Observations on large-scale outdoor maize storage in jute and woven polypropylene sacks in Zimbabwe

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Abstract

Sacks made from woven polypropylene are replacing jute sacks for commodity storage in developing countries. In sub-Saharan Africa this has coincided with an increase in stackburn, a condition in which maize becomes discoloured during storage, losing commercial and possibly nutritional value. This has occurred mainly in Zimbabwe but also in Ghana and Malawi. Investigations have shown that stackburn is due to chemical changes in the grain induced by high temperatures during storage; it may in part be due to non-enzymic browning. In Zimbabwe insect metabolic activity may be a possible cause of heating.

The possible link between these high temperatures and the adoption of woven polypropylene (wpp) sacks was investigated by monitoring identical 1100 t stacks of jute and wpp sacks in Zimbabwe. Heating attributed to insects occurred throughout each bagstack, causing temperature rises to 40°C, but the effects were dissimilar in each bagstack. The jute bagstack, especially in the lower half, cooled for a period when fumigated but the wpp bagstack showed much less or no reaction. The wpp bagstack, especially at mid height, heated at a higher rate than the jute stack. These factors caused the temperature to be generally cooler for longer periods in the jute bagstack than in the wpp bagstack.

Introduction

Jute and woven polypropylene sacks

Heavy duty sacks made of woven jute are widely used for the storage and transport of agricultural commodities. They are cheap, tough, flexible, have high tensile strength and have good handling and stacking properties (Coveney 1969). Sacks with a capacity of 60–90 kg are typically used. Other natural fibres, e.g. sisal, may also be used for sacks, but the amounts involved are small in comparison.

Woven polypropylene (wpp) sack manufacture was developed in Japan in the late 1960s and was quickly adopted in Europe, South Africa, Australia and North America (Paine 1991). High density polypropylene film is extruded and slit into narrow tapes which are heated, stretched and woven into sacks, usually of a plain weave. These sacks are lighter than jute but relatively stronger.

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Wpp sacks have replaced jute sacks in a number of African countries for commodity storage. For example, in Zambia in 1988, 10 million natural fibre sacks were made in comparison to 60 million synthetic sacks (FAO 1992). They are produced locally using imported raw materials and are cheaper than imported jute sacks. Little work appears to have been done to investigate the effects of the new sacks on the quality of commodities stored in them.

Stackburn

Large quantities of maize, up to 1.2 Mt, are stored annually in Zimbabwe (Tyler 1992). One of the main storage methods is to build large outdoor stacks from sacks of maize, covering them with tarpaulins and sometimes plastic sheets, a technique called cover-and-plinth or CAP storage. These bagstacks may hold up to 5000 t of maize and may be left for one year or more.

Wpp sacks have largely replaced jute sacks for the storage and handling of maize in Zimbabwe. During recent years, coinciding with the introduction of wpp sacks, maize throughout the centre of some bagstacks has been found to be discoloured from a light tan through to a dark red-brown colour after storage. The discoloration, termed stackburn, results in the affected maize being downgraded with attendant financial losses. Instances of stackburn have been reported in Ghana and Malawi, also in maize stored in wpp stacks (Tyler 1992).

Investigations by NRI have so far identified the discolouration as partly due to non-enzymic browning, or the Maillard reaction. Further work on the nature of the chemical reactions is under way. The extent and rapidity of browning was found to be closely linked to the temperature and moisture content (m.c.) of the maize. Field trials using wpp bagstacks in Zimbabwe showed that heating was occurring in bagstacks during storage, raising the temperature in the interiors to approximately 40°C over a prolonged period. It seemed likely that these prolonged high temperatures were a major factor in the discoloration process.

Causes of heating within stored grain include the following:

a. mould respiration, releasing heat, which occurs when the moisture content of grain is higher than a critical limit and mould growth occurs;
b. insect respiration, again releasing heat, caused by heavy insect infestations in the grain;
c. grain respiration, releasing heat;
d. rises in ambient temperature.

In all cases the grain acts as a thermal insulator, retarding the escape of heat from the grain in cases a, b and c so that a temperature rise results, while inhibiting the transmission of heat into the grain in case d; only long-term (seasonal) changes in ambient temperature affect the interiors of stored grain.

Preliminary investigations in Zimbabwe showed that the moisture content of the maize during bagstack storage was insufficient for mould growth, less than 14.25%, and no moulding was observed. Analysis of samples from the bagstack showed that some insects, mainly *Tribolium* spp. and *Sitophilus* spp., were present at many positions in the bagstack at the beginning of the investigation; after 12 months they were distributed throughout the bagstack, often at high densities. The peak temperatures observed, around 40°C, were considerably above those on the stack surfaces, ruling out heating from ambient temperature rises. Aerobic grain respiration heating was thought to play only a minor role because of the high rate of heating observed in comparison to the low rates of heating attributed to aerobic respiration by Christensen and Sauer (1982) and Gough (1985), though the potential role of anaerobic respiration was not clear. Insect heating may therefore be a likely cause of the high temperatures which in turn led to the discoloration of the maize.

The preliminary trials suggested the mechanism of the discoloration but did not throw any light on the possible link between the change from jute to wpp sacks and stackburn. A further trial, described in this paper, was therefore undertaken to compare the storage conditions within otherwise identical wpp and jute bagstacks.

Method

The trial was undertaken in Zimbabwe, at the Grain Marketing Board (GMB) depot at Concession, approximately 40 km north of Harare. Two bagstacks of approximately 1100 t of white dent maize were built during August 1991 on adjacent earth plinths covered with wooden poles on tarpaulins. One bagstack was built of 21226 new wpp sacks of 50 kg capacity, the other of 12662 re-used jute sacks of 90 kg capacity. The maize for both stacks was the current season's harvest. That for the wpp stack was of mixed commercial and communal origin, transferred from a nearby depot, while that in the jute stack was of commercial origin only, transferred into jute sacks from a bulk silo at Concession. The bagstacks were approximately 16 m long, 14 m wide and 5.75 m high to eaves. Fumigations were carried out by the GMB on day 13 after building started (wpp only), then on days 84,170 and 246, by covering the stacks with airtight sheets and applying methyl bromide gas for two days. The trial was concluded prematurely after 7 months since the maize was required to offset shortages caused by the drought which developed in southern Africa in early 1992.

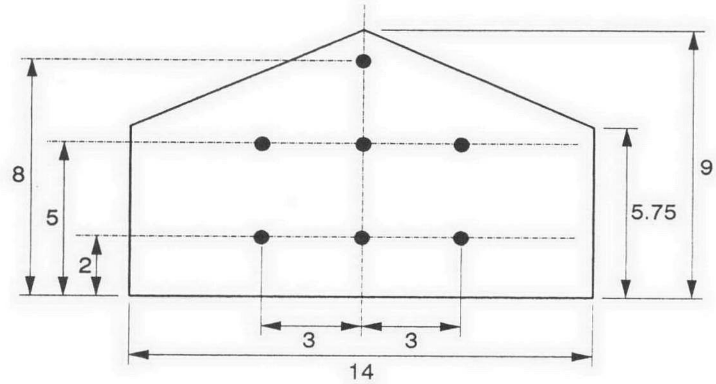

Fig. 2. Cross-section of bagstack showing sensor positions (dimensions in metres).

Each bagstack was instrumented identically during construction. Figures 1 and 2 show the position of thermocouples in the bagstacks. The majority were in seven vertical planes spaced evenly along the length of each stack, labelled A to G in Figure 1. Each plane contained seven thermocouples placed 2 m, 5 m and 8 m from the base of the stack, shown in Figure 2, forming three horizontal planes through the bagstack. Thermocouples were also placed between the tarpaulin and sack surfaces on the outside faces of the bagstacks and underneath the bottom layer. The thermocouples were connected to automatic dataloggers which recorded temperatures every 2 hours.

Changes in moisture content were recorded every 2 weeks using a total of 13 moisture sensors (Gough 1980) positioned next to thermocouples at the bases, on one face and at the centre of each vertical plane in each bagstack.

Nine microphones were also placed in each stack next to thermocouples on vertical planes C, D and E. At the time of this trial, NRI was developing an acoustic detection technique for insect infestations, and had produced a prototype system which was used here. It was subsequently confirmed in the laboratory that exposure to methyl bromide (or phosphine) does not affect the response of the microphones. The microphones were monitored and recorded every 2 weeks.

Maize samples taken from thermocouple positions at the start and finish of the trial were analysed for moisture content by the ISO routine method (ISO 1980) and assessed for insect infestation by the GMB. Note that all moisture content data are expressed on a wet weight basis. Meteorological data were taken from the nearest recording station.

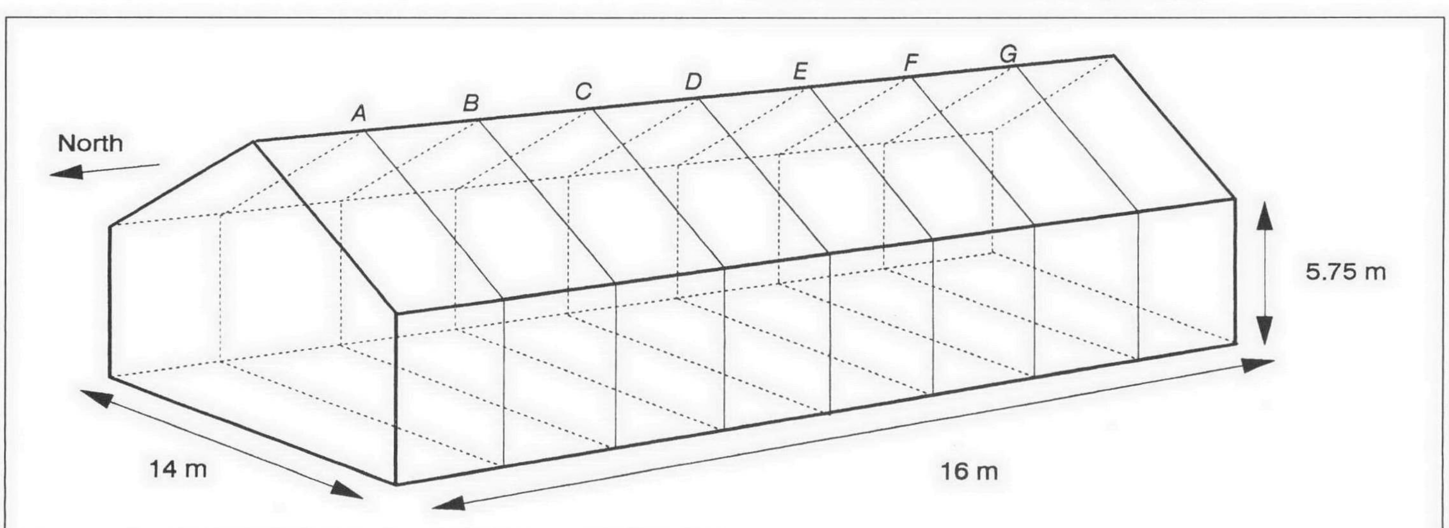

Fig. 1. Bagstack showing sensor planes (not to scale).

Results

Ambient conditions

Daily average maximum and minimum ambient temperatures for the trial period are shown in Figure 3. These were similar to 15-year averages for Harare.

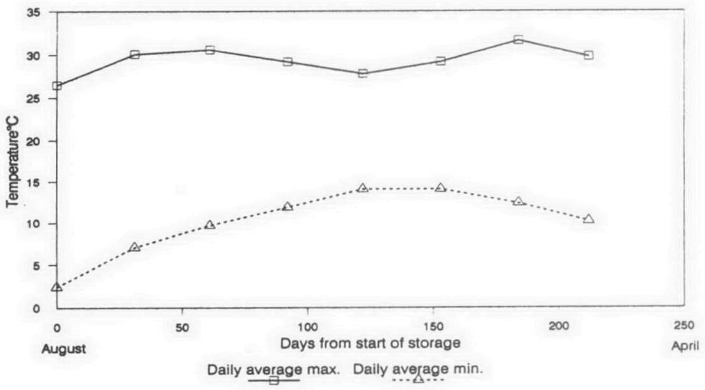

Fig. 3. Daily average ambient temperatures.

The jute bagstack

Temperatures in the bagstack interior were remarkably consistent between vertical planes. Planes B and F are largely typical of the whole stack and are shown in Figures 4 and 5 (reduced to 24 hour averages) with results for equivalent wpp positions. On the faces of the jute bagstack temperatures were higher than the average ambient at the start of the trial and tended to rise, reaching 35°C in some cases. At the base the temperatures rose by approximately 5°C from 20°C.

The lower level temperature sensors (2 m from the bagstack base) showed temperatures rising at approximately 0.3°C/day from the start of the trial until the day 84 fumigation, after which temperatures fell sharply for a period of 30–60 days. Heating then resumed. At some positions temperatures rose to around 40°C by day 130 and stayed approximately constant until the fumigation on day 170, after which they fell. At other positions, where cooling had been greater after the day 84 fumigation, the subsequent heating was slower and temperatures did not reach 40°C before the day 170 fumigation, after which they fell sharply.

The mid-level sensors (5 m from the base) showed much lower but steadily accelerating temperature rises at first and did not cool after the day 84 fumigation. All positions reached 40°C by around day 120, stayed approximately constant until the day 170 fumigation, then fell sharply, though some positions started to cool before the fumigation.

At the top of the bagstack (8 m from the base) temperatures rose from approximately 25°C to 30°C between days 0 and 160, falling slightly after the day 84 fumigation. All positions rose sharply to 40°C after day 160. A few positions cooled after the day 170 fumigation.

The critical moisture content for the maize, above which mould will grow, was determined as 14.75% at 27°C and approximately 14.25% at 37°C in earlier trials. Moisture content determinations for samples from the jute bagstack were in the range 11.4–13.0% at the start of the trial and 10.5–13.6% after. During the trial the moisture content sensors at the mid-level interior positions showed a rise to day 130 then a fall. The highest peak was at 14.2% moisture content, most others were between 13.5–13.7% moisture content. Positions at the base mostly stayed level though one rose to above the critical moisture content level.

The microphones detected insects at many of the monitored positions between the start of the trial and the fumigation at day 84. There were no detections 4 days after the day 84 fumigation but they gradually returned until the day 170 fumigation, after which they again stopped except at one position. Inspection of samples taken from the bagstack at the end of the trial revealed *Sitophilus* spp. at most positions and *Tribolium* spp. at all positions.

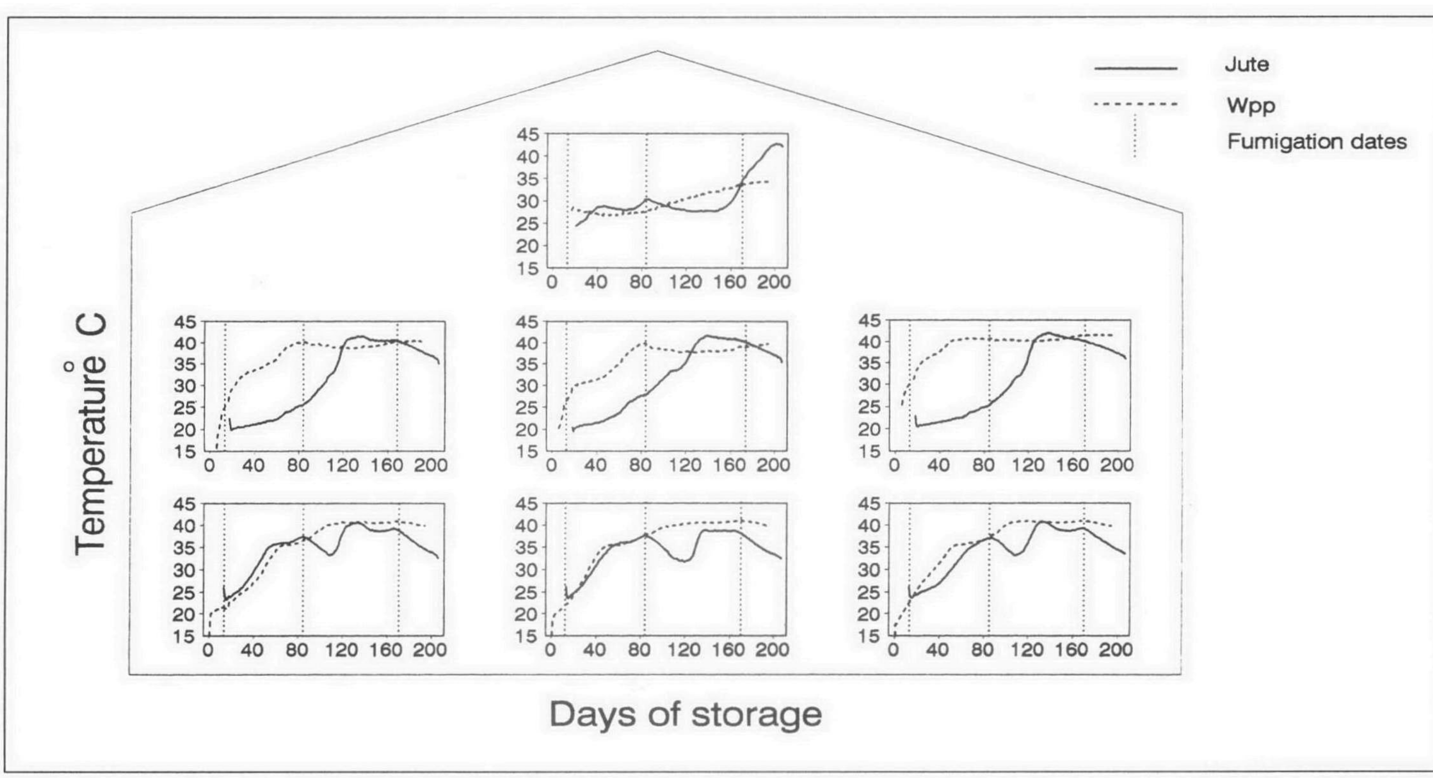

Fig. 4. Plane B temperatures, jute and wpp bagstacks.

The wpp bagstack

Temperatures on the base and faces of the wpp stack were again slightly above ambient and rose during the trial in a very similar manner to those in the jute stack. In the interior of the stack the temperature records were again very consistent for each vertical plane. Results for planes B and F are shown in Figures 4 and 5 with those for the jute bagstack.

About half of the lower level temperature sensors (2 m from the bagstack base) showed rapid initial temperatures rises which were very similar to those at equivalent positions in the jute bagstack. These positions reached a steady limit of approximately 40°C at around day 100. At the other positions, towards the south and east of the stack, the heating rate was lower; temperatures were still rising at the end of the trial, reaching only 30°C in some cases. All positions showed steady but slow cooling or a reduction in heating rate after the day 170 fumigation, and this continued until the end of the trial. Only a few positions showed any cooling after the day 13 and 84 fumigations.

The mid-level sensors (5 m from the base) showed temperatures rising very rapidly to 40°C by day 100 then staying steady until the end of the trial. In many positions there was limited cooling after the day 84 fumigation but not after the day 170 fumigation. A few positions towards the east and around the mid-length of this level heated at a very much lower rate, not reaching 40°C by the end of the trial.

At the top of the bagstack, temperatures behaved in a similar way to those in the jute stack, rising from approximately 25°C to 30°C, though they showed no cooling after fumigation. The most significant difference was the complete absence of any temperature rise at the end of the trial.

Moisture content determinations were in the range 11.1–14.2% before the trial and 10.5–13.3% after. Sensors at the mid-level showed no rises during the trial in contrast to the slight rises in the jute bagstack. Base positions did show rises but only above the critical moisture for mould growth at one position.

Microphone results were very similar to those from the jute stack, showing insects present at all monitoring positions at various times throughout the trial, with detections generally stopping after fumigations, though there was one instance of a detection immediately after one fumigation. Inspection of samples taken from the bagstack at the end of the trial revealed a similar situation to the jute stack, i.e. widespread infestations of *Sitophilus* spp. and *Tribolium* spp.

Discussion

The similarities between the two stacks may be considered first. Heating to above ambient temperatures occurred over long periods throughout the interior of both stacks, especially at the lower and mid levels. At many positions the temperature reached 40°C then remained approximately steady. Temperature records were remarkably similar over similar levels in each stack, with the exception of the lower wpp level which showed two distinct heating rates. The higher of these rates, seen at half of the lower level positions, was very similar to heating rates at equivalent jute bagstack positions. Positions at the edges of the bagstacks heated but were cooler than the interiors. Moisture contents were below critical levels for mould growth for each stack throughout the trial with only minor exceptions.

As noted earlier, the main causes of heating inside a stack of grain are mould respiration, insect respiration, grain respiration and seasonal ambient temperature changes. As moisture contents were below critical limits in each stack, mould heating could not be regarded as playing a significant part in any heating that occurred. Aerobic grain respiration heating may also be ruled out for the same reasons given in the introduction. Temperatures inside each stack were without exception higher that those on the surfaces of the stacks and outside the bagstacks, ruling out seasonal ambient effects. This leaves heat from insect respiration as the likely cause of the temperature rises. The microphone results show that there

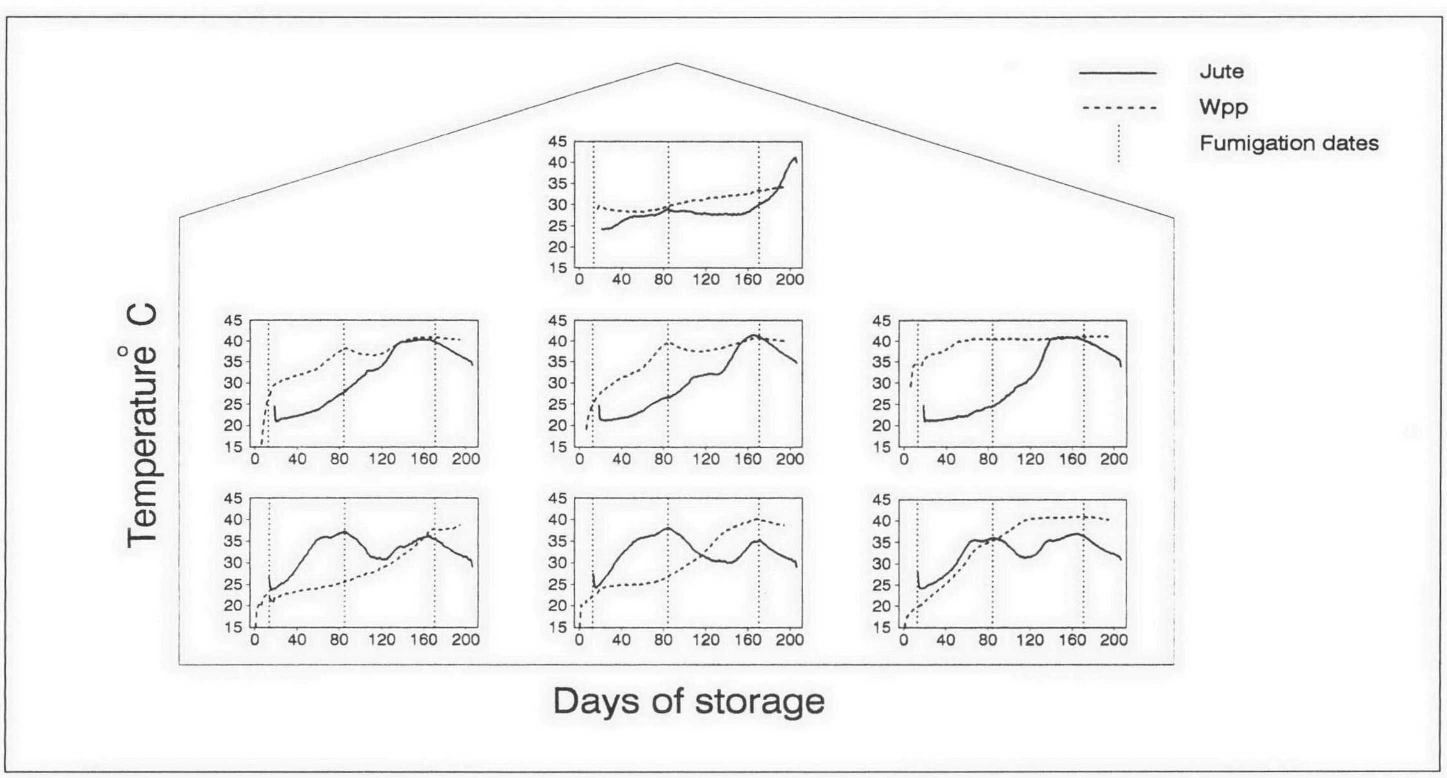

Fig. 5. Plane F temperatures, jute and wpp bagstacks.

were insects present throughout the trials in each stack, and sample analyses show widespread insect infestations at the end of the trials. Other evidence supporting this conclusion is the temperature limit of 40°C seen in each stack and the cooling which occurred after fumigation to varying degrees in each stack. The lethal temperatures for *Sitophilus* spp. and *Tribolium* spp., insects which were found in greatest number in the sample analyses, are reported by various researchers (Howe 1962a, Reddy 1950, Gonen 1977) as 35–40°C.

Howe (1962b) proposed a process by which insect heating in grain may progress. An insect infestation in the grain respires and produces heat, causing a rise in temperature which in turn increases the reproductive and metabolic rate of the insects. The infestation thus grows at an accelerating rate, releasing heat at an increasing rate and resulting in greater temperature rises. This autocatalytic process continues, with ever-increasing temperature rises, until the temperature becomes unfavourable for the insects and they either migrate or die. This hypothesis was substantiated with field and laboratory observations of insect heating, which showed rapid increases in insect populations accompanied by rapid temperature rises to a limit of approximately 40°C.

The heating observed in the present trials follows many of the patterns described by Howe (1962b), supporting the conclusion that insect respiration is a likely cause of heating in both bagstacks. The principal difference in behaviour was the relative uniformity of heating seen throughout the bagstack layers; Howe (1962b) observed nuclei of heating known as hotspots.

This leads to a consideration of the differences between the two bagstacks. The jute bagstack cooled after both of its fumigations, mainly in the lower levels, while the wpp stack remained almost unaltered, or cooled at a much lower rate. In about half of the lower wpp positions, temperatures rose at a lower rate than equivalent jute positions. Conversely, temperatures at mid-level positions in the jute stack rose, at least initially, at a very much lower rate than equivalent wpp positions. At the top level of the jute stack there was a sharp rise in temperature at the end of the trial that did not occur in the wpp stack.

Possible reasons for the differences in behaviour after fumigations between the two bagstacks, assuming that insect heating occurred, include the following:

- fumigations were more effective at controlling infestations in the jute stack than in the wpp stack;
- fumigations were effective in both stacks but the jute stack was able to cool while the wpp was not, i.e. the ability to cool could be dependent on the sack material or bagstack geometry.

The first reason is to be favoured since both stacks showed the ability to cool on different occasions, though higher rates were seen in the jute stack. Note, however, that the jute stack cooled significantly only at the lower level, for a relatively short time, and at the middle level there was cooling after the last fumigation but not after earlier ones. The conclusions that may be drawn are that fumigations were of variable effectiveness, were at best only partially successful but were more effective in the jute stack than in the wpp stack. This may indicate differences in the way in which the fumigant gas penetrates the sacks. Nevertheless, temperature differences caused by the thermal effects of the different sack materials or the methods of construction of the two stacks cannot be ruled out totally.

The lower rate of cooling in about half of the lower wpp positions occurred only towards one end of the stack. Differences in the amount of solar radiation falling on the different faces of the bagstack could not have caused this difference as both the wpp and jute bagstacks received equal amounts of solar radiation but the effect was apparent only in the wpp bagstack. Differences in thermal behaviour of the jute and wpp sack materials or in the methods of stack construction are unlikely to be significant in this case as only half of the lower wpp positions heated at the lower rate, the other half matched the heating rate in the jute stack. Differences in the degree of insect infestation in the wpp sacks might have contributed to the temperature differences. The maize in the wpp stack was of mixed commercial and communal sources and was likely therefore to have had widely varying initial insect concentrations. Although fumigated at the start of the trial, the evidence from this work suggests that this may not have been as effective as supposed. The reversed situation at the mid-level, with the jute stack heating more slowly than the wpp stack, again supports differences in insect infestations.

The sudden rise in temperature at the top of the jute stack is difficult to explain. There was no equivalent rise at the top level of the wpp bagstack. Before the rise, the temperatures and temperature patterns at the top of the wpp and jute bagstacks were very similar; they were cooler than the lower positions, which would be expected by their closeness to the stack exteriors. The sudden rise in temperature in the jute bagstack may have been caused by a sudden increase in insect numbers, though the occurrence of the rise all along the stack length would not be expected, and the positions were close to where the fumigant gas was applied to the bagstack. The rise was too sharp to have been caused by heat rising from lower levels.

Conclusions

The following conclusions are drawn:

- heating occurred in each stack and may be attributable to insect respiration
- fumigations varied in effect and were at best only partially effective in stopping heating
- fumigations were consistently more effective in the jute stack than in the wpp stack, causing some positions to be cooler for longer periods in the jute stack than in the wpp stack
- differences in heating rate between the two stacks could not be positively attributed to differences in sack materials or the method of stack construction, although it is not possible to discount these factors.

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