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# The temperature and moisture content of stored grain in two Saudi Arabian Provinces

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## ABSTRACT

The temperature and moisture content of bulk wheat, maize, and wheat bran stored in bins or general stores (in sacks), in the Riyadh and Dammam provinces, Saudi Arabia, were surveyed periodically during 1987 and 1988. The temperature of experimental and control bins of wheat and maize increased in direct proportion to the length of the period of storage. This was true for all heights inside the bins on the same date of observation, for each height on all dates and in both provinces and years.

In the Riyadh province, temperature of the headspace air in all bins showed a trend to increase with increasing period of storage. In the same storage plant, temperature at any particular height inside a bin varied according to the type of grain and the year. Individual variation between bins was also recorded.

Storage in bins increased the temperature of the stored grain above that of the environment in both provinces and years. The temperature of stores in both provinces fluctuated in parallel with that of the environment.

The moisture content of grain was significantly affected by height inside bins of experimental and control wheat, year, period of storage and province. The moisture content of maize was always higher than of control wheat.

In general, interactions between province (Riyadh and Dammam), year (1987 and 1988), period of storage (six periods each year), type of commodity stored (wheat in experimental and control bins, maize in a control bin and in general stores, and wheat bran in general stores), storage site (inside bins or in general stores), height inside bin (7 heights inside each bin) and identity of the bin were significant sources of variation in temperature and moisture content of stored commodities. To predict pest infestation, storage conditions should be accurately assessed with respect to these factors.

## INTRODUCTION

Forty nine species of granivorous and non-granivorous insects and mites have been extracted from stored grain and animal feed in Riyadh and Dammam provinces, Saudi Arabia (Rostom 1993). The abundance and distribution of stored product pests are known to be influenced by several factors, of which the temperature and moisture

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content of the product, as well as the relative humidity (R.H.) of the atmosphere are among the most important. The present work surveyed the temperature and moisture content of wheat, maize and wheat bran stored in a central arid (Riyadh) and an eastern humid (Dammam) province of Saudi Arabia. Both provinces have a different milieu with respect to ambient temperature and R.H. This is thought to affect infestation differently. Revealing the pattern of fluctuations of these factors may be of value in explaining and predicting pest infestation.

## MATERIALS AND METHODS

Wheat, maize and wheat bran stored in the Riyadh and Dammam plants (complexes) were surveyed over two years, 1987 and 1988. Storage extended for about 11.5 months each year. In the Riyadh plant, the wheat surveyed was stored in 10 concrete star bins, selected from an inner row of bins least exposed to direct sunlight (to minimize the heat effect as much as possible). Each bin (29.3 m high) was filled with about 350,000 kg of grain. Five bins of wheat were treated as controls, viz. exposed to routine treatments of fumigation with pesticides and/or recycling, whenever necessary during storage. The remaining five bins were not exposed to any treatment during the whole storage period (experimental bins of wheat). The limited amount of maize grain (260,000 kg) was stored in one star bin only, and was treated as a control on account of its high susceptibility to pest infestation and heating. Bran, kept in a general store in the plant, was packed in 50 kg bags and also treated as a control.

Due to limited space in the Dammam plant, only 2 concrete star bins were used. Each of these was 28 m high and filled with 255,000 kg of wheat. Wheat in one bin was used as a control and the other as experimental. Maize and bran were kept in a general store in the plant, and regarded as controls.

The temperature of the grain inside the bins was recorded weekly by a built-in sensor at about the center of the bin, which extended throughout most of its length. The sensor recorded temperature at 15 (Dammam plant) or 7 (Riyadh plant) different heights inside the bins. Height number 1 was the lowest. However, in the statistical analysis, values of temperature at every 2 successive heights at the same date in the Dammam plant were combined, in order to equal the number of levels in the Riyadh plant. Temperature and R.H. of the air in the headspace above the grain inside the bins were measured by a certified hair hygrometer and temperature indicator (Abbeon Cal. Inc., model HTA-176), lowered to about midway in the space. The temperature and R.H. of the stores were measured with a normal Hg thermometer and a battery operated digital hair hygrometer. Records of ambient temperature and R.H. in Riyadh and Dammam provinces were supplied by the Meteorology and Environmental Protection Administration, Ministry of Defense and Aviation, Riyadh.

The moisture content of grain stored in the bins was surveyed in samples taken from two (Dammam) or three (Riyadh) different heights inside the bins (upper, middle and lower heights). Samples from the upper height were taken by a grain sampler, 1.5 m in length, from the upper mouths of the bins. The middle and lower samples were obtained after a predetermined time during partial (Dammam) or complete (Riyadh) discharge of the bins. Samples from cereals in the general stores were obtained from different bags.

During each year, samples were obtained periodically from each plant in January,

February, April, June, September and November (A–G in 1987 after periods of storage for $19 \pm 9.7$, $60.2 \pm 5.1$, $118.8 \pm 12.1$, $189.2 \pm 11.6$, $272.2 \pm 11.6$ and $335.2 \pm 11.6$ days respectively, and H–L in 1988, after storing for periods of $23.8 \pm 15.9$, $70.3 \pm 16.3$, $133 \pm 16.1$, $208.8 \pm 35.7$, $292.8 \pm 18.5$ and $341.5 \pm 16$ days respectively).

The moisture content of the grain samples was determined by weighing before and after being placed in an air circulating oven at 105°C until constant weight had been reached. The temperature, moisture content and R.H. measured during each year were presented graphically by plotting mean values against period of storage (1–6), sample (A–G, H–L) and height inside the bin (1–7). Statistical analysis of the data was carried out by Duncan's multiple range test (N.S. = non-significant, $p > 0.05$; S = significant, $p = 0.05 - 0.01$; H.S. = highly significant, $p < 0.01$).

## RESULTS

1. The temperatures on different dates of observation after various periods of storage are shown in Figs 1–5. Except for the shortest period (No. 1), the mean temperature of the sum at all heights inside the bins on the same date increased with increasing period of storage (S and H.S.). This was valid for most experimental and control bins of wheat and maize, in both years and plants. Parallel results were also obtained for each height inside the bins on all dates of observation.

2. The temperature of air in the headspace of the bins (Figs 1, 2 and 5) increased substantially with increasing period of storage (S & H.S.) in both years in the Riyadh plant. This was discernible in most experimental and control wheat and maize grains stored for periods 3–6. R.H. in the same space fluctuated significantly (S and H.S.), although not consistently, during the same period. In no case was there a significant difference between values in experimental and control bins of wheat. No similar data were recorded in the Dammam plant.

3. The temperature at the 7 different heights inside the bins (Figs 5, 6 and 7) was compared. In both years in the Riyadh plant, the mean temperatures at the upper heights (3, 4 and/or 5, 6, 7) in both experimental and control bins of wheat were usually higher than those lower down (1, 2 and/or 3, 4; S, H.S.). In the case of maize, the differences between height were N.S. in the first year, and H.S. in the second year (1, 2, and 4 > 3, 5, 6 and 7). In the Dammam plant, differences between different heights in the experimental and control bins of wheat, were never significant.

4. In each year in the Riyadh plant, temperatures of 5 experimental or of 5 control bins of wheat varied. The mean temperature in the 5 experimental bins of wheat (27.4–31.5°C and 31.5–33.2°C in the first and second years, respectively) varied significantly from each other (H.S.). The same was true for the control bins (25.7–29.7°C and 29–32.4°C in the first and second years, respectively; H.S.). This may refer to the importance of the identity of bin (ID, individuality or entity) in affecting temperature of stored grain. In the Dammam plant, only one experimental and one control bin of wheat were tested each year.

5. The mean temperatures of the 5 experimental bins of wheat (29.6–32.5°C) were higher than those of the 5 control bins (28.9–31.5°C; H.S.) in the Riyadh plant. In the Dammam plant, differences between the temperature of one experimental bin (32.4°C) and one control wheat bin (31.7–32.9°C) were N.S. in either year.

6. In the Riyadh plant, the mean temperature of 5 control bins of wheat

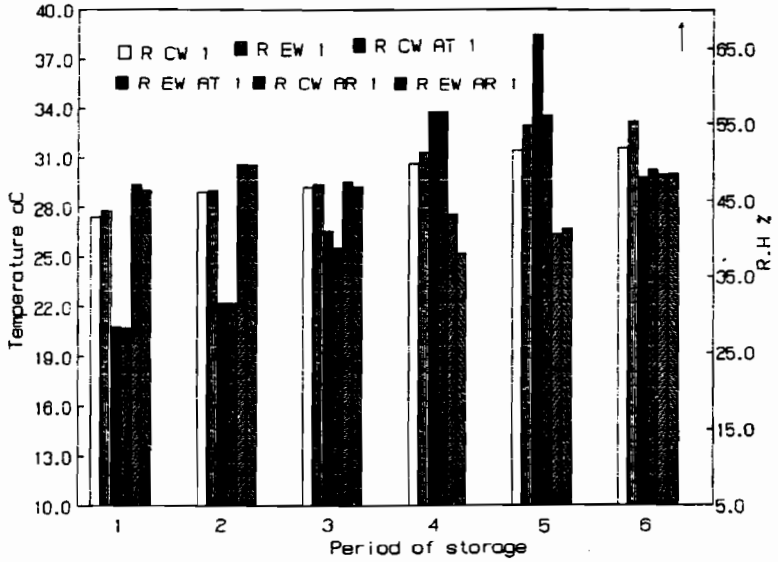


**Fig. 1.** Temperature and R.H. during different periods of storage in the Riyadh plant (R) during 1987 (1): R CW 1 and R EW 1 = mean temperature of sum of all heights on the same date, of wheat stored in control (CW) and experimental (EW) bins; R CW AT 1 and R EW AT 1 = mean temperature of the headspace air above wheat (AT) in control and experimental bins; R CW AR 1 and R EW AR 1 = mean R.H. of air of the headspace air above wheat (AR) in control and experimental bins.

(28.9–31.5°C) was either similar to (2nd year) or lower than (1st year) that of the single bin of maize (31.0–31.2°C; H.S.).

7. The mean temperature of 5 experimental + 5 control bins of wheat (29.4–32°C) and of 1 bin of maize (31.2–31.0°C) was higher than that of a store in the same plant

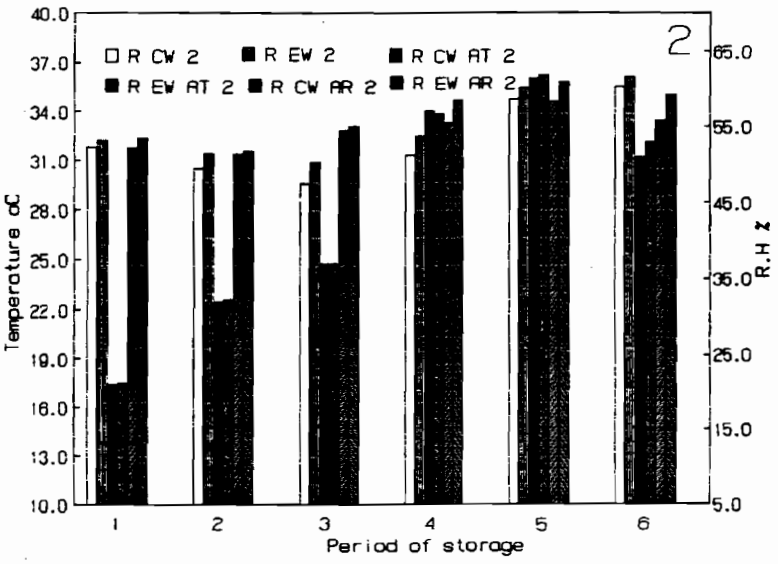


**Fig. 2.** Temperature and R.H. during different periods of storage in the Riyadh plant (R) during 1988 (2); abbreviations as for Fig. 1.

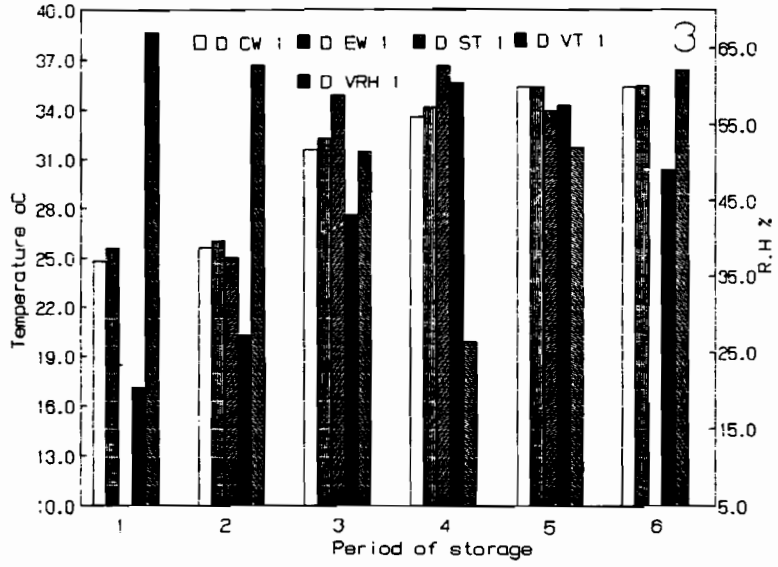


**Fig. 3.** The temperature after different periods of storage in the Dammam plant (D) and ambient temperature during 1987: D CW 1 and D EW 1 = mean temperatures of some of all heights on the same date, of wheat stored in control and experimental bins; D ST 1 = mean temperature of store (ST) in the Dammam plant; D VT 1 and D VRH 1 = mean ambient temperature (VT) and R.H. (VRH) in the Dammam area; other abbreviations as for Fig. 1.

(24.7–26.9°C; H.S.) in both years in the Riyadh plant. In the Dammam plant (where bran and maize were kept) this was also the case in the second year (32.6 and 30.1°C in bins and stores, respectively), but there was no significant difference in the first year (31.8 and 32°C).

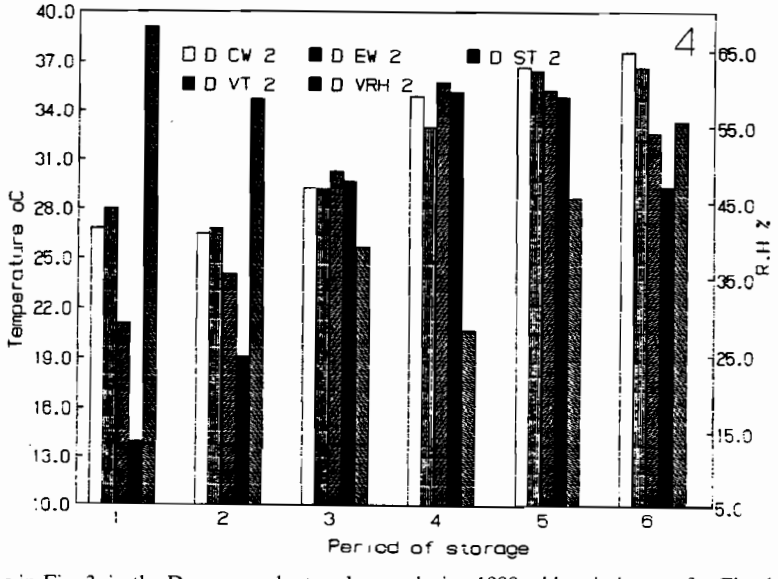


**Fig. 4.** As in Fig. 3, in the Dammam plant and area, during 1988; abbreviations as for Figs 1, 2 and 3.

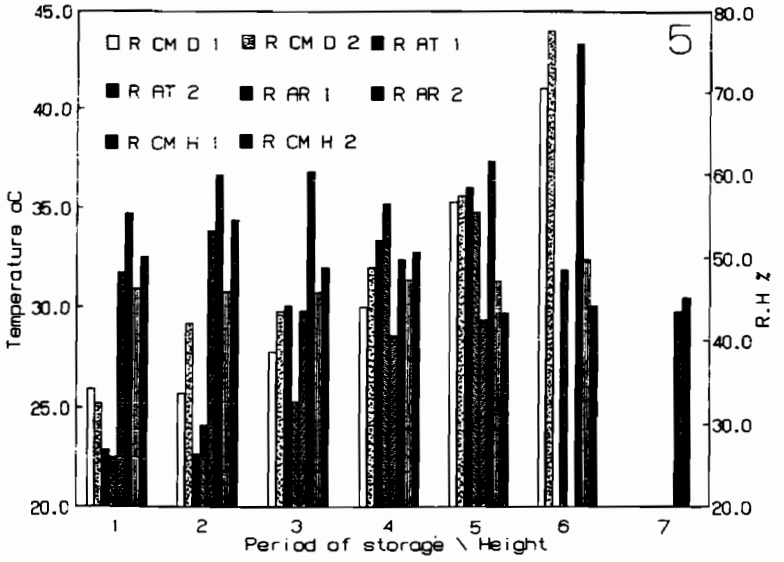


**Fig. 5.** Temperature and R.H. of maize stored in control bins (CM), after different periods of storage and at different heights inside bins in the Riyadh plant during 1987 and 1988: R CM D 1 and R CM D 2 = mean temperature at all heights on the same date (D), in both years; R AT 1 and R AT 2 = mean temperature of the headspace air above grain in both years; R AR 1 and R AR 2 = mean R.H. of the headspace air above grain in both years; R CM H 1 and R CM H 2 = mean temperature at the same height inside bin (H) and all dates of observation in both years.

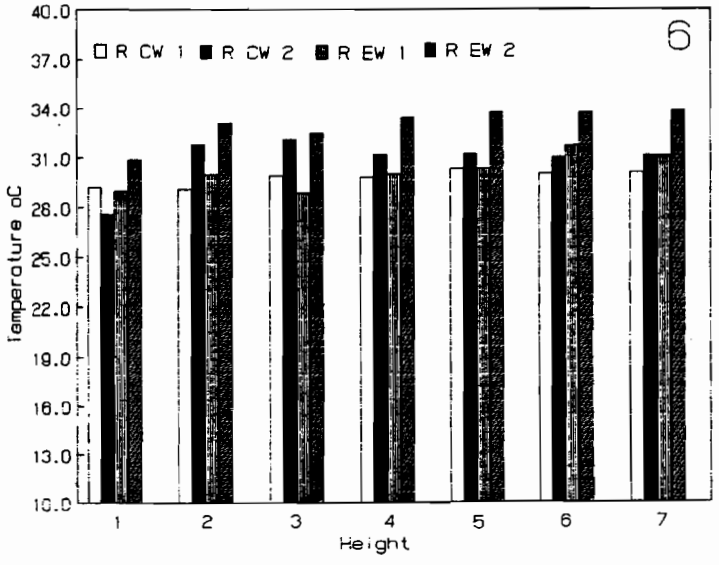


**Fig. 6.** Mean temperatures at the same height inside bins and dates of observations in the Riyadh plant during both years of storage: R CW 1 and R CW 2 = wheat stored in control bins in both years; R EW 1 and R EW 2 = wheat stored in experimental bins in both years; abbreviations as for Figs 1 and 2.

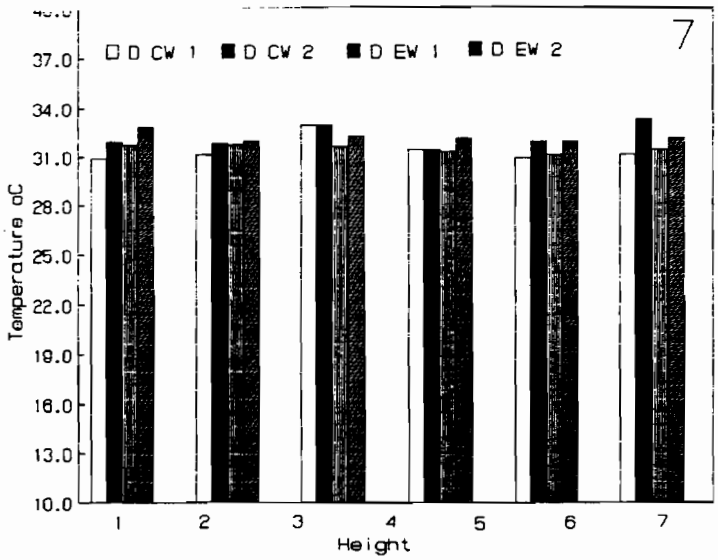


**Fig. 7.** As Fig. 6, in the Dammam plant; abbreviations as for Figs. 3 and 4.

8. The mean temperature of 5 experimental bins of wheat (29.6–32.5°C), of 5 control bins (28.9–31.5°C) or of 1 bin of maize (31.0–31.2°C) was higher than that of ambient temperature in the Riyadh area (25.1–26.6°C, H.S.) in both years. A similar trend was also noted in both years in the Dammam plant (experimental bin of wheat 32.4°C, control bin 31.7–32.9°C, ambient temperature 27.1–28.9°C; S and H.S.).

9. The temperature and R.H. of the stores vs ambient temperature and R.H. are shown in Figs 3, 4 and 8. In both years in the Riyadh plant (Fig. 8), the mean temperature of a store (24.7–26.9°C) was similar to that of ambient temperature in the Riyadh area (25.1–26.6°C). Values of R.H. in the same store (45.6–48.2%) were always higher than those of ambient R.H. (23.6–25%, H.S.). In the Dammam plant (Figs 3 and 4), the mean temperature of a store (30.1–32°C) was higher than the ambient temperature in the Dammam area in both years (27.1–28.9°C, S and H.S.) R.H. was not recorded in the Dammam store.

In the Riyadh and Dammam plants, the mean temperature of the stores increased successively towards spring and summer, reached climax values between May and September in both years, to decline towards the end of the year (H.S.). This paralleled a similar trend of change in ambient temperature in each province. The mean ambient R.H. in the Riyadh and Dammam areas, and of a store in the Riyadh plant, fluctuated significantly during the year. However, unlike temperature, R.H. reached minimal values in summer (S and H.S.).

10. In the first year, the means of temperature of the experimental and control bins of wheat in the Riyadh plant were lower than the corresponding values in the Dammam plant (H.S.). In the second year, the difference was H.S. for control bins (Dammam > Riyadh) but N.S. for the experimental bins.

11. The mean temperature of a store in the Riyadh plant was considerably lower than that of one in the Dammam plant (H.S.) in both years.

12. In the first year, the means of ambient temperature and R.H. in the Riyadh area were lower than those in the Dammam area (S and H.S.). In the second year,

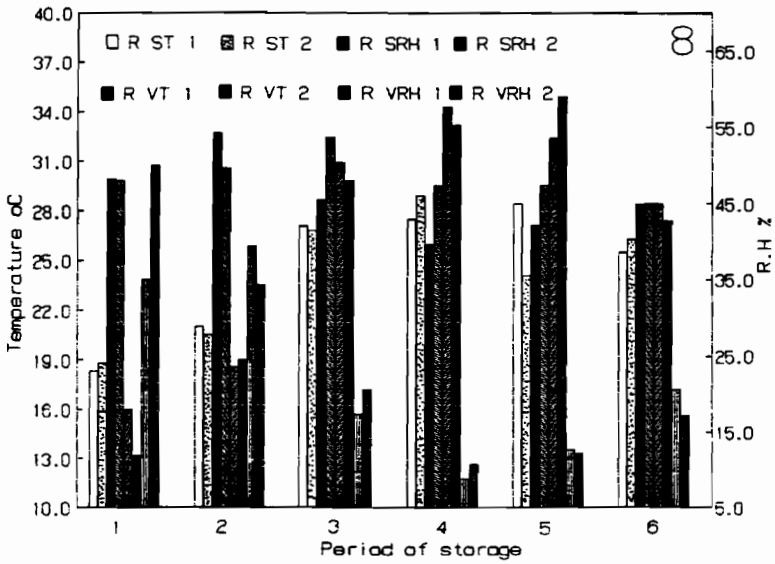


**Fig. 8.** Temperature and R.H. of a store in the Riyadh plant and of the environment in the Riyadh area over two years: R ST 1 and R ST 2 = mean temperature of a store in both years; R SRH 1 and R SRH 2 = R.H. of store (SRH) in both years; R VT 1 and R VT 2 = mean environmental temperature in both years; R VRH 1 and R VRH 2 = environmental R.H. in both years.

however, the difference between temperature in both provinces was N.S., although the R.H. in Dammam was higher than in Riyadh (H.S.).

13. The mean temperature in the experimental and control bins of wheat were higher at the second than at the first year (H.S.) in the Riyadh plant. In the Dammam plant, however, the mean temperatures of experimental bins of wheat did not differ significantly from each other in either year, although the mean temperature in the control bin was higher in the second than in the first year (H.S.).

14. The mean temperature of maize did not differ in both years in the Riyadh plant. Maize was not stored in bins in the Dammam plant.

15. The mean temperature of the air in the headspace of the control bins of wheat was higher in the first than in the second year (H.S.) in the Riyadh plant. Corresponding values in the experimental bins of wheat did not differ significantly in both years. The R.H. of the headspace air was higher in the second than in the first year, both in experimental and control bins of wheat (H.S.). In the maize bins the mean temperature of the headspace air did not differ significantly in either year, although R.H. was higher in the second than in the first (S). No similar records were obtained in the Dammam plant.

16. The mean temperature of a store in the Riyadh plant did not differ significantly in the two years, although R.H. was higher in the second than in the first year (S). Corresponding values of temperature were higher in the first than in the second year (H.S) in the Dammam plant, but R.H. was not recorded.

17. The corresponding means of ambient temperature and R.H. in the Riyadh and Dammam areas did not differ significantly in either year.

18. The moisture content of samples of wheat obtained from different heights inside experimental and control bins fluctuated irregularly in the Riyadh plant, but

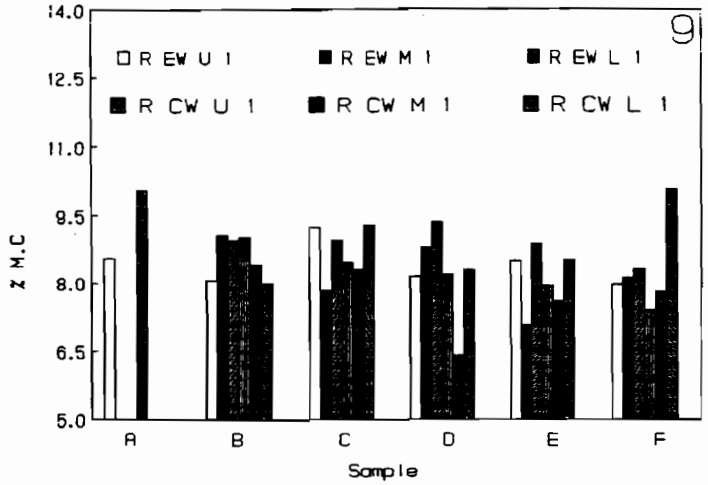


**Fig. 9.** Moisture content of wheat samples A–F, from upper (U), middle (M) and lower (L) heights inside experimental (EW) and control (CW) bins in the Riyadh plant (R), during 1987.

showed a trend to be greater at either the lower (1st year, Fig. 9) or the upper (2nd year, Fig. 10) height than in the others. The moisture content of maize samples from different heights inside the control bin did not differ significantly or consistently in either year (Fig. 13).

Height inside bins was, in most cases correlated, although inconsistently, with the moisture content of the wheat in both experimental and control bins in the first year, in the Dammam plant (Fig. 11). In the second year, however, differences between heights were usually N.S. (Fig. 12).

19. In the first year, and in both plants, the moisture content of maize dropped successively and significantly with increasing period of storage (Figs 13 and 14). Significant changes were also observed in most samples of wheat obtained from

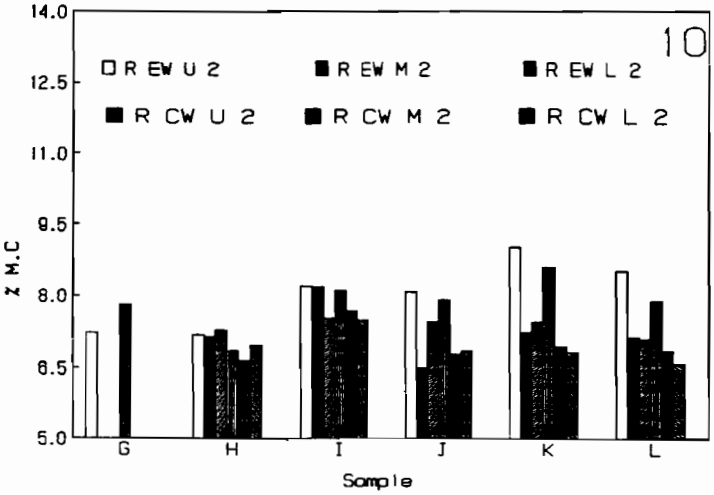


**Fig. 10.** Moisture content of wheat samples G–L, from upper, middle and lower heights inside experimental and control bins in the Riyadh plant during 1988; abbreviations as for Fig. 9.

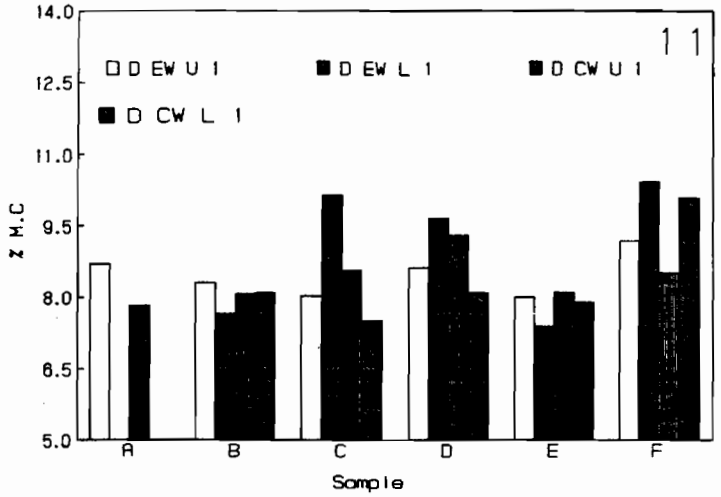


**Fig. 11.** Moisture content of wheat samples A–F, from upper and lower heights inside experimental and control bins in the Dammam plant (D) during 1987; abbreviations as for Fig. 9.

experimental and control bins in both plants, though a definite pattern of change was not clear (Figs 9 and 11).

In the second year significant irregular changes in the moisture contents of wheat and maize over increasing period of storage were only observed in the Dammam plant (Figs 12 and 14).

20. The moisture content of wheat from experimental and control bins and of maize did not differ significantly in the first year in either plant. In the second year, however, the corresponding values of wheat were higher in the Dammam than in the Riyadh plant while, in the case of maize moisture in the Riyadh plant surpassed that in the Dammam plant.

21. The moisture content of wheat in both the experimental and control bins in the

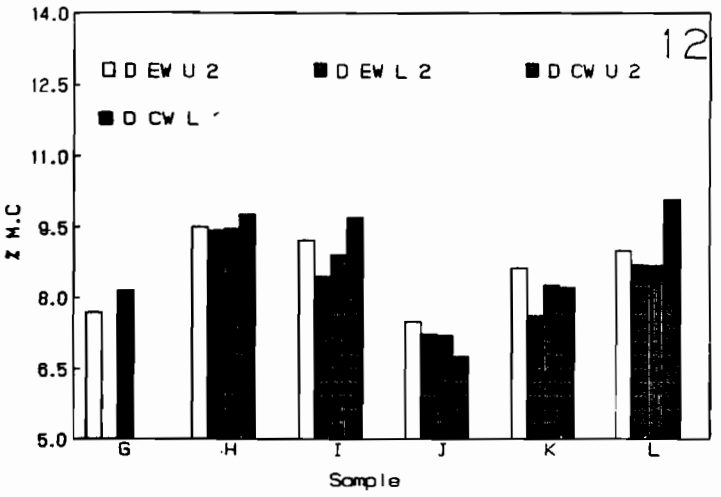


**Fig. 12.** Moisture content of wheat samples G–L, from upper and lower heights inside experimental and control bins in the Dammam plant during 1988; abbreviations as for Figs 9 & 11.

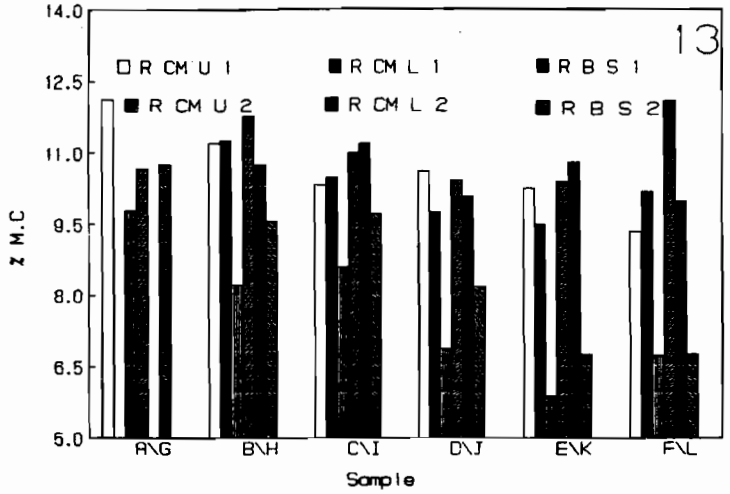


**Fig. 13.** Moisture content of samples A–L of maize (CM) from upper (U) and lower (L) heights inside control bins, and of bran (BS) from a store in the Riyadh plant during 1987 (1) and 1988 (2).

Riyadh plant was higher in the first than in the second year. In the Dammam plant, the differences between the moisture content of both experimental and control wheat were N.S. in either year. The moisture content of maize did not differ significantly in either year in both plants.

22. The moisture content of wheat from the experimental bins was not significantly different from that from the control bins in most samples, either in plants or years.

23. The moisture content of maize was significantly higher than that of wheat in the control bins in most samples, both in plants and years.

24. The moisture content of wheat bran was significantly higher than that of wheat in control bins in both years in the Dammam plant. Irregular fluctuations occurred in the Riyadh plant.

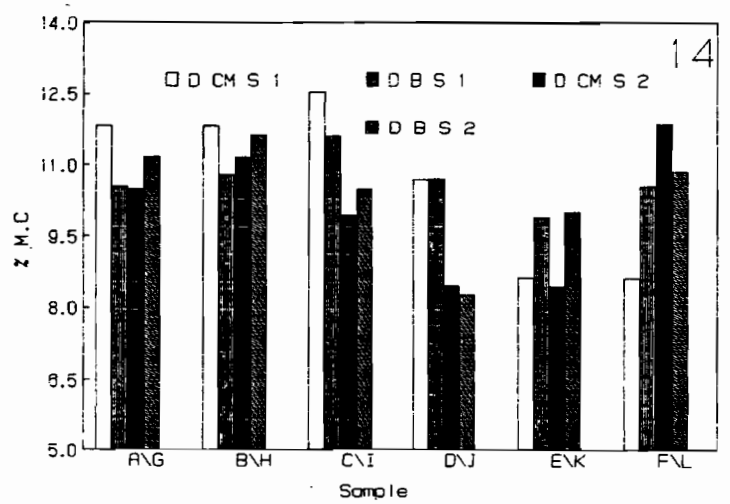


**Fig. 14.** Moisture content of samples A–L of maize (CM) and of bran from a store (BS) during 1987 and 1988, in the Dammam plant (D); other abbreviations as for Fig. 13.

## DISCUSSION

The present study has revealed that the temperature of grain stored inside bins increased in direct proportion to the length of the period of storage. This was true of all heights on the same date of observation, for each height on all dates, for experimental and control bins of wheat and maize, and in both Riyadh and Damman plants and years. This observation is in accordance with results of Smith (1978), who recorded a range of variation of temperature in the center of a mass of wheat between −5 and 22°C throughout a 4-year period of storage. Contradictory results have been recorded by other authors, e.g. Smith & Loschiavo (1978) in Canada, who reported that, after one year of storage in a star bin, the temperature of wheat grain did not exceed 19°C. Below 12 m depth in the bin, the grain temperature was 10°C in September. In a farm in Oklahoma, the temperature in bins of stored wheat grain ranged between 35 and 38°C during June–August, and between 24 and 30°C during September–November (Cuperus *et al.* 1986). The temperature of wheat in the top meter of cylindrical metal farm bins in Kansas, was uniform within a favorable range of 27–34°C for the first 12 weeks of storage, and then declined at rates of 1.3–2.0°C/week (Hagstrum 1987). Environmental conditions in all these localities differ, however, from those in Saudi Arabia.

In all seasons in Riyadh, the mean temperature of the headspace air in experimental and control bins of wheat and maize showed a trend to increase with increasing period of storage, in parallel with that of grain. R.H. in the same space fluctuated inconsistently, though significantly. Temperature and R.H. of the headspace air of bins are known to be affected by ambient conditions, and thus may influence infestation of the upper layers of grain in bins.

Temperature at any particular height inside a bin varied according to the type of grain and the year, in the Riyadh plant. In the Dammam plant, however, the temperature at different heights did not vary significantly with either year or with type of cereal. Comparable results have been obtained by Birch (1946), who recorded the highest temperature in the middle of bulk wheat stored in piles, by Zdarkova *et al.* (1983) who found that the temperature of different layers of wheat in silos (45 m high and 6 m diameter containing 900,000 kg of wheat) was 16–36°C, and by Loschiavo (1985) who found the temperature of post-harvest grain to be considerably higher at the center than near the openings on the roofs of steel granaries.

The present investigation also suggested some other deductions with respect to temperature:

(1) In the Riyadh plant, identity (ID, entity or individuality) of the bin of wheat was an effective factor in modifying its temperature in both years.
(2) In the Riyadh plant, but not in Dammam, the treatment of wheat grain (experimental or control) affected the temperature of storage in both years.
(3) In the Riyadh plant, the temperature was always higher inside the bins than in a store while, in the Dammam plant, the temperature in both storage areas was affected by the year.
(4) Storage in bins increased the temperature of the stored grain above that of the environment in both provinces and in both years.
(5) The temperature in a general store varied according to the province. R.H. in the Riyadh store was always higher than that of the environment. In general, the

temperature of stores in both provinces fluctuated in parallel with that of the environment.

(6) Temperature during the same year varied in the two provinces, as did the R.H. of the headspace air inside bins, stores and the environment.

(7) The temperature and/or the R.H. of headspace air in wheat bins (but not in maize bins), and in stores differed in the two years within the same province. Ambient temperature and R.H., however, did not differ.

Temperature is considered to be the sole factor affecting the abundance of insects and mites in stored grain and other commodities (Birch 1946; Cotton *et al.* 1960; Singh 1977; Armitage 1980, and Cuperus *et al.* 1986). Temperature, combined with the moisture content of the stored products and/or other factors, have also been found to affect infestation (Wafa *et al.* 1966; Burrel & Harves 1976; Fleurat-Lessard 1976; Hardman 1977; McGanghey *et al.* 1978; Hurlock *et al.* 1980; Stratil *et al.* 1981; Tseng 1981; Cotton & Wilbur 1982; Zdarkova *et al.* 1983; Loschiavo 1985).

The results of the present investigation also revealed that height affected the moisture content of wheat stored in the experimental and control bins, but not of maize. This effect, however, varied with year and province. Storage period and province were also correlated with the moisture content of the cereals, though no regular pattern could be discerned. The moisture content of wheat from experimental and control bins did not differ significantly, but the moisture content of maize was always higher than of control wheat. Smith (1978) recorded variations in the moisture content of stored wheat by as much as 5% more at the center than near the surface of each grain mass during one year's storage, but it did not vary more than 1% in other localities.

In conclusion, interactions between the province, year, storage period, type of stored commodity, storage site (bins or general stores), height inside the bins and identity of the bin were significant sources of variation in temperature and moisture content of stored commodities in both Riyadh and Dammam provinces in the years 1987 and 1988. To predict a pest infestation, conditions of storage regarding these factors should be accurately assessed.

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# مسح لدرجات الحرارة والمحتوى المائي للحبوب المخزونة في منطقتين بالمملكة العربية السعودية

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## خلاصة

تم تسجيل درجات الحرارة وتقدير المحتوى المائي دوريا لمخزون كبير من القمح والذرة والنخالة داخل صوامع أو في مخازن عامة بمنطقتي الرياض والدمام بالمملكة العربية السعودية خلال عامي ١٩٨٧ و ١٩٨٨، وتبين أن درجة حرارة صوامع قمح التجربة والمقارنة والذرة قد ازدادت طرديا مع طول فترة التخزين عند كل الإرتفاعات داخل الصومعة في نفس يوم المشاهدة، ولكل ارتفاع على حدة في جميع الأيام في المنطقتين والموسمين.

وفي منطقة الرياض ازدادت درجة حرارة الفراغ العلوي لكل الصوامع بازدياد فترة التخزين، كما اختلفت درجة الحرارة عند أي من الإرتفاعات داخل الصومعة حسب نوع الحبوب والعام، وكان لعامل فردية (ذاتية) الصومعة أثرا فعالا في هدا الصدد.

وقد أدى التخزين داخل الصوامع رفع درجة حرارة الحبوب المخزونة الى مستوى أعلى من حرارة الجو المحيط في كل من المنطقتين والعامين، كما تذبذبت درجة حرارة المخازن العامة في المنطقتين بشكل موازي لحرارة الجو المحيط.

وكان لعوامل الإرتفاع داخل صوامع قمح التجربة والمقارنة والعام وطول فترة التخزين والمنطقة أثرا معنويا على المحتوى المائي للحبوب، وسجلت الذرة قيما أعلى للمحتوى المائي عن قمح المقارنة.

وبشكل عام يمكن القول بأن التفاعل بين عوامل المنطقة (الرياض والدمام) والعام (١٩٨٧، ١٩٨٨) وطول فترة التخزين (٦ فترات كل عام) ونوع المواد المخزونة (القمح في صوامع التجربة والمقارنة، والذرة في صوامع المقارنة وفي مخازن عامة ونخالة القمح في مخازن عامة) ومكان التخزين (داخل صوامع أو في مخازن عامة) وارتفاع المواد المخزنة بها (٧ ارتفاعات داخل الصومعة) وكيان الصومعة (فرديتها أو ذاتيتها) كانت مصادر معنوية للتأثير على درجة الحرارة والمحتوى المائي للمواد المخزونة، ولكي يمكننا التنبؤ باحتمالات الاصابة بالآفات يلزم تحديد ظروف التخزين بالنسبة للعوامل السابقة بشكل دقيق.

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