisture content range given for the conditioning of cereal grains prior to grinding is suitable for a temperature of approximately 20C and relative humidity of 40 to 70% in the laboratory. Under different atmospheric conditions the moisture content range would have to be altered.

11.2

Wet products and dry samples should never be put in the drying cabinet together, since this results in a partial rehydration of the dry samples.

Study Group: Moisture determination

Chairman: Dr. J.L. Multon, Nantes, France

Choice of method for temperature measurement

For measurement of the temperature of grain in bags, a bimetallic thermometer can be used but it is slow and measures an average of

temperature over a large proportion of the stem. A thermocouple or thermistor system incorporated in a metallic spear is preferable for bags or for taking spot measurements in bulk grain at depths up to five metres.

Monitoring of the temperature within a grain bulk over a long period is best carried out with either a thermistor or thermocouple system. In both cases the leads should be placed in situ before the silo is filled with grain. If monitoring at a small number of points is required, then the thermistor system is most suitable, and thermistors are essential if long-term monitoring by automatic recording is required. Thermocouples are cheap and convenient to use where large numbers of points are to be monitored.

Monitoring systems requiring many sensors also need a switching device, which should be located, if possible in an air-conditioned room. Otherwise, in hot humid climates, they may fail.

Temperature gradients near the surfaces of a bulk of grain can be severe in tropical and subtropical climates. Such gradients are best measured with thermocouple or thermistor systems, because their sensing heads can be made

small enough to take meaningful measurements of temperatures at points in close proximity to each other.

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Check of the calibration of moisture meters

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Part 1: Moisture meters for cereals

INTRODUCTION

The calibration of moisture meters may, for stable samples and ideal

measuring conditions, prove entirely satisfactory. On the other hand, the results obtained with the same moisture meter can be affected by many variables of cultivation, ripeness, humidity, temperature, harvesting, transport and level of impurities, particularly for cereals received with high moisture content.

SCOPE AND FIELD OF APPLICATION

This part of ISO 7700 specifies a method of checking the calibration of moisture meters in service for measuring the moisture content of cereal grains, by checking some values or a range covering all the values for which the moisture meter is used.

It is applicable to oats, durum wheat, wheat, maize, barley, rice, rye and sorghum.,

REFERENCES

ISO 712, Cereals and cereal productsDetermination of moisture content (Routine method).

ISO 5223, Test sieves for cereals.

ISO 6540, Maize-Determination of moisture content (on milled grains and on whole grains).

PRINCIPLE

Preparation of several test samples, or a range of test samples, with different moisture contents, under specified conditions, determination of their moisture contents by a reference method and measurement with the moisture meter to be checked.

REAGENT

Use only distilled water or water of equivalent purity.

Sodium hypochlorite (bleach) solution of approximately 5, 7 % (m/m) active chlorine (18 chlorometri degrees).

APPARATUS

Usual laboratory apparatus, and in particular,

Bottles, with airtight seals, of capacity approximately 21, cleaned with a bactericide and fungicide, such as the bleach (4.1), rinsed three times with distilled water and dried.

Apparatus required for the routine reference method of determining moisture content (see ISO 712 of ISO 6540).

Sieves, for cleaning the grain, complying with the requirements of ISO 5223, and in particular sieves with long rounded apertures of width 1,80; 200; and 2,24 mm and with round holes of diameter 4,50 mm, or a mechanical separator.

PROCEDURE

Selection and cleaning of samples

Select a variety or varieties or better still a mixture of varieties of a cereal from those which are the most prevalent in the region where the moisture meter is used. In the case of maize, the choice depends on the type of grain (dent, flint, dent-flint rather than on the variety.

Clean the samples by removing undersize material, including shrivelled grains, by manual sieving using appropriate sieves (see 5.3) and removing larger impurities by hand or using a mechanical separator (5.3).

As an indication, use the following sieves:

- **sieve with long rounded apertures of width 1,80 mm for rye and durum wheat;**
- **sieve with long rounded apertures of width 2,00 mm for wheat;**
- **sieve with long rounded apertures of width 2,24 mm for barley;**
- **sieve with long round holes of diameter 4,50 mm for maize.**

Preparation of test samples

1. Procedure when checking several values

1.1 According to the number of values to be checked, prepare a greater or lesser number of test samples, each having a mass of approximately 1 kg and various moisture contents between 10 and 25 % (m/m) for cereals other than maize, and between 12 and 45 % (m/m) for maize.

Preferably choose moisture contents close to those which are most frequently observed iri the region where the moisture meter is used.

1.2 To prepare the test samples, in the case of cereals other than maize, use by preference the samples selected in which in their natural state have the moisture contents necessary for the test, or if necessary samples specially conditioned by the procedure specified in 3.

In the case of maize, it is essential to select samples which, in their natural state, have the moisture contents necessary for the test, as any drying or wetting is prohibited for instruments measuring electrical properties.

Place the samples in the bottles and seal them.

2. Procedure when checking a range

2.1 Prepare a range of 10 test samples each having a mass of approximately 1 kg and various moisture contents, at intervals as regular as possible, between 10 and 25 % (m/m) for cereals other than maize, and between 12 and 45 % (m/m) for maize.

2.2 To prepare this range of test samples, proceed as specified in 1.2.

3. Conditioning of samples

This subclause does not apply to maize; maize shall not be conditioned (see 1.2).

3.1 If conditioning is necessary, take a sample having a moisture content at the time of harvesting equal to or less than the lowest moisture content selected for the calibration range, or failing that, bring the required quantity of sample selected to this minimum moisture content by drying very gradually at a temperature not exceeding 30C, using ventilation if necessary.

3.2 For each desired moisture content, place in a bottle a quantity of the sample such that the bottle is between a half and two-thirds full.

3.3 Calculate the quantity of distilled water necessary to bring each sample to the selected moisture content, using the formula

$$m \times \frac{H_2 - H_1}{100 - H_2}$$

where

H_1 is the moisture content, expressed as a percentage by mass, of the sample;

H_2 is the moisture content, expressed as a percentage by mass, selected for the calibration.

Using a burette or graduated pipette, add in rapid drops to esch sample, in one or two portions, as the case may be (see 3.4), the volume of distilled water thus calculated, while shaking the bottle. Seal the bottle.

3.4 In order to ensure that the water is evenly distributed, shake the bottles by inverting them by hand, under the following conditions:

- If the difference between the desired moisture content and the moisture content of the sample is less than 10 % (m/m) (absolute), add the quantity of the water calculated above in one portion, and shake energetically over 4 days

as described in table 1, taking great care to turn the bottle upright again after shaking.

- If the difference between the desired moisture content and the moisture content of the sample is more than 10 % (m/m) (absolute), add the quantity of the water calculated above in two equal portions at an interval of 24 h and shake energetically at regular intervals over 5 days as described in table 2, taking great care to turn the bottle upright again after shaking.

In all cases, the bottles shall be kept at a temperature of approximately 5C, for example in a refrigerator.

NOTE- Instead of shaking by hand, it is possible to use an apparatus allowing either very slow, continuous shaking to be carried out over $ days at 5C, or vigorous shaking in accordance with the timetable given in Tables 1 and 2 for manual shaking.

Table 1

	Period	Approximate duration of shaking s
	As soon as water has been added	60
	First hour	15
First day	Second hour	15
	Third hour	15
	Between the third hour and the end of the first day	15
Second day		15
Third day		15
Fourth day		15

Table 2

	Period	**Approximate duration of shaking s**
	As soon as the first fraction of water has been added	60
	First hour	15
First day	Second hour	15
	Third hour	15
	Between the third hour and the end of the first day	15
	As soon as the second fraction water has been added	60
	First hour	15

Second day	Second hour	15
	Third hour	15
	Between the third hour and the end of the second day	15
Third day		15
Fourth day		15
Fifth day		15

Checking the moisture meter

1. Procedure when checking several values

1.1 If the test samples have not been conditioned, ensure that they have been kept under the same temperature conditions as the moisture meter before the test; if not keep them under these conditions to allow them to reach thermal equilibrium with the moisture meter. If the test samples have been

conditioned, remove the bottles from the refrigerator at feast 16 h (usually overnight) before the test, to allow them to reach thermal equilibrium with the moisture meter. In all cases, note the temperature at which thermal equilibrium is reached.

Reject the test samples if they emit an odour of fermentation or are mouldy (in the case of a range, it is necessary to start again).

1.2 On each previously mixed test sample, carry out the following operations:

a) Determine the moisture content by the routine reference method specified in ISO 712 or, in the case of maize, in ISO 6540.

Take as the result the arithmetic mean of two determinations. It is imperative to comply with this condition.

b) Using the moisture meter, carry out four successive measurements using four test portions taken from the test sample.

In the case of moisture meters designed to take readings on whole grains, which in general require large test portions, transfer each test portion back into the bottle containing the test sample after each measurement, and mix by shaking the bottle before taking a new test portion.

In the case of moisture meters for taking readings on ground grains, which, in general, require small test portions (less than 509), carry out the grinding and measurement strictly according to the manufacturer's instructions. Discard all test portions after use.

c) After four measurements have been taken, again determine the moisture content by the routine reference method, proceeding as described in a).

2. Procedure when checking a range

On each test sample, carry out the same operations specified above and repeat the operations specified in 1.2 at an interval of 24 h using the same test samples for cereals other than maize, and different test samples for maize.

EXPRESSION OF RESULTS

Procedure when checking several values

1. For each test sample, the following values are available:

- two results obtained by the routine reference method, x.

The difference between these two results shall not exceed 0,15 9 of moisture per 100 9 of sample for products not requiring preconditioning (defined in 6.2.3), and 0,20 9 of moisture per 100 g of sample for products requiring preconditioning. Otherwise, repeat the test;

- four measurements carried out with the moisture meter, y.

2. For each test sample, calculate the difference between the result of each measurement carried out with the moisture meter, y, and the mean of the two results obtained by the routine reference method, x, i.e. y - x.

The values y - x shall be less than the maximum permitted errors such as those specified in the Annex.

Procedure when checking a range

1. Deal separately with the two series of measurements carried out at an interval of 24 h and compare them to ensure that there has been no development of the grain (maize excluded) and/or variation in the response of the moisture meter over this 24 h period.

2. For each test sample and for each series of measurements, the following values are available:

- two results obtained by the routine reference method, x.

The difference between these two results shall not exceed 0,15 9 of moisture per 100 9 of sample for products not requiring preconditioning and 0,20 9 of moisture per 100 9 of sample for products requiring precondi-requiring preconditioning. Otherwise, repeat the test.

- four measurements carried out with the moisture meter, y.

3. For each test sample and for each series of measurements, calculate the difference between the mean of the four measurements carried out with the moisture meter, y, and the mean of the two results determined by the routine reference method, x, i.e.y-x.

For each series of measurements, the values of y x should be less than the maximum permitted errors, such as those specified in the annex. If a value of y - x is greater than the maximum permitted error, repeat the measurements on the corresponding test sample.

TEST REPORT

The test report shall show the method used, the test temperature, the type of moisture meter used and its precision class, and the results obtained. In addition, it shall mention any operating details not specified in this

International Standard, or regarded as optional, as well as any incidents likely to have influenced the results.

The test report shall include all the information necessary for the complete identification of the sample.

MAXIMUM PERMITTED ERRORS

The maximum permitted errors for moisture meters In service, In accordance with draft OIML International Recommendation No. 59 concerning moisture meters for cereals and oilseeds, are as follows.

A.1 Class I moisture meters (see also the figure)

- For cereals other than maize, rice and sorghum: 0,7 (absolute) for a moisture content, x, less than 10 % (m/m); 0,4 (absolute) plus 3 % (relative) for a

moisture content, x, greater than 10 % (m/m).

- For maize, rice and sorghum: 0,8 (absolute) for a moisture content, x, less than 10 % (m/m); 04, (absolute) plus 4 % (relative) for a moisture content, x, greater than 10 % (m/m).

A.2 Class II moisture meters

- **For cereals other than maize, rice and sorghum: 0,8 (absolute) for a moisture content, x, less than 10 % (m/m); 0,4 (absolute) plus 4 % (relative) for a moisture content, x, greater than 10 % (m/m).**
- **For maize, rice and sorghum: 0,9 (absolute) for a moisture content, x, less than 10 % (m/m); 0,4 (absolute) plus 5 % (relative) for a moisture content, x, greater than 10 % (m/m).**

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ASAE Standard: ASAE S352

Developed by the ASAE Physical Properties of Agricultural Products Committee; approved by Electric Power and Processing Division Standards Committee; adopted February 1972; reconfirmed for one year, December 1976.

Section 1 - PURPOSE AND SCOPE

1.1 This standard is to provide a uniform method for determining the moisture content of unground samples of agricultural seeds. Only those seeds are included for which documented comparisons with the Karl Fischer method are available. These techniques should become common practice and their use referenced in all technical presentations where moisture content determinations have been a factor. Deviations from these methods should be reported.

1.2 S'pecifying sampling procedures is not within the scope of this recommendation. It will be assumed that the portion used for analysis is representative of the sample as a whole.

Section 2 - APPARATUS

2.1 Moisture dishes. Moisture dishes should be made of heavy gauge aluminum that does not dent readily. The dishes should be provided with tightly fitting covers. Both the dish and its cover should be identified by the same number.

Before using, dry the moisture dish for one hour at the drying temperature to be used and obtain the tare weight. Other similar containers may be used provided they are tarred before and after drying and their use is mentioned in referring to the moisture measurement techniques used.

2.2 Desiccator. Desiccator should be airtight and should contain activated alumina or other equally suitable desiccant. Silica gel and anhydrous calcium are not suitable desiccant.

2.3 Oven. Oven may be of gravity-convection or mechanical convection (forced-draft) type. It should be well insulated, maintain a reasonably uniform temperature throughout the chamber and maintain specified temperature at shelf level. A properly ventilated oven, equipped with removable perforated or wire shelves and a suitable thermometer accurate to within 0.5 deg C, is required to insure uniformity of heating, ovens should be in operation for several hours prior to the drying operation.

2.4 Balance. An analytical balance should be used for all weighings in making moisture content determinations. Weighings should be made to the nearest

0.01 9 or about 0.001 of the total sample weight.

Section 3 - PROCEDURE

3.1 Place a minimum of 15 9 of a representative portion of the unground sample in each of two or more tarred moisture dishes. For high-moisture content seeds (over 25 %), use 100 9 portions instead of 15 9 portions for the determination. Weigh the covered dishes and contents. Subtruct the weight of each dish from the total weight of the portion. Uncover the dishes and place them with their covers in the oven. The oven temperature and heating period depend on the seed as shown in Table 1.

3.2 The dishes should be placed with the bulb of the oven thermometer as close to them as possible. At the end of the heating period, cover the dishes as soon as possible and place them in a desiccator. Weigh the dishes when they reach room temperature. Calculate the percentage of moisture by dividing the loss in weight due to heating by the weight of the original sample and multiply

by 100. Replace determinations should check within 0.2 percent moisture.

(cited from "AGRICULTURAL ENGINEERS YEARBOOK" p.417, (1977))

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Status of research on detection and control of mycotoxins in food grains in Bangladesh

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Mycotoxins are chemically unrelated groups of fungal metabolises characterized by their ability to induce a toxic response in human and animals when food or feed containing them is consumed. Mycotoxins are produced by a number of genera of fungi, however, only the aflatoxins produced by the genus Aspergillus have drawn great attention almost universally. Bangladesh is situated in the monsoon belt of tropical region. Hot and humid climate of the country is very conducive for growth, development and multiplication of microflora. The frequent heavy rainfall and floods during "Kharif" and occassional early shower during late Rabi seasons expose cereals pulses and oilseeds to fungal invasion and accumulation of mycotoxins and damage in storage.

Bangladesh has to feed a population of around 105 million (BBS 1989) with a deficit production of 2-3 million tonnes foodgrains. The national food balanced of the country per capita-day during 1987-88 was 52.1 gm of protein, 46.1 gm of fats producing 2078 calories of energy from sources like cereals, pulses, oilseeds, tuber and root crops, meat, egg, milk, animal & vegetable products,

(BBS-1989). In this paper we shall, however, discuss the assessment of microflora associated with the different food grains, level of mycotoxins elaborated by them and the attempt made to prevent the food stuff from mycotoxins contamination.

AFLATOXIN PRODUCING FUNGI

Around 20 aflatoxins have been reported to be produced by fungi in storage. Most of them are produced by imperfect fungi like Aspergillus flavus, A parasiticus, A wentii, A niger A ochraceous, A oryzee, and species of Penicillium like P citrinum, P puberulum and P frequentans and species of Rhizopus. But systematic study of Wilson, et al (1968) revealed that only two species of Aspergillus viz. A flavus and A parasitic us produced aflatoxins. Although besides aflatoxins other mycotoxins like cyclopiazonic acid and sterigmatocystin are also produced by A flavus (Luck et al. 1978, Burkhardt and Forgaes, 1968).

MYCOFLORA OF FOOD GRAINS

Bangladesh is a tropical country with hot and humid climate which makes a suitable environment for the growth of moulds. Moreover, during the harvesting time of paddy in Kharif season frequent shower occurs which hinder the proper solar drying. Similarly at maturity of pulses and oilseeds crops also starts post winter rain making them vulnerable to mould and other pathogenic fungal attack. Studies were conducted to assess the fungal flora associated with different foodgrains. With paddy varieties Mia et. al (1986) reported 19 fungi belonging to 17 genera which includes moulds as well as seed-borne pathogens.

Jonarder et al (1980) has studied the incidence of fungi in both raw and parboiled paddy of Bangladesh. Their results are given in Table 2-3.

It should be noted that during parboiling the contaminating fungal flora are destroyed and the husks are opened. The drying and handling of the parboiled

paddy are carried out on the hardened earth floor; this results in fungal recontamination of the paddy.

A total of 14 fungal species belonging to 12 genera were recorded on wheat seeds stored under farmers conditions (BARI, 1984, 1968). Fungi like species of Aspergillus, F!hizopus, Penicillium

Cladosporium and Alternaria were more prevalent than the others, The incidence of Alternaria, Cladosporium, Fusarium and Curvulaia were higher in the prestored condition which gradually decreased with the increase of stored period while species of Aspergillus, Penicillium and Phizopus increased during storage. In a similar study Basak et al. (1987) reported 14 fungail species belonging to 8 genera (Table 1). In another more recent survey on wheat seed storage mould in Government food storage and ration shops in Dhaka and Joydebpur, it was reported that all the seed samples were infected/infested with storage fungi like species of Aspergillus, Pericillium, Rhizopus and bacteria. Among the storage moulds Aspergillus spp. was the highest (47 to 100%) followed by Rhizopus spp. around 30% and Penicillium 20% (Goswami, unpublished). Mould infestation of seeds of other cereals like maize, millets

and kaon were also studied by different workers and reported the similar type of incidence.

Regarding pulses and oilseeds, reports on seed micoflora infestation are also available. In a survey of storage fungi of pulses seed at farmers level storage, 25 fungal species belonging to 21 genera were identified in 6 pulses (BARI, 1984). Here also the field fungi like the species Alternaria Fusarium and Curvularia observed gradually decrease in population with the increase stored period. On the other hand the storage fungi like the species of Aspergillus, Penicillium, Rhizopus and Cladosporium increased with increase of storage period.

In another study on the prevalence of seed mycoflora on mustard seeds 18 different fungal species representing 10 genera were identified (BARI, 1986). The genera are Alternaria, Aspergillus, Chaetomium, Cladospori.um, Curvularia, Fusarium, Penicillium, Drechslera, Rhizopus and Trichothecium out of them the prevalence of Aspergillus was next only to Alternaria. The population by Aspergillus also increased with the increase of storage time.

In a similar study on storage mould of peanut under farmers storage condition 16 fungal species representing 13 genera were recorded (BARI, 1988), out of which prevalence of A. flavus was the highest (68%)

AFLATOXIN PROBLEM IN DIFFERENT FOOD GRAINS

The four main aflatoxins are aflatoxic B1, B2, G1 and G2. The letters so assigned are due to the blue and green fluorescence they produce when irradiated with UV light and the subscripts 1 and 2 according to their polarities in TLC plates. When aflatoxin B1 is ingested some transformation occur and secondary new aflatoxin M1 and M2 having same acute toxicity as B1 are produced which are generally found in cow's milk (Coker, 1979).

Aflatoxin is a particularly noxious compound because at acute dose levels it induces liver lesions and death when administered to a number of animals and at chronic levels it produces liver tumours (Bainton, et al. 1980).

1. Aflatoxin in rice

A preliminary study on the aflatoxin content of rice from Bangladesh was carried out in the University of Dhaka in 1968, the results are given in Table 4.

Although no definitive conclusion can be drawn from this data the results indicate that aflatoxin contamination occurs in rice produced in Bangladesh.

A more recent study by Hug (1980) of rice samples from Bangladesh, as a part of a broader project "Rice in Bangladesh Appropriate Technology for the Intra-Village Post-Harvest System" organised by the Institute of Development Studies, University of Sussex, Brighton, UK, in collaboration with the Bangladesh Council of Scientific and Industrial Research has shown a high incidence of aflatoxin in rice and paddy.

2. Aflatoxin in other cereals

Table 5 reveals that other cereal products in Bangladesh, like wheat, maize,

kaoin and chcena, are also susceptible to aflatoxin contamination.

A sample of damaged selected wheat has been found to contain a level of 5 ppm-kg. This is a cause for concern and indicates further studies on wheat.

3 Aflatoxin in pulses

A preliminary survey for aflatoxin contamination in pulses was carried out at the University of Dhaka and BCSIR. The results are given in Table 6.

Although some pulses are not susceptible to aflatoxin contamination, a thorough investigation of pulses grown in Bangladesh is needed to establish those that are affected by this compound. Chickpea and Lathyrus are the two most important pulses in Bangladesh which are badly affected by aflatoxin.

4. Aflatoxin in oilseeds and oilcakes

The aflatoxin content of some of the oilseeds and oilcakes produced in Bangladesh are given in Table 7.

It is to be noted that three of the important oilseeds, groundnut, cottonseed and leutil are affected by aflatoxin. Further work on these commodities is required.

PREVENTION FROM MYCOTOXINS

The moisture content of the grains as well as the type of containers play an important role in enhancing the growth and multiplication of mycoflora. Higher moisture content encourages the incidence of moulds while the air tight containers reduces them. Studies were therefore, undertaken to prevent the growth of seed mycoflora by manipulating moisture content of seed and designing suitable storage containers to be used in the farmers level. With six pulses like lentil, chickpea, blackgram, mungbean field pea and lathyrus stored in containers like earthen "motka", gunny bag, kerosin tin, plastic bag, bamboo "dol" etc. showed that kerosine tin and plastic bags were more suitable than those of the other containers (BARI, 1985).

In another study conducted at Plant Pathology Division, BARI with peanut seed stored in eight different types of storage containers like tin containers, gunny bag, gunny bag with potythene lining, polythene bag, earthen motka, earthen motka with polythene lining inside, earthen motka with outside coaltar coating and bamboo "dole" with polythene lining inside. It was found that this earthen motka which farmers are using could safely be used giving a polythene lining inside or allowing a coaltar coating outside (BARI, 1988).

Regarding moisture content in grains studies were also conducted at BARI with chickpea as well as maize seeds maintaining moisture level 10, 12, 14 and 16%. It was found to have bacteria and Rhizopus sp at 10% moisture content of maize seed. In overall observation it was noted that the incidence of mycoflora was encouragingly less in samples stored at 10% moisture content which increased gradually at higher percentage of moisture (Table 8). With chickpea seed stored at 8, 12 and 16% moisture cement also found to have the lowest incidence of mould at 8% (Table 9).

It seems from the above discussion that the foodgrains can be provented from aflatoxin by preventing the growth of the mould by proper and sufficient

drying and storing them in suitable containers.

CONCLUSION

Evidence reported herein makes it quite conspicuous that the foodgrains of Bangladesh are not free from mycotoxin. Research work done to prevent them from toxins is quite meagre. Work on detection and quantification of mycotoxin are in progress at BCSIR under the financial support of Ministry of Science and Technology and at the Nutrition Institute at the University of Dhaka. Some isolated projects are working under Ministry of Agriculture by financial support from different agencies like IDRC, DANIDA etc. But this works is still to come out as conclusive recommendation. It is, therefore, essential to look into ways and means of prevention and control of foodgrains from mycotoxins.

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Prevention and control of mycotoxins in foodgrains in India

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1. INTRODUCTION

India is predominantly an agrarian country with nearly three fourths of the people dependent on agriculture or rural economy. The most outstanding achievement of Indian agriculture since independence is the phenomenal growth of foodgrains output. During the last three decades, Indian agriculture has experienced a revolutionary breakthrough in foodgrain production leading the country from deficit and import arena to the positive situation of self-sufficiency and buffer stocks. The foodgrain production in the country increased from 50.8 million tonnes in 1950-51 to 152.37 million tonnes in 1983-84, but the growth of Indian agriculture still continues to be linlked with the vagaries of nature. Some of the states in the country have come across the unprecedented draught of the century for the fourth successive year which has caused tremendous hardship to the people as also loss of production of foodgrains in those states.

Nearly seventy percent of the total production of foodgrains in India is

retained at farm level where the unscientific and faulty storage conditions enhance the chances of fungal attack and thereby mycotoxin production. The decomposers of foodgrains i.e. fungi, bacteria etc. are always present on foodgrains in dormant conditions (usually as spores) and grow under favourable climatic and other conditions (1). The fungal growth may cause decrease in germinability, discolouration of grain, heating and mustiness, loss in weight, biochemical changes and production of toxins. All these changes may occur before the responsible fungi could be detected on visual examination (2).

The fungi produce a large number of mycotoxins in foodgrains and their products. Mycotoxins are a group of highly toxic secondary metabolises of the fungi produced under certain favourable environmental conditions (3). Because of their potent toxic nature and fairly common occurrence under natural conditions, mycotoxins have attracted world-wide attention in the recent years. The diseases or physiological abnormalities resulting due to ingestion of mycotoxins are known as "mycotoxicosis" (4).

2. GENESIS OF THE PROBLEM

Association of mould produced toxins with food commodities has been knowri since Biblical times but their role in inciting disease syndrome was realised only when it was discovered that "ergotism" was caused due to consumption of barley and rye infected with Claviceps purpurea (5). Cardiac beriberi caused by Penicillium citreovirde was recorded in Japan due to consumption of contaminated rice; Stachybotryotoxicosis of horses in Soviet Union in 1931; Red Mould Diseases or Black Spot Diseases Caused by Fusarium sps. in Japan during 1940-50 and Alimentary Toxic Aleukia (ATA) caused by Fusarium and Cladosponum species in USSR during 1942-47 (6).

The severity of mycotoxin problem was realised during World War II when Russians eating mouldy overwintered grains sufferred with severe dermal necrosis, leukopenia, haemorrhages and destruction of bonemarrow._ Fusarium was found to be the causal organism (7). World-wide scientific recognition of mycotoxin problem was, however, only in 1960 when it was discovered that the aflatoxins were responsible for the death of about a lakh turkey poults (Turkey x disease) in England (8). According to Blount, the

"poisonous feed" which caused the havoc and which was the preparation of Brazilian peanuts, was contaminated with Aspergillus flavus (9).

3. NATURAL OCCURRENCE OF MYCOTOXINS IN INDIA

Cereals constitute the most important food and feed sources which are affected by various mycotoxic fungi. The problem of natural occurrence of mycotoxins in cereals aggravated to some extent due to rapidly changing agricultural technology (10). In general, mycotoxins and particularly aflatoxins seem to pose great problem in the tropics than in the temperate regions but no part of the world can be considered to be mycotoxin-free zone due to the movement of various foodstuffs from one part of the globe to the other (4).

Some of the important commodities which have been found to be naturally contaminated with one or the other mycotoxins are listed below:

3.1 Maize:

Maize is an excellent substrate for mould growth and mycotoxin production. In India, systematic survey of maize grains for mycotoxins contamination has been undertaken in some parts only. However, some reports mainly on aflatoxin contamination in stored grains have indicated that the problem of aflatoxin contamination is much more serious than usually visualised (4). In an extensive survey of the important maize growing areas of Bihar, natural contamination of mycotoxins and particularly of aflatoxin was reported in the grains of field maize crop (11). Surveys conducted by the Indian Grain Storage Institute during 1978-79 and 1980-81 indicated contamination of stored maize grain samples with aflatoxin B1 in the range of 40-510 ppb (12,13).

Under a FAO sponsored Food Contamination Monitoring Project, out of 10 maize samples collected from Western Uttar Pradesh, 3 samples were found contaminated with aflatoxin B. in the range of 20-80 ppb (14). Samples of maize collected from traditional storage structures from various parts of India have shown contamination of aflatoxin B1 in the range of 15680 ppb (15). Fifteen varieties of maize were screened by Bilgrami et al (16) for aflatoxin production by artificial inoculation of A. parasiticus. Practically ail the

varieties favoured aflatoxin production, but in varying degrees. Maize is a good substrate for the production of Zearalenone which has been detected frequently in commercial varieties. Reports of natural occurrence of Zearalenone in standing maize crop are also available (4).

3.2 Rice:

Rice is also one of the important cereals which favours mycotoxin production. Natural occurrence of aflatoxin and aflatoxin producing fungi in rice has been reported from various parts of the world (16). In a survey of paddy harvested from rain affected crop in Punjab and Haryana, out of 83 samples only 3 ewre found contaminated with aflatoxin B. in the range of 10-40 ppb (17,18). Rice stored for prolonged periods i.e. 4-8 years has also been reported to be contaminated with aflatoxin B. in various parts of India (12, 13, 14, 15, 10, 20, 21).

Presence of some other mycotoxins like citrinin, Sterigmatocystin and Ochratoxin has been detected as natural contaminants of rice in one or the other region of the world. Only scanty information is available pertaining to

these toxins in India (4).

3.3 Wheat:

Wheat does not appear to be a good substrate for aflatoxin elaboration. Survey reveals that natural contamination of wheat occur but in low profile (30). Out of 223 samples collected from wheat growing belt of Western U.P. (India), only 9 samples were found contaminated with aflatoxin B. in the range of 8-40 ppb (4,19,22). In 1985, all the six flood affected wheat samples collected from Punjab were found contaminated with aflatoxin B1 in the range of 8-40 ppb (24). There are few other reports of the natural contamination of aflatoxins in wheat in India (23, 31). Reports of natural occurrence of Sterigmatocystin in the domestic and imported red & white wheat are also available from India (32).

3.4 Barley, oats, millets etc.:

Like wheat these small grains also do not favour natural contamination of mycotoxins. However, some of these grains have been reported suitable

substrates for aflatoxin production. All the four aflatoxins B1, B2, G1, G2 as natural contaminants were isolated from sorghum grains obtained from ears affected by A. flavus in North India (25). In Western India sorghum samples were found contaminated with aflatoxin B., the level of which was significantly correlated with moisture content as well as A. flavus population (26). A survey in Central U.P. (India) has indicated that sorghum and bajra are also naturally contaminated with aflatoxin B. during storage (19). It was also noticed that contamination of aflatoxin degraded quantity-wise with the increase in storage period during May to September. Perhaps, it was because of the fact that the production of aflatoxin diecreases with increase in the temperature beyond 25C. Out of the total contaminated samples, only 2 samples of sorghum contained 40 ppb, beyond the prescribed limit of 30 ppb for food in India.

3.5 Pulses & Oilseeds:

A survey under FAO sponsored Food Contamination Monitoring Project in Western Uttar Pradesh revealed that few samples of pulses including green gram, black gram & lentil and few samples of cotton seed were found contaminated with aflatoxin B1. The range being 4-80 ppb in pulses and 35-

200 ppb in oilseeds (14). Similarly, ten percent of stored soybean samples were found contaminated with aflatoxin B. in the range of 4-40 ppb, in a survey in Uttar Pradesh (27).

A survey carried out by the Central Food Technological Research Institute, Mysore and Regional Research Laboratory Hyderabad revealed that 80 percent of the peanut meal produced in different states in India was found contaminated with aflatoxin at varying levels (28).

3.6 Dry fruits & spices:

Aflatoxin has been reported as the main contaminant of coconut and other dry fruits viz. almond, cashew nut, walnut, raisin, makhana and emblic. In some samples of these dry fruits, presence of Zearalinone, Citrinin and Ochratoxin has also been reported. Natural contamination of aflatoxin in various samples of chillies, fennel, cumin, coriander, black pepper, ginger, cardamom and turmeric and presence of Orchratoxin, Citrinin and Zearalinone has also been reported in a few samples of spices (33). In a limited survey in Uttar Pradesh conducted by the Indian Grain Storage Institute, Hapur during 1984-85, it was

revealed that out of 99 dry fruit samples only 19 samples were contaminated with aflatoxin B1 in the range of trace to 50 ppb (19).

3.7 Milk & Milk Products:

Milk and milk products are consumed by the people of all age groups and are also important sources of mycotoxin exposure. So far no systematic survey of milk or milk products has been done in India (33). Some reports indicate that aflatoxin M, upto 8 mg/l were detected in the milk of buffaloes in Andhra Pradesh (34).

3.8 Cattle & Poultry Feed:

Cereals and oilseeds constitute more than 70 percent fraction of cattle and poultry feed. Usually, the food which is declared unfit for human consumption finds its way as feed for animals and poultry birds (33). A number of reports indicated the presence of high concentrations of aflatoxins as natural contaminants in cattle feed. Presence of Ochratoxin A and Sterigmatocystin has also been shown in some samples of cattle feed containing sunflower cake

and green gram (35).

4. HIGH RISK AREAS IN INDIA

Being aerobic in nature, mycotoxic fungi require air, moisture, nutrients and suitable temperature for their growth and metabolism (4). Moisture content of the grain or the relative humidity surrounding the substrate are the most important factors governing the growth and aflatoxin production by A. flavus. Climatic conditions in India are most conducive for mould invasion proliferation and elaboration of mycotoxins. The high risk areas identified in India are Kerala, Western India, Gangetic plains, north eastern as well as coastal areas of Andhra Pradesh, Karnataka and Tamil Nadu (16). Unseasonal rains, flash floods are very common in India which enhance the moisture content of the grain making them more vulnerable for fungal attack (30).

5. PROBABILITIES OF CONTAMINATION

Warm humid climate provides congenial atmosphere for the growth of fungi and production of toxins. Aspergillus flavus which is known as storage fungi may infect and produce aflatoxins in crops in the fields also (30).

Foodgrains are normally harvested at higher moisture content and then dried to bring down the moisture content up to safe level before storage. Delay in drying to safe moisture levels increases risks of mould growth and mycotoxin production.

Natural calamities like floods or torrential unseasonal rains during pre, mid or post-harvest stages may render the crops vulnerable to microbial attack. Annual loss due to spoilage of high moisture paddy is conservatively estimated to be 10-15% of the total production of paddy, produced during rainy season in India (22).

Faulty storage conditions may also enhance the chances of microbial attack and production of mycotoxins. Thus, starting from harvesting of the crop till

the food or food products are consumed by the consumers, there are chances of microbial invasion/fungal attack at each and every stage/step.

6. R & D CENTRES FOR STUDY OF MYCOTOXINS IN INDIA

Considerable R & D work on mycotoxin contamination is being carried out at the following centres:

i. **National Institute of Nutrition (NIN), Hyderabad.**
ii. **Central Food Technological Research Institute (CFTRI), Mysore.**
iii. **Indian Grain Storage Institute (IGSI), Hapur.**
iv. **Central Drug Research Institute (CDRI), Lucknow.**
v. **Industrial Toxicology Research Centre (ITRC), Lucknow.**
vi. **Vallabh Bhai Patel Chest Institute, New Delhi.**
vii. **Universities/Regional Research Laboratories under the CSIR.**
viii. **I.C.A.R. and its Centres.**

7. REGULATIONS

Eighteen countries all over the world have guidelines or regulations which prescribe maximum acceptable limits for aflatoxins in food and feeds.

The limits prescribed vary from 0 to 50 ppb in foods and from 0 to 1000 ppb in feeds (30). The Protein Advisory Group of United Nations has recommended intake maximum 30 ppb aflatoxin in foods rich in protein, where use of contaminated food cannot be avoided.

In India, the Governmental agencies procure foodgrains confirming to prescribed specifications thereby minimising the chances of contamination and thus ensure the supply of good quality foodgrains to the consumers through PDS. At farm level also quality consciousness is created amongst the farmers through a network of 17 teams of Save Grain Campaign. These teams educate, motivate and persuade the farmers to adopt scientific methods of foodgrains storage with a view to minimise the qualitative and quantitative

losses in foodgrains during storage likely to occur due to insects, rats and moulds. The Quality Control Teams monitor the quality of foodgrains at commercial level.

8. PREVENTION AND CONTROL OF MYCOTOXINS

Hazards of mycotoxin infected food are now well recognised. Considerable concern has, therefore, been shown in the recent years towards the control of these toxic metabolises. Control is attained by preventing the growth of moulds, separation of infected grains, detoxification and by growing resistant varieties (33).

8.1 Prevention of mould growth:

In stored grain, mould damage may be prevented mainly by three kinds of methods viz. drying of grain, controlled atmosphere storage and chemical treatment.

8.1.1 Drying of grain: It is an established fact that dry grain stores long, safe from insects and moulds because the requirements of moisture for their development are not met. The average Indian farmer perform drying of grain conventionally under direct sun light (36). The most widely used indigenous practice of grain drying is to spread threshed grains in thin layers on Kachcha floor with cow-dung in the open sun and stirring it by human labour till the grains are dried to safe level. Some farmers have also been using Pucca floors. Sun drying of grains on Kachcha surface was quicker as compared to Pucca surface, transparent polythene & black polythene. 5.30 percent loss in the moisture content of maize dried in sun-light could be achieved during 8.5 hours time (36). Exposure of aflatoxin contaminated groundnut oil to sun light has given very promising results as it destroyed about 99 percent of the aflatoxins (4). Other methods of grain drying include mechanical drying, in-bin drying, infrared, microwave or sonic and solar energy drying. Researches are being conducted to employ these methods also (37).

81.2 Controlled atmosphere storage: The significance of underground storage lies behind the philosophy of grain cooling and depleting the oxygen content to the desired level whereby the microbes and insects cannot grow. Air-tight

storage also works on the same phenomenon where the depletion of oxygen by grain respiration manipulates disinfection by inhibiting aerobic fungi, elimination of mycotoxin production and conservation of desirable quality factors in the grain. Natural cooling is another effective method of preserving grain. The low temperature does not allow the microflora to grow as most of them are thermophillic.

8.1.3 Chemical treatment: Chemical control of fungal deterioration to stored grain is restricted to the treatment of grain for seed purposes only but not for food and feed. Experiments conducted by Indian Grain Storage Institute showed that "Grain treat" (Mixture of propionic acid, acetic acid and benzoic acid) against Aspergillus & Penicillium sps. did not produce effective results in maize. Seed treatment with Bavistin and TMTD (Trimethyl thiuram disulphide) at 0.25 per cent concentration gave 100 per cent protection to wheat grain in one year storage against Aspergillus and Penicillium sps (37). Certain mild phenolics like perulic acid and O-Vanillin have also been reported to prevent aflatoxin production on rice, wheat, maize, groundnut and mustard seeds (33).

8.2 Separation of infected grains:

Physical separation of infected grains is an efficient and feasible method of minimising mycotoxin contamination. This is effected either by manual operation or with the help of an electronic sorter. Fungal infection of seeds or grain usually imparts characteric colour or other physical properties.

8.3 Detoxification:

Cooking at atmospheric pressure can destroy about 50 percent of the toxins. Dry roasting and oil roasting of groundnut reduces aflatoxins to a significant degree. Cooking rice under 15 Ibs. pressure for 5 minutes gave maximum destruction of aflatoxins (72 percent) as compared to ordinary cooking or cooking with excess water. Light has also been employed successfully to destroy aflatoxin in crude groundnut oil. Studies have shown that visible light is more effective than either ultra-violet or infra-red light (30).

8.4 Growing resistant varieties:

In view of the hazardous effects of mycotoxins, efforts are being made to develop mould resistant varieties which will be mould free not only in fields as standing crops but during storage also they will restrict development of moulds.

List of important mycotoxins, producer fungi and principal toxic effects

Mycotoxins	Producer fungi	Principal toxic effect
Aflatoxins	Aspergillus flavus,	Potent carcinoge-
	A. oryzae,	nic, mutagenic,
	A. parasiticus	teratogenic.
Sterigmatocystin	A. versicolor,	Carcinogenic
	A. nidulans,	
	A. rugulosus	
Ochratoxins	A ochraceus,	Hepatotoxic,
	A. flavus,	nephrotoxic

	Penicillium	
	viridicatum	
Citrinin	P. citrinum,	Nephrotoxic
	P. viridicatum	
Patulin	P. patulum,	Induces subcutane
	P. expansum	ous sarcomas
Citreoviridin	P. citreoviride	Nephrotoxic,
(Yellowed rice		producing
toxin)		convulsions
Penicillic acid	P. pulberulum,	Cell necrosis
	Penicillium sp.	
Rubratoxins	P. rubrum,	Haemorrhage
	P. purpurogenum	
Zearalenone (F-2)	Fusarium	Hyper-estrogenic
	graminearum,	

	F. tricinctum	
Trichothecenes	F. poae, F. roseum	Teratogenic,
(T-2)		emetic, cytotoxic
Ergotoxins	Claviceps purpurea	Abortive;
		gangarence
		development

EEC Tolerance limits for aflatoxin B.' in animal feed

Sl. No. Commodity	Aflatoxin B1 tolerance not more than (g/kg) or ppb.
1. Produce for processing into mixed feed	50
2. Complete feed for cattle, sheep and goats	50

(with the exception of dairy animals, calves and lambs)	
3. Complete feed for pigs and poultry (with the exception of infant pigs, chicks, ducklings and turkeys).	20
4. Animal teed supplements for dairy animals	20
5. Other complete feeds.	10

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Aflatoxin Limits in Different Countries

Country	Commodity	Aflatoxin limit (kg or ppb.)
1. Belgium	Animal feed	40 ***
2. Brazil	Ground oilseed cake (export)	50
3. Canada	Nuts and their derived products	15 **
4. Denmark	Groundnuts & Brazil	5-10

	nuts	
5. France	Animal feed	700
6. India	Groundnut kernel	30
7. Israel	All foods	20
8. Italy	Groundnuts	50***
9. Japan	All foods	10
10.	Groundnuts cake for animal feed mixes	1000
11. Malaysia	All foods	0
12. Malavi	Groundnuts	5
13. Netherlands	Foods & Feeds	5
14. Norway	Oilseed cake	600
15. Poland	All foods and feeds	5
16. Rhodesin	Groundnuts	25
	Animal feed	50-400

17. Sweden	All foods particularly	
	Brazil nuts, groundnuts,	
	groundnut butter	5
	Raw-materials for further	
	processing in Sweden	20
18. U.K.	Confectionery, groundnuts,	50
	Groundnut flour for	
	animal feeds	0 - 500 ***
19. U.S.A.	Confectionery, groundnuts	20*
	All foods & animal feeds	20 - 25

*** Aflatoxin B**

**** Total of aflatoxin B1, B2, C1, C2**

***** See Table-3 - EEC limits may apply.**

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