HGCA

PROJECT REPORT No. 201

LIMITING MOISTURE UPTAKE AT THE GRAIN SURFACE TO PREVENT MITE INFESTATION

SEPTEMBER 1999

Price £3.00

PROJECT REPORT No. 201

LIMITING MOISTURE UPTAKE AT THE GRAIN SURFACE TO PREVENT MITE INFESTATION

by

D M ARMITAGE AND D A COOK

Central Science Laboratory, Ministry of Agriculture, Fisheries and Food,
Sand Hutton, York YO41 1LZ

This is the final report of a one year project which started in July 1998. The work was funded by a grant of £9,965 from HGCA (Project No. 1895).

SUMMARY

Published details of seasonal changes in moisture content at the surface of grain bulks give an idea of maximum moisture contents (m.c.) of 17% likely to be achieved during the winter. In boxes with closed bases, which were effectively unaerated, barley rose from 12.2% m.c. to 16.3% m.c. in October while in the boxes with a closed base, the increase was greater, illustrating the difference between purely surface absorption and the increase that can occur as a result of temperature gradients. In a 24 h period in August the ambient relative humidity (r.h.) rose from about 40% between midday and 1700, to over 90% at about 0600 in the morning. In contrast, the surface m.c. rose slowly from about 10.5% to nearly 13%, reaching a peak at about 1000, lagging about 4h behind the ambient r.h., giving some indication of diurnal changes in m.c. The moisture content of rapeseed at the surface of a sealed airtight bin of rapeseed varied between about 7.5 and 9%, in winter and summer, compared with 5% and 12% in the unaerated bin. As a result, mite numbers were severely limited.

Observations made between autumn and spring, 1998-9 at the storage facility at CSL, York, showed differences between the m.c.s achieved at the surface of flat and bins stores within the same building. In the bin stores, surface m.c.s were between 16.2% and 17.7%, in November and February, but in the flat store, the surface range was only 14.7-16.2%.

Bins containing 25 kg of wheat were held at constant conditions of 15°C and 80% r.h. (17.6% m.c.) and sealed with shrouds of nylon woven tarpaulin, plastic sheeting (nylon polythene laminate) or butyl rubber or left uncovered as a control. The controls steadily absorbed moisture and had median surface m.c.s of 16.3% after 18 weeks. The shrouded replicates also steadily absorbed moisture but here uptake was reduced, with differences from the controls of 0.5 - 1% depending upon the material. The best reduction in mite population was in the region of x10 for *Acarus*. The best of the materials was the plastic sheeting by virtue of the lowest m.c. and mite infestation after 18 weeks.

INTRODUCTION

Mite infestations are a major UK problem due to the maritime climate with its mild winters and high ambient relative humidities (r.h.). Living mites, their bodies and excreta cause allergies and they damage the grain directly by hollowing out the germ (Hughes, 1976). Infestations in grain for export inhibit trade and their treatment is difficult since two fumigations are required to allow all eggs which are not very susceptible, to hatch (Bowley and Bell, 1981). Similarly, mites are not very susceptible to organophosphates (OP) and, in any case many are resistant and may survive twice the recommended application rate (Starzewski, 1991).

Many mites cannot develop below 5°C (Cunnington, 1976) but will increase in numbers before cooling is complete and in the spring when the grain warms up, unless the equilibrium r.h. of the seed is reduced below 65%. [14.5% moisture content (m.c.) @ 25°C]. However, even when the grain is properly dried, grain at the surface rises in m.c. and allows mite infestations during mid-winter (Armitage, 1984). These can be prevented using prophylactic admixture to the grain surface of cooled bins (Armitage et al., 1994) but curing the problem once it has arisen is more problematical (Wilkin and Stables, 1986).

Since the phenomenon of surface mite infestation seems related to moisture uptake it seems logical to address the problem in a non-chemical way by preventing this uptake. This could be effected by placing a relatively close-fitting canopy to the grain surface to reduce contact between ambient air and the grain. The r.h. under the canopy would be controlled by the relatively low equilibrium r.h. of the grain and not the high r.h. of ambient air. There is already some evidence that this approach will work as dry rapeseed stored in a butyl bin did not show the same m.c. uptake as open-topped bins (Armitage, 1980). The material selected will ideally need to allow air movement, so that cooling can continue but provide a barrier to moisture; a Gore-Tex fabric, for example. An alternative approach would be to put the barrier in place after cooling was complete and a future development might be to impregnate it with insecticide, as a barrier to infestation ingress and as a replacement to the OP top-dressing required in the MAFF / HGCA integrated storage strategy.

1. SEASONAL CHANGES IN MOISTURE CONTENT AT THE SURFACE OF GRAIN BULKS

Hurlock et al. (1980) described m.c.s at the surface of three unaerated and three aerated 20 t bins over three winters and three summers. The wheat, delivered at 14-15% m.c., fluctuated between a minimum of 12% in summer and a maximum of about 17% in winter for two to three months while the m.c. at 1 m and 2 m remained little changed.

Armitage et al. (1994) more recently showed a similar trend in six aerated bins of wheat initially at 15% m.c. In this case, the maximum mean winter surface moisture again achieved nearly 17% for three months, while the summer minimum was about 13%. During the same period, grain at 1m and 2m fell in m.c. by about 0.5% and 0.2% respectively as a result of the aeration.

These observations give an idea of the maximum m.c.s likely to be achieved during the winter and of minimum m.c.s likely to occur in the summer as well as the duration of elevated m.c. at the grain surface.

2. OBSERVATIONS IN FARM AND COMMERCIAL - SCALE FACILITIES IN 1998-99

During experiments carried out between autumn and spring, 1998-9 at the storage facility at CSL, York, observations were made of m.c. changes in six, 3 m deep, 20 t bins and in a 250 t floor store which was divided into four quadrants. In each of the 20 t bins, five samples were taken by 200 g gravity spear, from the surface and depths of 1 m and 2 m in each bin at approximately monthly intervals. In each quadrant of the 250 t floor store, 12 samples were taken from the surface and 12 from a depth of 1m by gravity spear, also at about 1 month intervals. Moisture content was determined by the ISO method, by drying in a ventilated oven at 130°C for 2h.

These observations show a curious difference between the m.c.s achieved at the surface of flat and bins stores within the same building. In the bin stores (Table 1), surface m.c.s were between 16.2% and 17.7%, corresponding to bulk m.c.s of 13.8-15.5% between November and February, but in the flat store (Table 2), the surface range was only 14.7-16.2%, with bulk m.c.s between 13.5 and 14.4%.

These measurements raise questions about the extent that the surface m.c. is controlled by the bulk m.c. and the airflow or possibly that there may be a difference between moisture uptake in flat and bin stores.

3. MOISTURE CHANGES AT THE SURFACE OF WARM BINS OF MALTING BARLEY DURING OCTOBER

In an unpublished experiment Burrell (PICL, Slough) compared the m.c. of barley in an unspecified number of boxes of undescribed dimensions with open or closed bases, at the surface of a bulk of warm barley at 25-32°C. In the boxes with closed bases, which were effectively unaerated, the barley rose from 12.2% to 16.3% in October as a result of absorption of water from the atmosphere (Fig. 1) . However, in the boxes with a closed base, the increase was greater, to 16.9% and there were additional increases of about 1.7% at 1 cm intervals to about 6 cm depth.

This observation illustrated the difference between purely surface absorption and the increase that can occur as a result of temperature gradients.

4. THE DIURNAL RELATIONSHIP BETWEEN ATMOSPHERIC RELATIVE HUMIDITY AND SURFACE MOISTURE UPTAKE

Burrell (1979) measured ambient r.h. and surface m.c. during downward aeration in a 24 h period in August. The ambient r.h., as measured in the roof space of the bin, a Stephenson's screen in a nearby field and the concrete plinth of the bin, rose from about 40% between midday and 1700, to over 90% at about 0600 in the morning (Fig. 2). In contrast, the surface moisture rose slowly from about 10.5% to nearly 13%, reaching a peak at about 10.00, lagging about 4h behind the ambient r.h.

<u>5. THE EFFECT OF STORAGE OF RAPESEED IN SEALED BINS UPON SURFACE UPTAKE OF ATMOSPHERIC MOISTURE</u>

Incidentally, Armitage (1980) showed the effect of using a barrier to moisture uptake upon moisture uptake and, to some extent, mite populations, when he made a comparison of aerated, unaerated and airtight storage of rapeseed initially at 8% m.c. Airtight storage was achieved by holding the seed in a butyl bag and so contact between the atmosphere and the stored seed was minimised.

As a result, the m.c. at the surface of the airtight bin varied between about 7.5% and 9%, in winter and summer, compared with 5% and 12% in the unaerated bin. As a result, mite numbers at the surface of the airtight bin were always about the same as those beneath, while in the unaerated bin, mites were commonest at the surface in the winter, when it was dampest and less so in the summer, when it was driest.

It was this observation that led substance to the theory that limiting moisture uptake at the surface might also limit mite numbers there.

<u>6. A COMPARISON OF THE WATER VAPOUR PERMEABILITY OF SOME MATERIALS</u>

Moisture vapour transmission rates (MVTR) are available for many packaging materials and are commonly given as g/ sq. m / 24 h at 38°C and 90% r.h. in publications such as Modern Packaging Encyclopaedia and Directory and Packaging Users Handbook although U.S. publications (e.g. Brown, 1992) give the data as gm mil / 100 sq. in.

Some materials that have been used as fumigation sheet include LDPE (low density polyethylene), plasticised PVC (polyvinyl chloride), and EVOH (ethylene vinyl alcohol) but ultimately, the decision was made to use commonly two available agricultural materials :- nylon woven tarpaulin and butyl rubber as well as plastic sheeting (nylon polythene laminate). The latter is a comonly used and CSL-recommended fumigation sheet. The moisture transmission rates of some of these materials is set out below.

Material	LDPE	PVC	EVOH	Nylon
MVTR (g/m2/24h)	18	200	20-80	35-200

7. LABORATORY TESTING OF 3 CANDIDATE SHROUD MATERIALS IN 25 KG BULKS.

OBJECTIVES

The experiment described here was designed to demonstrate that moisture uptake at the surface of a grain bulk could be limited by covering the surface with an impermeable barrier, to show the degree of inhibition of mite population which was likely to occur and investigate which of a number of materials would be most successful in achieving this.

MATERIALS AND METHODS

Mites:

The mites used were insecticide susceptible laboratory strains of *Acarus siro L.* (9266/1) and *Lepidoglyphus* (= *Glycyphagus*) *destructor* Schrank (G6). All of the mites had been bred at the CSL without exposure to pesticides.

Grain:

Three hundred kilograms of animal feed wheat was obtained of mixed variety, 15% m.c. and pesticide free, harvested in 1998 from North Yorkshire, U.K.

Test materials:

Three candidate shroud materials were tested. These were woven nylon tarpaulin sheet, plastic fumigation sheet ("Bromotek") and rubber pond liner (Table 3). For each material, three circular shrouds of 0.45 m diameter were prepared.

Wheat preparation and mite infestation:

The grain was divided into twelve 25 kg batches and was held at 5°C prior to testing. The batches were tumbled in a concrete mixer for around 10 minutes to allow thorough mixing. The m.c. of each batch was confirmed using the oven method (BS4317), by grinding 5 g of wheat, drying in a ventilated oven at 130°C for 2 h and calculating percentage water loss by comparing wet and dry weight. Each batch was transferred into separate metal dustbins measuring 0.55 x 0.46 m, giving a grain depth of 0.25 m. The bins were then coated around the inside at the top with white petroleum jelly to limit mites escaping. The filled bins were put into a controlled environment (CE) room at 15°C and 80% r.h. in a 3x4 grid arrangement of columns and rows.

Sufficient numbers of mixed stage mobile mites of both species were added to each bin to give an infestation corresponding to approximately 100 mites per kg. These were taken directly from culture. Prior to seeding, the culture was assessed by taking a spatula tip full (0.01 g) and counting mite numbers under a binocular microscope. Where numbers were high, mites found in random areas of a divided disk were counted (Solomon 1962). This assessment was replicated three times per species and the means were used to determine how many spatula tips of culture were needed to seed each bin. This data was used to give an assessment of initial mite numbers (Table 4).

Each of the three candidate shroud materials was tested in triplicate, with three bins left uncovered to act as controls. Immediately after infestation, the candidate shrouds were applied to cover the grain surfaces and secured to the bin sides using white PVC electrician's tape. Bin designations for the test materials were determined by ensuring that no treatment was repeated within a column or row.

<u>Sampling and pest assessment, mites:</u>

After 2 weeks and then at monthly intervals for 6 months, the bins were sampled to monitor mite numbers and to measure the m.c. Five equidistant samples were taken at the surface and from the bottom of each bin using a compartmental spear of 20 g capacity. For each bin, samples from each level were combined giving two 100 g samples. Each combined sample was sieved over a 0.71 mm mesh and the dust fractions were examined under a low-powered binocular microscope and live mites counted. Where numbers were high, mites were counted using Solomon's disc (1962). After counting, the samples of grain were retained for moisture determination using the oven method (BS4317).

RESULTS

<u>Limitation of moisture increase:</u>

The grain was adjusted to an intended starting m.c. of 15%. However, there was a slight variation in mean starting m.c. for the 4 materials, particularly for the rubber liner shrouded bins (Table 4, week 0) which was higher than the others by 0.2/0.3%. Moisture increases are therefore expressed as the mean cumulative increase from week 0 (Figure 3). All of the bins absorbed moisture throughout the experiment, although there was slight desorption by all at the last assessment.

At the surface, the m.c. in the controls rose by a mean of 0.7 % after 2 weeks and by 1.2% after 14 weeks (Fig. 3). In contrast, the m.c. increase under the least effective of the shroud materials was below 0.3% after 2 weeks and only about 0.5% after 14 weeks. At 0.25 m, the m.c. changes were less. The greatest increase was achieved by the 18th week when the controls had increased by 0.7% and the grain under the shrouds by no more than 0.5%.

Of the candidate materials, the plastic sheet and the butyl liner were the best in limiting moisture increase. Comparison of the pooled data (time) for surface moisture increase of each material using ANOVA showed that the controls were significantly different from the tarpaulin sheet ($p = 0.000$); the plastic sheet and the rubber liner were the same ($p = 0.212$); the rubber liner and the tarpaulin sheet were significantly different ($p = 0.024$). This bears out the trend shown in Fig. 3. This data pattern can also be seen at the 0.25 m depth although the rate of absorption was much lower.

Inhibition of mite populations:

Mite numbers of both species dropped at week 2, and then increased thereafter. Mean mite numbers peaked at week 14 with shrouded populations reduced compared to the controls (Table 4 and 5). The trend at this assessment for *A. siro* suggests that the plastic sheet gave greatest population inhibition with little difference between the tarpaulin and rubber liner. There was a positive correlation between mite numbers and actual % m.c. of each bin (Table 6). This was strongest for surface numbers of *A. siro* where from week 6 onwards the correlation coefficient was significant at 1%. The correlation for *L. destructor*, although positive, was much weaker.

DISCUSSION

Moisture changes and mite populations in these experiments were greater at the surface than at 0.25 m and some of the changes at depth may have been due to repeated sampling disrupting the layers (Howe, 1965).

All of the materials limited moisture uptake at the surface when compared to the controls, with the plastic sheet and rubber liner being more effective than the tarpaulin. For example, at week 14, the Tarpaulin sheet had limited mean mc uptake by 0.7% m.c. (x2) with the plastic sheet and rubber liner by 1% (x5) & 0.9% (x3) respectively. A 1% change in m.c. is an approximate change of 5% r.h. for these conditions (Pixton,1982).

Mite numbers were limited accordingly. However, as stated above, the mean starting m.c. of the rubber liner treatments was slightly higher than the others. This is likely to have had an effect on mite numbers which would have distorted the population trends. At weeks 14 and 18, the mean numbers suggest that the plastic sheeting had the greatest effect. This conflicts with the moisture uptake data that suggests that the plastic sheeting and rubber liner were as effective as each other. Since moisture content and mite numbers are positively correlated, it can be inferred that if the rubber liner replicates had been of the same starting m.c. as the others, then the mite numbers would have followed the same trend as the moisture uptake.

It is also of note that the *A. siro* populations peaked at a much higher number than *L.destructor*. Under these conditions of temperature and humidity, *A. siro* breed faster than *L.destructor* (Cunnington, CSL, unpublished) and it is possible that the latter were suppressed by being outcompeted. This has also been noted in other experiments (Cook and Armitage, unpublished). This may also have accounted for the lower significance for the mite number / m.c. correlations for *L. destructor*.

This experiment has shown that materials can be successfully used to limit moisture uptake at the surface by as much as 1% m.c. and that this can in turn reduce mite populations by up to 90%. In a practical field situation, the reduction in m.c. uptake may also have been the difference between conditions permitting mite increase and those preventing mite survival. In this case, shrouding may act as a means of preventing mites from starting to infest grain. Moisture increases would be expected to occur at the edge of a grain surface if a cover was employed. In these experiments, using small bins, the edge effect would have been much greater than in a large, covered grain store and therefore moisture uptake in these experiments would have been greater than in practise.

Further experiments therefore need to test this strategy under larger scale, field conditions. It would also be of advantage to test a breathable material such as the Gore-Tex fabric which was unavailable for testing here. This is important because of the implications of shrouding where low volume aeration is used for cooling and subsequent inclusion of shrouding as part of an integrated grain storage strategy. It is also important to examine the relationship between bulk m.c. and maximum surface m.c. during the winter.

8. REFERENCES

Armitage, D.M. 1980 The effect of aeration on the development of mite populations in rapeseed. J.stored Prod. Res. 16, 93-102.

Armitage, D.M. 1984. The vertical distribution of mites in bulks of stored produce. Acarology, VI, 1006-1012.

Armitage, D.M., Wilkin, D.R. and Cogan, P.A. 1994. Integrated pest management in stored grain: combiing surface insecticide treatments with aeration. J. stored Prod. Res. 30, 303-319.

Bowley, C.R. and Bell, C.H. 1981. The toxicity of twelve fumigants to three species of mites infesting grain. J. stored Prod. Res.17, 83-87.

Brown, W.E. 1992. Plastics in Food Packaging. Marcel Dekker.

Burrell, N.J. 1979. Grain drying using solar energy. Conference (MI) on practical applications for solar energy in industry and commerce. L.F. Jesch (Ed.) Univ of Birmingham, Sep. 1979. International Solar Energy Society, UK Section, Midlands Branch. 39-7.

Cunnington, A.M. 1976. The effect of physical conditions on the development and increase of some important storage mites. Ann. appl. Biol. 82, 175-178.

Howe, R.W. 1965. Investigation of he efficiency of spear sampling of bulk grain. Proc. XIII Int. Cong. Ent., London, 1964, 629.

Hurlock, E.T., Armitage, D.M. and Llewellin, B.E. 1980. Seasonal changes in mite (Acari) and fungal populations in aerated and unaerated wheat stored for three years. Bull. ent. Res. 70, 537-548.

Hughes, A.M. 1976. MAFF Tec. Bull 9., 400pp. HMSO, London.

Pixton, S.W. 1982. The importance of moisture and equilibrium relative humidity in stored products. Trop. Stored Product. Inf. 43,16-29.

Solomon, M.E. (1962). Notes on the extraction and quantitative estimation of the Acaridae (Acarina). Progress in soil zoology. Proceedings of a colloquium on research methods in soil zoology. Rothamstead, 1, 305-307.

Starzewski, J.C. 1991. The incidence of resistance to pirimiphos-methyl in stored-product mites collected from commercial grain stores in the United Kingdom. pp 53-56 in; Prickett A.J. and Muggleton, J.M. (eds) Comercial grain stores 1988/9 England and Wales. Pest incidence and storage practice HGCA Proj. Rep. 29, 99pp +119pp, HGCA, London.

Wilkin, D.R. and Stables, L.M. 1986. The effects of dusts containing etrimfos, methacrifos or pirimiphos-methyl on mites in the surface layers of stored barley. Exp. & Appl. Acarol. 1, 203-211.

Table 1: Change in moisture content at the surface and a depth of 1m in six, 20 t farm bins during 1998-9 (n=5)

	Date	Bin	30-Nov	06-Jan	08-Feb	08-Mar	12-Apr
Surface		7	17.2	17.4	16.9	16.7	15.7
		8	17	17.4	17.2	16.7	15.7
		9	16.2	17.1	16.3	16.4	15.3
	Mean		16.8	17.3	16.8	16.6	15.6
		10	17.6	17.7	17.1	17.2	15.7
		11	16	16.6	16.2	16.5	15.1
		12	16.6	17.2	16.7	16.9	15.9
	Mean		16.7	17.2	16.7	16.9	15.6
1m		7	15.2	15.5	15.2	14.9	14.8
		8	15.5	15.2	15.5	15	154
		9	13.8	13.8	13.9	13.7	13.6
	Mean		14.8	14.8	14.9	14.5	146
		10	15.5	15.5	15.6	15.5	15.3
		11	14.1	14	13.9	14	13.7
		12	15.2	15.4	15.2	15.3	15.2
	Mean		14.9	15	14.9	14.9	14.7

Table 2: Change in moisture content at the surface and a depth of 1m in four quadrants of a 300 t grain bulk during 1998-9 (n=9)

Date	Quadrant	7.12	11.1	15.2	22.3	19.4
Surface	A	14.7	15.4	15.6	15.3	15.4
	B	15.6	15.6	16.1	15.6	15.6
	Mean	15.2	15.3	15.9	15.5	15.5
	C	16.2	15.6	15.6	15.7	15.7
	D	15.2	14.7	16.1	15.2	15.3
	Mean	15.7	15.2	15.9	15.5	15.5
1m	A	13.5	13.9	13.9	13.7	13.7
	B	14.2	14.4	14.3	14.1	14.2
	Mean	13.9	14.2	14.1	13.9	14
	C	13.9	13.9	13.8	13.5	13.9
	D	13.5	13.9	14	13.3	13.8
	Mean	13.7	13.9	13.9	13.4	13.9

Table 3: Details of the three materials tested in laboratory experiments.

Material =	Tarpaulin	Plastic sheet ("Bromotek")	Rubber liner
Composition =	Polypropylene	Nylon sandwiched between 2 layers of polythene	Butyl rubber
Availability =	Agricultural suppliers	Lawson Mardon Group, distributed by Igrox for soil fumigation	Garden centres
Cost =	approx. 50 pence m^2	£224 per roll (100m x 4m)	approx. £5 m^2

Table 4 : Mean moisture contents (calculated equilibrium relative humidity) and mite numbers at the surface of 25 kg bins of wheat, either uncovered or covered with one of three shrouding materials, absorbing at 15°C and 80% rh (n=3).

Week	Treatment	mc% (range)	Calculated erh% (range)	Mite nos. per kg *A. siro* (range)	Mite nos. per kg *L. destructor* (range)
0	Control	15.1 (14.9-15.2)	69 (68-69)	111 (83-156)	134 (106-167)
	Tarpaulin	15 (15)	68 (68)	111 (83-156)	134 (106-167)
	Plastic sheet	15.1 (15.15.1)	69 (68-69)	111 (83-156)	134 (106-167)
	Rubber liner	15.3 (15.1-15.5)	70 (69-71)	111 (83-156)	134 (106-167)
2	Control	15.8 (15.7-15.9)	72 (72-73)	17 (9-22)	13 (11-18)
	Tarpaulin	15.3 (15.2-15.3)	70 (69-70)	46 (32-54)	14 (0-33)
	Plastic sheet	15.2 (15.1-15.2)	69 (69)	25 (20-32)	7 (0-11)
	Rubber liner	15.4 (15.2-15.6)	70 (69-71)	4 (0-11)	0 (0)
6	Control	15.9 (15.7-16)	73 (72-73)	1448 (1030-2217)	85 (84-86)
	Tarpaulin	15.2 (15-15.5)	69 (68-71)	204 (106-341)	41 (11-62)
	Plastic sheet	15.1 (15-15.1)	69 (68-69)	112 (40-207)	30 (20-49)
	Rubber liner	15.4 (15.1-15.5)	70 (69-71)	130 (52-208)	14 (10-21)
11	Control	16 (15.7-16.2)	73 (72-74)	7277 (1378-12378)	278 (86-498)
	Tarpaulin	15.4 (15.3-15.7)	70 (70-72)	1489 (1202-1659)	115 (0-175)
	Plastic sheet	15.2 (15.2)	69 (69)	469 (296-604)	61 (0-99)
	Rubber liner	15.5 (15.2-15.9)	71 (69-73)	1939 (502-4359)	228 (85-348)
14	Control	16.3 (16.2-16.4)	75 (74-75)	8009 (2950-13687)	509 (268-963)
	Tarpaulin	15.6 (15.4-15.7)	71 (70-72)	3382 (2249-5605)	414 (92-760)
	Plastic sheet	15.3 (15.2-15.5)	70 (69-71)	1290 (541-2263)	258 (90-394)
	Rubber liner	15.7 (15.4-16)	72 (70-73)	3101 (1081-4236)	178 (99-315)
18	Control	16.2 (16-16.3)	74 (73-75)	5929 (3318-7512)	294 (190-497)
	Tarpaulin	15.5 (15.5-15.6)	71 (71)	1351 (546-1949)	159 (0-292)
	Plastic sheet	15.4 (15.3-15.4)	70 70)	1011 (605-1689)	29 (0-86)
	Rubber liner	15.7 (15.4-16)	72 (70-73)	1320 (696-2129)	103 (0-206)
24	Control	16 (15.8-16.1)	73 (72-74)	7433 (3658-10510)	0 (0)
	Tarpaulin	15.5 (15.3-15.8)	71 (70-72)	3239 (860-5354)	269 (0-808)
	Plastic sheet	15.1 (15-15.2)	69 (68-69)	560 (144-1129)	44 (0-94)
	Rubber liner	15.4 (15-15.7)	70 (68-72)	2140 (1652-2716)	124 (103-165)

Table 5: Mean moisture contents (calculated equilibrium relative humidity) and mite numbers at 0.25 m depth in 25 kg bins of wheat, either uncovered or covered with one of three shrouding materials, absorbing at 15°C and 80% r.h. (n=3).

Week	Treatment	mc% (range)	Calculated erh% (range)	Mite nos. *A. siro* (range)	Mite nos. *L. destructor* (range)
0	Control	15.1 (14.9-15.2)	69 (68-69)	111 (83-156)	134 (106-167)
	Tarpaulin	15 (15)	68 (68)	111 (83-156)	134 (106-167)
	Plastic sheet	15.1 (15-15.1)	69 (68-69)	111 (83-156)	134 (106-167)
	Rubber liner	15.3 (15-15.5)	70 (68-71)	111 (83-156)	134 (106-167)
2	Control	15.3 (15.2-15.4)	70 (69-70)	11 (0-20)	7 (0-11)
	Tarpaulin	15.1 (15.1-15.2)	69 (69)	7 (0-21)	3 (0-10)
	Plastic sheet	15.2 (15.1-15.2)	69 (69)	30 (19-51)	10 (0-21)
	Rubber liner	15.3 (15.1-15.5)	70 (69-71)	19 (11-35)	11 (0-22)
6	Control	15.3 (15.2-15.4)	70 (69-70)	569 (398-740)	135 (0-244)
	Tarpaulin	15.1 (15-15.1)	69 (68-69)	428 (161-716)	108 (80-163)
	Plastic sheet	15 (15)	68 (68)	95 (35-173)	26 (20-33)
	Rubber liner	15.2 (15.1-15.4)	69 (69-70)	50 (49-64)	33 (26-37)
11	Control	15.4 (15.3-15.5)	70 (70-71)	1530 (857-2500)	223 (164-333)
	Tarpaulin	15.1 (15-15.1)	69 (68-69)	859 (174-1517)	27 (0-81)
	Plastic sheet	15 (15)	68 (68)	429 (180-826)	123 (0-188)
	Rubber liner	15.3 (15.1-15.5)	70 (69-71)	1596 (412-3726)	249 (82-422)
14	Control	15.7 (15.5-15.8)	72 (71-72)	5673 (3059-7024)	257 (95-390)
	Tarpaulin	15.5 (15.3-15.9)	71 (70-73)	2112 (1741-2769)	298 (192-410)
	Plastic sheet	15.3 (15.2-15.3)	70 (69-70)	838 (487-1246)	379 (292-488)
	Rubber liner	15.5 (15.3-15.7)	71 (70-72)	2607 (2147-3361)	167 (101-288)
18	Control	15.8 (15.7-15.9)	72 (72-73)	4926 (2558-7226)	297 (192-492)
	Tarpaulin	15.4 (15.3-15.6)	70 (70-71)	785 (292-1337)	160 (0-286)
	Plastic sheet	15.5 (15.2-15.3)	71 (69-70)	586 (184-1185)	498 (368-638)
	Rubber liner	15.6 (15.3-15.8)	71 (70-72)	1144 (554-1653)	176 (0-306)
24	Control	15.7 (15.7-15.9)	72 (72-73)	6216 (5422-7264)	126 (95-186)
	Tarpaulin	15.2 (15.1-15.3)	69 (69-70)	2381 (1191-3571)	61 (0-183)
	Plastic sheet	15.1 (15-15.1)	69 (68-69)	669 (346-937)	0 (0)
	Rubber liner	15.3 (15-15.6)	70 (68-71)	1971 (521-4133)	31 (0-92)

Table 6: Correlation (Pearson) between moisture content % and mite numbers infesting 25 kg bins of wheat absorbing at 15°C and 80% rh (n=12).

Week	Surface		0.25 m depth	
	A. siro	*L. destructor*	*A. siro*	*L. destructor*
2	-0.417	0.233	0.21	-0.153
6	0.854***	0.739***	0.399	0.098
11	0.862***	0.547	0.702**	0.763***
14	0.718***	0.316	0.712***	0.038
18	0.831***	0.541	0.574	0.148
24	0.871***	0.173	0.94***	0.544

Two-tailed significance levels of the correlation coefficient *r* (df 10)

* = 5% ** = 2% *** = 1%

Figure 1.

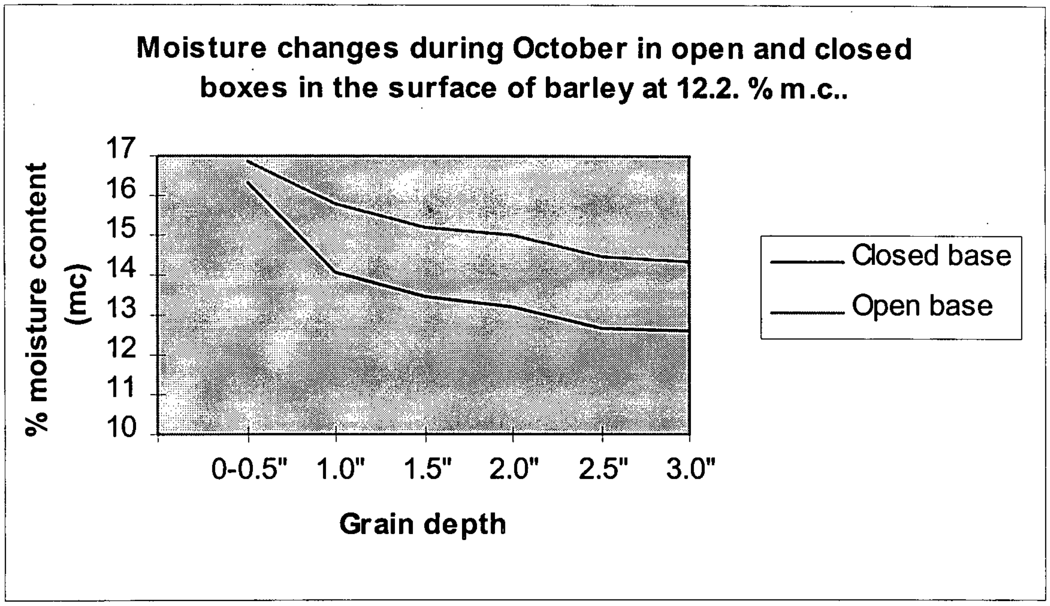


Figure 2.

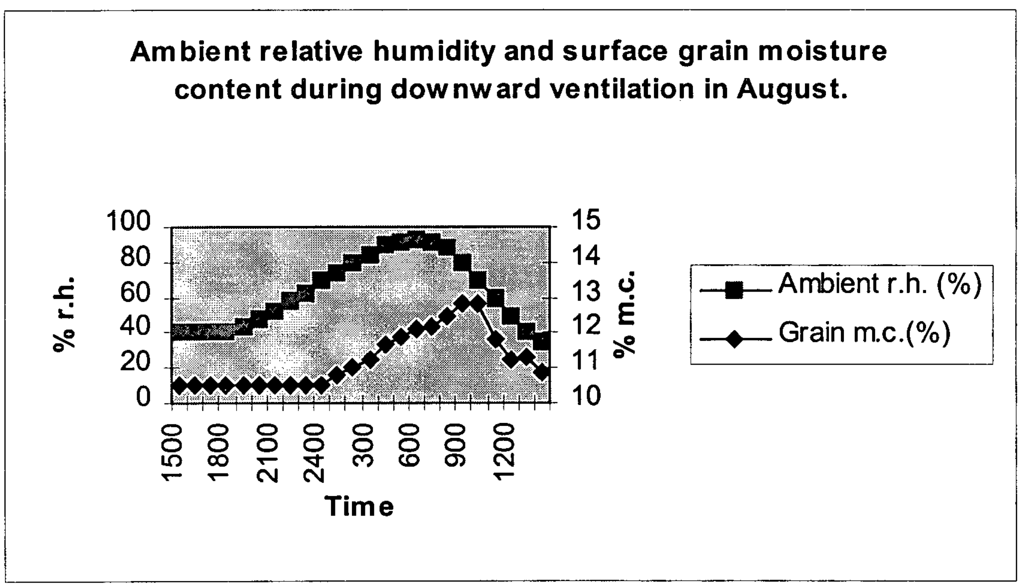
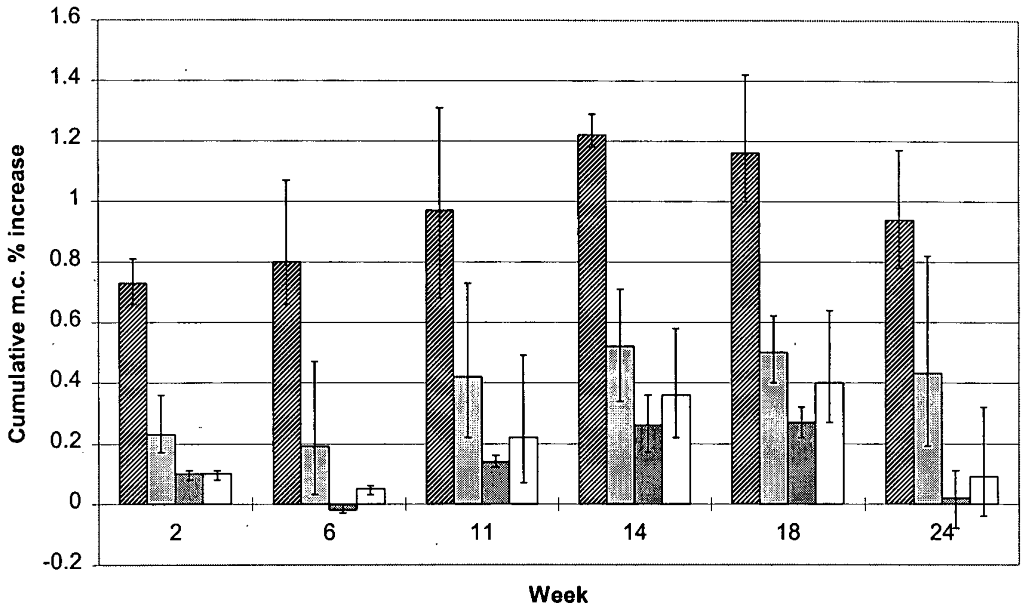


Figure 3.
Cumulative increases in moisture content % for 25 kg bins of wheat, either uncovered or covered with one of three shrouding materials, absorbing at 15°C and 80% r.h. (n=3).

(a) Surface



(b) 0.25 m depth