HGCA

PROJECT REPORT No. 15

REDUCING MICROBIAL COUNTS IN HOME-GROWN WHEAT BY STORAGE AT ELEVATED TEMPERATURES

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by

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Final report of a project lasting one year commencing 1 September 1987 which was carried out at the Flour Milling and Baking Research Association, Chorleywood. The project was funded with a grant of £18,900 from the Home-Grown Cereals Authority (Project No. 0043/1/87)

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HGCA *Project 0043/1/87*

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Final Report on a one year project commencing 1st September 1987

ABSTRACT

The work was divided into two separate phases.

In the first phase the reductions in counts of total bacteria, enterobacteriaceae, mesophilic spores, moulds and yeasts in wheat adjusted to moisture contents of 13.1, 14.8, 16.0 and 17.8% were determined at storage temperatures of 21, 30, 37 and 44°C. At suitable intervals samples were taken for milling and the resultant flours tested for microbial content and baking quality characteristics. The count of all organisms except mesophilic spores declined during storage at a rate that increased with increase in temperature and wheat moisture content. The same trend occurred in flour but the counts were lower by a factor of about 100-fold than in the corresponding wheat. At 44°C, even with the highest moisture content wheat (17.8%), it took several days to obtain a 90% reduction in counts. Some loss in baking quality was observed in the wheats stored for prolonged periods at the highest temperatures and moisture contents. Of the various tests used to assess the baking quality of flours from the stored wheats the SDS sedimentation test and loaf crumb structure provided the best indication of loss in quality. Of particular interest was the unexplained finding that the Hagberg Falling Number increased during warm storage although the *alpha*-amylase activity was unaffected.

The second phase of the project was a study to determine the shortest heating time/temperature combination for obtaining a worthwhile reduction in bacterial numbers in wheat without causing gluten damage as measured by germination rate and the protein solubility test. The results indicate that storage at a temperature of about 50°C for 16-24h may be optimum although further research is needed to assess whether or not carrying out such a procedure is feasible commercially and to investigate how it might be achieved.

OBJECTIVE

To ascertain whether storage of home-grown wheat at elevated temperatures will cause a worthwhile reduction in the numbers of microorganisms in flour without damaging its baking properties.

1 INTRODUCTION

In recent years there has been an increasing demand by food manufacturers for the flours they use to meet prescribed microbiological specifications. The following examples illustrate why such specifications are required.

1) In flours used for baby foods, which are either unprocessed or lightly processed, food poisoning bacteria must be absent, and the overall level of bacterial contamination should be low as the very young are very susceptible to food borne infections and intoxications.

2) To ensure safety and an adequate shelf-life low microbial numbers are required in flour used in pasta products, unbaked refrigerated or frozen dough or pastry goods and cereal based fillers and coatings used for certain meat and fish products.

3) Flour used in canned foods must meet strict specifications for the number of thermophilic spores that they contain. If too many are present some may survive processing resulting in spoilage or a food poisoning hazard.

The miller is frequently unable to meet the specifications demanded since there is usually a direct relationship between the numbers of microorganisms in flour and in the wheat from which it is derived (Oulsnam, 1981), and the microbiological condition of wheat can vary greatly depending on growing and harvesting conditions. In years when adverse weather conditions are experienced during growth and harvest, the microbial counts in wheat, and hence in flour, will be much higher than in good years. Moreover, even in a good year, counts in wheat will vary widely according to the locality in which it is grown, the method of harvesting and the way it is stored prior to receipt at the mill. Thus, the miller has little control over the microbiological condition of the wheat that he purchases.

A certain amount can be done to reduce the numbers of microorganisms in wheat by the cleaning procedures used in the screen room of the mill by adopting good hygiene standards at all stages during the milling process (Seiler, 1986). However, the counts in flour will still be influenced greatly by the initial quality of the wheat received at the mill.

It is possible to obtain a worthwhile improvement in the microbiological condition of flour by treatment of wheat with chlorine just after damping, but the reductions achieved by this means are relatively small and tend to vary from one wheat to the next (Vojnovich *et al.*, 1967). Vojnovich and Pfeifer (1966) showed that significant reductions in the number of microorganisms in flour can be obtained by storage at elevated temperatures without affecting baking quality. Heating large quantities of flour is inconvenient and expensive, and it would be more appropriate to store wheat at an elevated temperature prior to milling. Therefore, the present study was undertaken to determine the reductions in microbial counts which might be achieved by warm storage of wheat. Since microbiological specifications often apply to flours used in baked products, the effect on the baking quality of flour milled from wheat stored at elevated temperatures was also assessed.

The work was divided into two separate phases. The first phase was a study of the reductions in count of microorganisms in wheat adjusted to four different moisture contents and stored at temperatures of 21, 30, 37 and 44^{o}C. At suitable intervals samples were taken for milling and the resulting flours tested for microbial content and baking quality characteristics. In the second phase the wheat was stored at higher temperatures and relationships established between reduction in microbial numbers and protein denaturation as measured by germination and protein solubility tests. The two phases are dealt with separately in this report.

2 MATERIALS AND METHODS.

2.1 Organisation of tests: In September 1987 a large quantity of Avalon wheat was obtained shortly after harvesting. This was sub-divided into four equal samples of 60kg and either dried or moistened to give moisture contents of approximately 12, 14, 16 and 18%. Four subsamples of 15kg were removed from each sample, treated with insecticide (Actellic dust at a rate of 200g per 1000kg) and double wrapped in heavy duty polyethylene bags which were tied tightly before being placed in incubators at 21, 30, 37 and 44^{o}C. Thus, wheats at four moisture contents were stored at four temperatures (16 samples altogether). According to storage temperature, microbiological tests and flour quality assessments were undertaken on the wheats of different moisture content at the time intervals indicated in Table 1.

The second part of the project involved a series of small scale tests in which wheat (4g) was placed in stoppered test tubes (15 mm internal diameter) and heated in an aluminium heating block (Dri-Block Unit 1; Griffin and George Ltd, London) set at different temperatures. Samples were removed for microbiological, germination, and protein solubility tests at suitable intervals.

2.2 Microbiological: For counts in wheat a primary tenfold dilution was prepared by soaking 40g in saline peptone diluent (0.85% w/v NaCl; 0.1% bacteriological peptone; 360ml) for 30 min prior to mixing with a Stomacher 400 for 10 min. A similar procedure was used for flour except that the sample was not soaked and only mixed for 2 min. Subsequent serial dilutions were prepared using the same diluent.

Counts of total bacteria (TVC), moulds and yeasts were carried out using a spiral plating system (Don Whitley Scientific, Shipley, W. Yorks). Enterobacteriaceae were enumerated using a pour plate method with overlay. Cysteine lactose electrolyte deficient (CLED) agar after incubation for 3 days at 30°C was used for TVC; oxytetracyline glucose yeast extract (OGYE) agar after incubation for 5 days at 25°C was used for moulds and yeasts; and violet red bile glucose (VRBG) agar after incubation for 1 day at 37°C was used for enterobacteriaceae. The method adopted for mesophilic spore counts* was based on that developed by Shapton and Hindes (1963) for enumerating thermophilic spores.** An appropriate dilution of wheat or flour (5ml) was added by pipette to a bottle containing molten CLED medium (90ml) at 45°C. The bottle was shaken and placed in a waterbath at 80°C for 34 min to destroy all vegetative cells in the inoculated medium. After cooling, the agar medium was poured into five petri dishes and allowed to set. The spore count was determined from the total colony count on all plates after incubation for 2 days at 30°C.

* Organisms with an optimum growth temperature between 30° and 40°C (Jay, 1970).

** Organisms with an optimum growth temperature greater than 40°C (Jay, 1970).

2.3 Milling and baking: At the time intervals shown in Table 1 the moisture content of the wheat was determined using a rapid capacitance method (Sinar Agritec, Weybridge, Surrey) and adjusted to 15.5% by drying or adding water prior to milling a sample (3kg) on a Buhler laboratory mill to produce a 'straight run' flour. The suitability of the flours for breadmaking was assessed by SDS sedimentation volume (Axford *et al.*, 1978) wet gluten (ICC Standard no.137) and Hagberg Falling Number (ICC Standard no.107). In baking tests a 400g loaf was produced from each of the flours using the Chorleywood Bread Process. Its volume was measured and the structure, texture and resilience of the crumb assessed.

2.4 Assessment of heat damage: Three techniques were investigated, namely a germination test, the turbidity test developed by Harrison *et al.*, (1966) and the protein solubility test developed by Every (1987). The last two of these measure loss in protein solubility in heat damaged wheat.

2.4.1 Germination test: Grains of wheat (100) were placed on moistened filter paper and stored at ambient temperature in the dark for 7 days. The proportion of grains that germinated was noted.

2.4.2. Turbidity test: Wheat (5g) was ground in a Glen Creston mill adjusted to a fine setting and the meal extracted with 0.5% (w/v) NaCl (100ml) for 3 min. The filtrate collected over the first 30 seconds was discarded before collecting 10ml volumes in marked test tubes. After adding 10% (w/v) gum acacia solution (1.0ml) to each tube and mixing well, the contents were heated for 3 min in a boiling water bath then cooled immediately under cold running water. The contents of the tubes were transferred to glass cuvettes and the turbidity readings measured using an Eel Absorptiometer with a neutral filter.

2.4.3. Protein solubility test: Wheat was milled in KT mill (0.8mm screen) and the resultant meal (1g) was extracted with 2% (w/v) NaCl (50ml) in a stoppered bottle by inverting the bottle once every second for 30 seconds. After allowing the suspension to settle for 30 seconds, an aliquot (100ml) of the supernatant was removed and mixed with 30% (w/v) Coomassie Blue G250 solution (BDH Ltd, prod. no. 44379) (3.0ml) in a cuvette. The absorbance at 595nm was measured using a Perkin Elmer spectrophotometer (Lambda 3UV/VIS) after 2 min and compared with a blank of protein stain reagent.

3 RESULTS

3.1 Effects of storing wheat at temperatures below 44°C

3.1.1. Microbial numbers: The mesophilic spore counts in the wheat during storage were very variable but there was no clear evidence of any reduction at any temperature. Spore counts in the flours were consistently lower in the wheat but again there was no indication of a reduction with storage time.

With the other groups of microorganisms there was a definite trend for reductions in counts in the wheat at all storage temperatures. For the most part this trend also applied to the flour. Using the lines of best fit from the data obtained from the test, the reductions in count of total bacteria (TVC), enterobacteriaceae and moulds/yeasts in wheat and the derived flour at the four storage temperatures are shown separately in Figure 1. Estimates of the time required to obtain a 90% reduction in the counts of the three groups of organism in wheat of different moisture content at the flour storage temperatures are given in Table 2.

As expected, the counts of all organisms decreased more rapidly as the storage temperature increased. At each temperature the decline in count was more rapid as the moisture content increased. The rate of reduction in count tended to increase in the order total bacteria, enterobacteriaceae and moulds/yeasts but the difference was small. At 21°C the counts were variable and the estimated times for a 90% reduction, given in Table 2, are very approximate.

With flour the initial counts were lower by a factor of about 100-fold than in the wheat with all groups of microorganisms. At 44°C and 37°C the rate of reduction in numbers of total bacteria and enterobacteriaceae were similar to those in wheat (Figure 1), but the mould/yeast counts in flour tended to reduce more slowly, possibly due to additional contamination during the milling process. Insufficient data were available for the flours from wheat stored at 30°C and 21°C to obtain a clear indication of the rate of reduction in count. However, the limited data that were available suggests that this occurred more slowly in flour than in wheat.

Figure 2 compares the reduction in counts of total bacteria obtained by Vojnovitch and Pfeifer in tests with flour stored at elevated temperatures with the average results obtained with wheat and this study. At the higher storage temperatures (37°C and above) the results are

similar, but at 28°C the rate of decrease in bacterial count in flour observed by Vojnovich and Pfeifer was considerably less than in the wheat stored at 30°C in the present tests and more like that for wheat stored at 21°C.

3.1.2 Flour quality: The results from the various tests to determine the effects of storing wheat at elevated temperatures on the quality of the derived flour are given in Table 3.

Impairment of baking quality was observed which, as anticipated, occurred more quickly in wheat of the highest moisture content (17.8%) stored at the highest temperature (44°C). No single test gave an accurate indication of flour damage. The best pointer was the SDS sedimentation test. Wet gluten determinations established damage in the higher moisture wheats stored at 44°C but not at other moisture contents or temperatures. Loaf volume measurements were erratic, possibly because the flour from the wheat selected for these tests produced poor volume bread even without storage under the different conditions. However, examination of the crumb structure gave a better indication of loss in quality.

Because of the time intervals between milling the wheat, it is only possible to obtain an approximate indication of the storage time before the wheat is damaged. Estimates based largely on SDS sedimentation and loaf quality criteria are given in Table 4, together with the time expected to give a 90% reduction in the TVC in wheat (see Table 2). It is clearly marginal whether the wheat will be damaged in the storage time required to give a worthwhile reduction in count at any temperature. However, there would appear to be a better chance of success at the highest storage temperature (44°C).

The results from the Hagberg Falling Number determinations are shown separately in Figure 3, where the changes in readings with storage time are plotted for flours from wheats of different moisture content stored at 30, 37 and 44°C. The Falling Number of the flour (initially 200-230) increased with wheat stored at all temperatures, the rate of increase being greater at the higher storage temperatures and moisture contents. These changes in Falling Number are not due to destruction of amylase since tests showed that the *alpha*-amylase activity in flours derived from wheats before and after storage at 44°C for 3 weeks was the same (7 Farrand units). There is no obvious explanation for these findings.

3.2 Effects of storing wheat at temperatures above 44°C.

3.2.1. Comparison of turbidity and protein solubility tests: To assess the turbidity method four separate tests were carried out on the wholemeal from wheat that had been heated at 70°C for 30, 60 and 120 min. The results are shown in Table 5.

There was no consistency between results obtained with meals from wheat that had been given the same heat treatment in different tests or between tests on the same meals on two separate occasions. According to Harrison *et al.*, (1966) a turbidity reading of 37% or below indicates heat damage. On this basis the results in Table 5 indicate that no damage occurred on heating wheat at 70°C for 30 min.

The protein solubility test was calibrated by blending wholemeal that had been derived from wheat that had been completely damaged by heating at 100°C for 2h with wholemeal derived from unheated wheat. Blends containing 0, 25, 50, 75 and 100 % of heat treated wholemeal were tested. The relationship between the proportion of heat damaged flour and absorbance at 595 nm is shown in Figure 4. The results in two separate tests were very similar and there was an excellent correlation (r=0.98) between heat damage and absorbance. According to Every (1987) bread wheats giving absorbance readings corresponding to 15% heat damage may be concluded to have suffered some degree of thermal denaturation of proteins. On this basis significant damage will have occurred if the absorbance reading is 0.73 or less.

The protein solubility test was also used with wheat heated at 70°C for 30, 60 and 120 min. Absorbance readings were well below 0.73 in all cases. Thus, the protein solubility test indicated significant damage after heating wheat at 70°C for 30 min, whereas the turbidity test did not. In view of the greater reproducibility between tests it was decided to use the protein solubility rather than the turbidity test for assessment of heat damage in the subsequent investigations.

3.2.2 Reductions in count v heat damage: A sample of Avalon wheat with a moisture content of 15.1% was used in all tests. This moisture content was chosen as being near the average for the wheats stored below 44°C in the first phase of this study. Samples of wheat in test tubes were placed in a heating block at the required temperatures and withdrawn at selected intervals for TVC, germination ability and protein solubility tests.

The reductions in counts of bacteria in the wheat stored at different temperatures are given in Figure 5(a). As expected, the rate of decline in count increased with increasing storage temperature. The rate of fall in count appeared to decrease after a 100-fold reduction was achieved. This may reflect the destruction of the more heat sensitive organisms during the early stages of storage and the longer survival of the more heat resistant organisms during the later stages. If this is the case, the number of organisms surviving a given time and temperature regime is likely to vary from one wheat to the next depending on the nature of the population present.

Using the data presented in Figure 5(a) the times for the bacteria count to decrease by 10 and 50-fold at the various storage temperatures were estimated and the relationships are shown on a logarithmic scale in Figure 6. At a temperature of 70^{o}C the count in wheat can be expected to be reduced by 50-fold within about 30 min, whereas at 51^{o}C the wheat would have to be stored for about 15h to achieve the same reduction.

The changes in germination rate and absorbance in the protein solubility test with time of storage of the wheat at different storage temperatures are shown in Figures 5(b) and 5(c), respectively. Both germination and absorbance decreased more rapidly as the storage temperature increased, the effect being most pronounced at temperatures of 60^{o}C and above.

The relationships between germination and absorbance, germination and $\log_{10}$ count of bacteria per g, and absorbance and $\log_{10}$ count of bacteria per g are shown in Figure 7. When germination was plotted against log absorbance (Figure 7(a)) a good correlation (r=0.86) was obtained. Thus, the two techniques for assessing the effects of heat treatment on the baking quality of flour produced from the wheat give comparable results. Plotting absorbance against the $\log_{10}$ bacteria per g (Figure 7(b)) also gave a good condition (r=0.87). It can be deduced that heat damage to the wheat protein correlates well with heat damage to the bacteria present. Rather surprisingly, the correlation between germination rate and bacterial count (Figure 7(c)) was relatively poor (r=0.64). The reason for this is not clear in view of the good correlation in Figure 7(a).

4. DISCUSSION

In the first part of the project useful information was collected on the

effects of moisture content and storage temperature on the changes in microbial numbers that might be expected in wheat and the derived flour. The results indicate that at 21°C, a typical summer storage temperature, microbial counts in wheat of moisture content 13-15% will be reduced by 90% in 14-16 weeks, whereas at 30°C the same reduction in count will be achieved in 7-9 weeks (Table 2). Counts in flour were about 100-fold less that in the corresponding wheat. This difference is the same as that found for bacterial counts in wheat and the derived flour taken from commercial mills (Oulsnam, 1981). Even at the highest temperature (44°C) and moisture content (17.8%) used in these tests it took several days to obtain a worthwile reduction in count. It is unlikely that there would be commercial interest in a procedure for obtaining 'low count' flours that involved storing wheat at elevated temperatures for such long periods.

The fact that spore counts in the wheat and flour remained constant during storage was not surprising. Similarly, it was not unexpected that the counts of moulds and yeasts decreased rather more rapidly than total bacteria or enterobacteriaceae since these organisms generally have a lower optimum growth temperature. The somewhat slower fall in count of total bacteria than of enterobactericeae was not anticipated since the latter usually prefer higher growth temperatures. The explanation may lie in the species of enterobacteriaceae present. It is often found that *Enterobacter agglomerans* is the predominant species in wheat and flour. This organism has a growth temperature much lower than other members of the family. Variation in the numbers of these and other microorganisms in different samples of wheat is likely to affect the rate of reduction in count at a given storage temperature. Similarly, differences in the load of heat resistant organisms may affect the level to which the counts will fall. Such factors could account for the difference between the rate of reduction in bacterial count found by Vojnovitch and Pfeifer in storage tests with flour and in the present tests with wheat. Further storage tests with a range of different wheats are clearly desirable if the effects of composition of the microbial flora are to be determined.

The results from tests to assess the baking quality of flours from the stored wheats were not convincing, largely because the wheat selected did not produce good volume bread even without storage under the different conditions, and it was not possible to carry out the milling and baking tests at more frequent intervals. A better indication of heat damage was obtained in the subsequent tests at higher storage

temperatures on the basis of germination rate and the protein solubility test. With the latter, absorbance readings on wheat stored at different temperatures correlated well with bacterial counts (Figure 7(b)), suggesting that there is a close relationship between heat damage to the wheat proteins and the destruction of the bacteria present. Despite this, examination of the data presented in Figure 5 suggests that it may be possible to obtain the desired rapid reduction in count without damaging the wheat by storage at a temperature around 50^{o}C. Further studies are required within the temperature range 46-52^{o}C to determine the optimum conditions, preferably using different wheat samples.

Based on these investigations it seems likely that flours suitable for baking purposes with a much reduced microbial count can be obtained by storage of wheat at temperatures of 48-52^{o}C within a period of 24h. In practice, a procedure whereby the wheat is damped (or taken straight from the field), heated to the desired temperature (or just above) in a screw conveyor, filled into a insulated storage bin and held for the desired time before cooling (if necessary) and milling might prove suitable for the production of 'low count' flours. Work to determine the feasibility of such a procedure may prove worthwhile.

One of the most interesting observations from this study was the increase in Hagberg Falling Number with storage at elevated temperatures which was not accompanied by any change in *alpha*-amylase activity in the wheat. This finding could have important commercial implications. When drying wheat after harvesting it is possible that the farmer could use temperatures and holding times sufficient to cause an increase in Falling Number. Since this measurement is widely used as an index of amylase activity, the purchaser of heat dried wheat might be misled into thinking that a high Falling Number necessarily means a low amylase activity and thereby produce flours that give rise to problems during manufacture of cereal based products. The possibility of such a situation arising warrants further investigation.

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TABLE 1: Plan of tests performed on stored wheat samples

Storage temp. ^{o}C	Time interval between tests	
	Microbial counts	Flour quality assessment
44	initial then weekly	initial then weekly
37	initial then weekly	week 2 then fortnightly
30	initial, week 4 then fortnightly	week 8
21	initial, week 8, then monthly	not tested

TABLE 2: Estimates of time required to reduce counts in wheat by 90%

Storage temperature °C	Moisture content %	Time (weeks) for 90% reduction TVC	Enterobacteria	Moulds/yeasts
44	13.1	1.3	1.0	0.9
	14.8	1.0	0.8	0.6
	16.0	0.8	0.7	0.7
	17.8	0.6	0.6	growth
37	13.1	4.4	3.4	2.8
	14.8	3.6	2.8	2.1
	16.0	2.7	2.0	1.5
	17.8	2.0	1.4	growth
30	13.1	9.5	8.7	7.0
	14.8	7.5	7.0	5.9
	16.0	6.2	5.6	4.8
	17.8	4.7	3.8	growth
21	13.1	15.5	16.0	13.5
	14.8	13.5	14.0	11.5
	16.0	12.5	13.0	10.5
	17.8	10.5	7.0	growth

TABLE 3: Changes in the baking quality of flours from wheat stored at different elevated temperatures using various methods of assessment

Wheat moisture content %	Wheat storage temp. °C	Wheat storage time (weeks)	SDS sedimentation volume (ml)	Wet gluten	Falling Number	Loaf volume (ml)	Crumb structure
17.8	44	0	80	30	200	1395	
		1	76[x]	*	257	1500	+
		2	70[x]	*	297	1325	++
	37	2	81	28.7	236	1415	+
16.0	44	0	80	30.2	187	1370	
		1	80	27.4	240	1425	
		2	80	*	266	1460	
		3	73[x]	26.2	287	1376	++
	37	2	80	30.0	229	1368	
		4	80	29.4	255	1365	+
	30	8	77[x]	28.3	217	1360	++
14.8	44	0	82	30.5	231	1360	
		1	81	30.4	257	1425	
		2	80	29.8	293	1430	
		3	78[x]	30.2	283	1350[x]	+
		4	74[x]	29.8	292	1295[x]	++
	37	2	81	30.5	254	1350	
		4	80	30.3	257	1345	+
		6	77[x]	30.1	270	1360	++
	30	8	76[x]	30.6	254	1325	++
13.1	44	0	81	30.6	227	1350	
		1	81	31.0	254	1375	
		2	80	30.1	263	1380	
		3	80	31.8	283	1326	+
		4	75[x]	29.9	289	1260[x]	++
	37	2	81	30.6	247	1313	
		4	81	30.1	245	1345	
		6	80	30.4	254	1135[x]	+
	30	8	76[x]	30.3	234	1320	++

* impossible to extract coherent gluten
x significant reduction from flour at start of storage
\+ open, rounded crumb structure with harsh and weak texture
++ very open, irregular crumb structure, with very harsh and weak texture, often with an off-odour

TABLE 4: Best estimates of time to damage and time to obtain a worthwhile reduction in microbial count in wheat of different moisture contents stored at elevated temperatures

Wheat moisture content %	Wheat storage temperature ^{o}C	Storage time (weeks) to cause loss in quality of flour	Storage time (weeks) to obtain a 90% reduction in TVC
17.8	44	<1	0.6
	37	<2	2.0
	30	<8	4.2
16.0	44	1-2	0.8
	37	2-4	2.7
	30	<8	6.2
14.8	44	2-3	1.0
	37	3-4	3.6
	30	<8	7.5
13.1	44	2-3	1.3
	37	4-6	4.4
	30	<8	9.5

TABLE 5: Turbidity readings for wholemeal from heated wheat in four separate tests

Heat treatment	% Turbidity Test 1	Test 2	Test 3	Test 4
70°C/30min*	49	63	64	41
70°C/30min*	52	76	74	-
70°C/60min	41	55	32	28
70°C/120min	28	19	23	28

*repeat tests on the same sample of wholemeal on consecutive days.

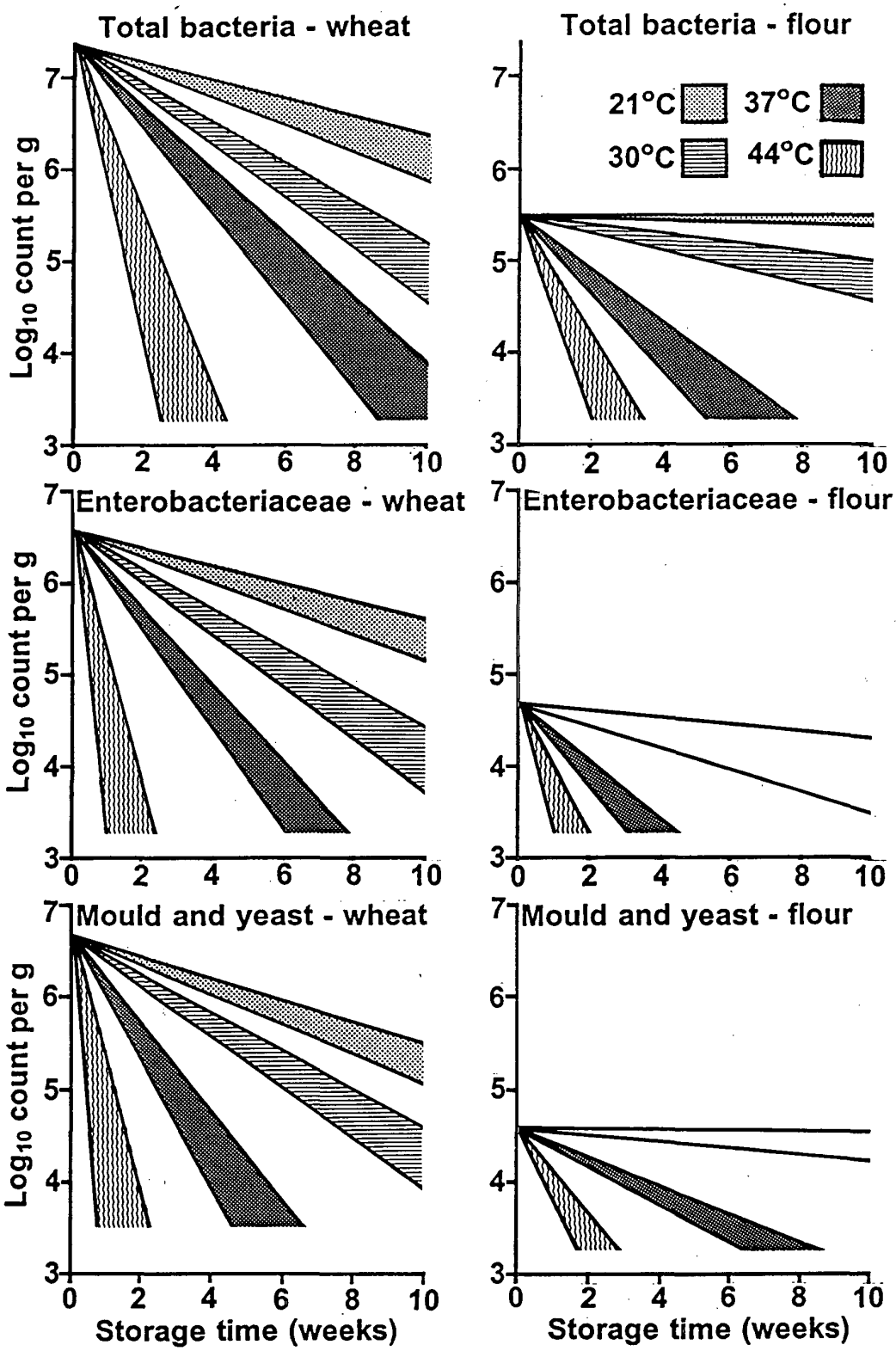

Figure 1: Reduction in counts of total bacteria, enterobacteriaceæ and moulds/yeasts in wheat and the derived flour during storage at elevated temperatures. Each sector contains the line of wheat or flour therefrom at the four moisture levels. Top line represents low moisture (13.1%) and the bottom line high moisture (17.8) in each case

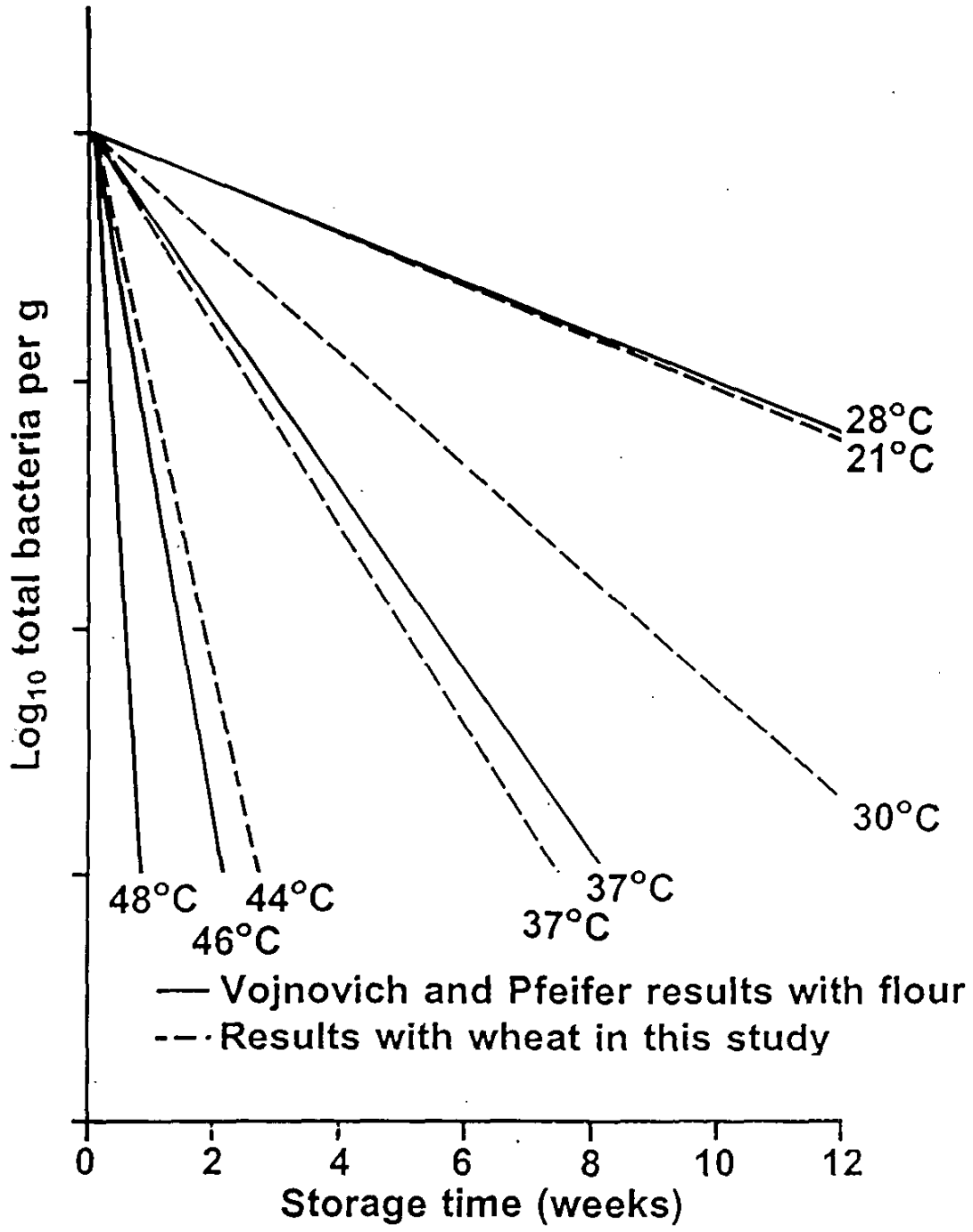

Figure 2: Comparisons of reductions in count of total bacteria in wheat and flour at various storage temperatures in two investigations.

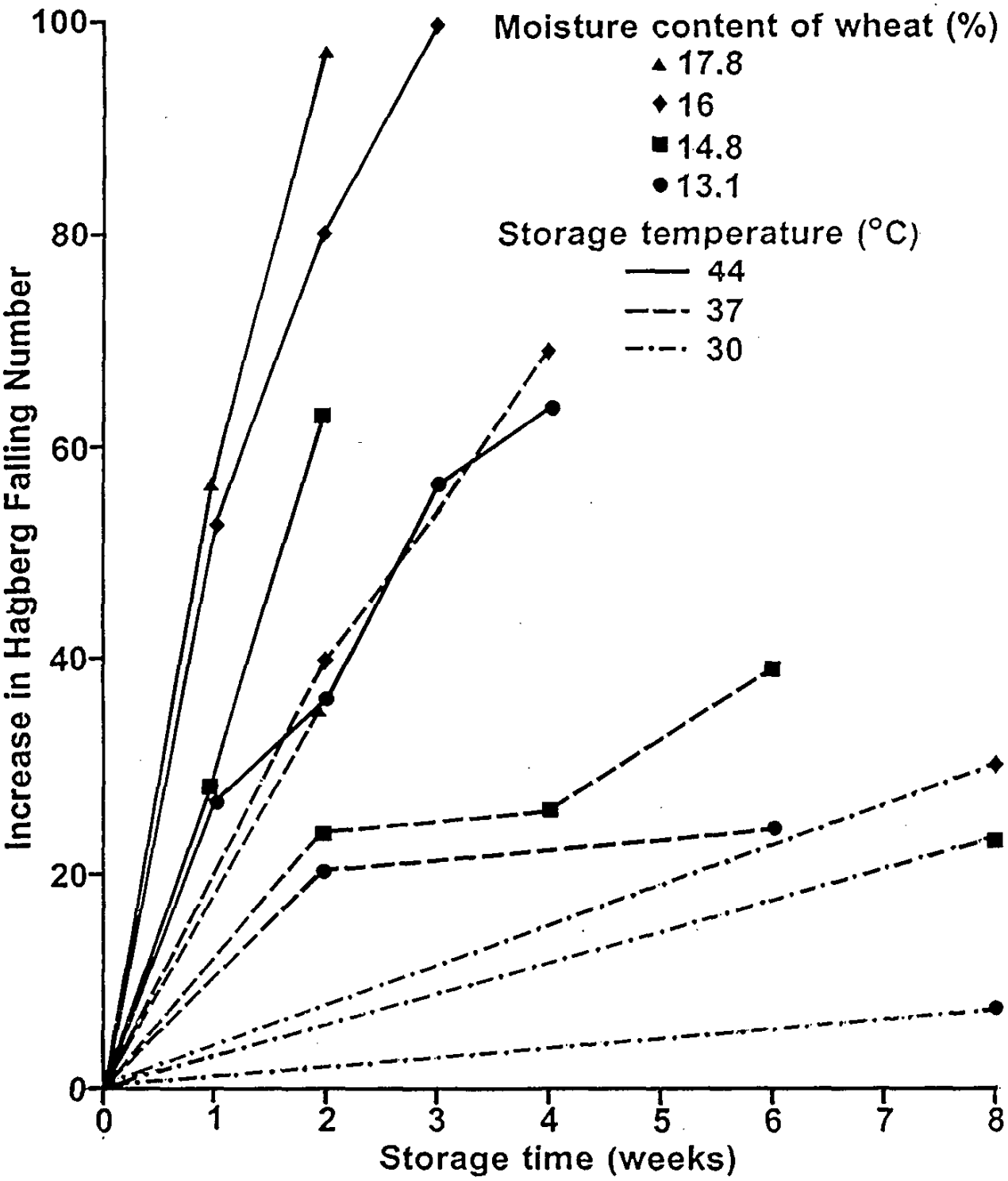

Figure 3: Changes in the Falling Number of flour from wheat of different moisture content during storage at elevated temperatures.

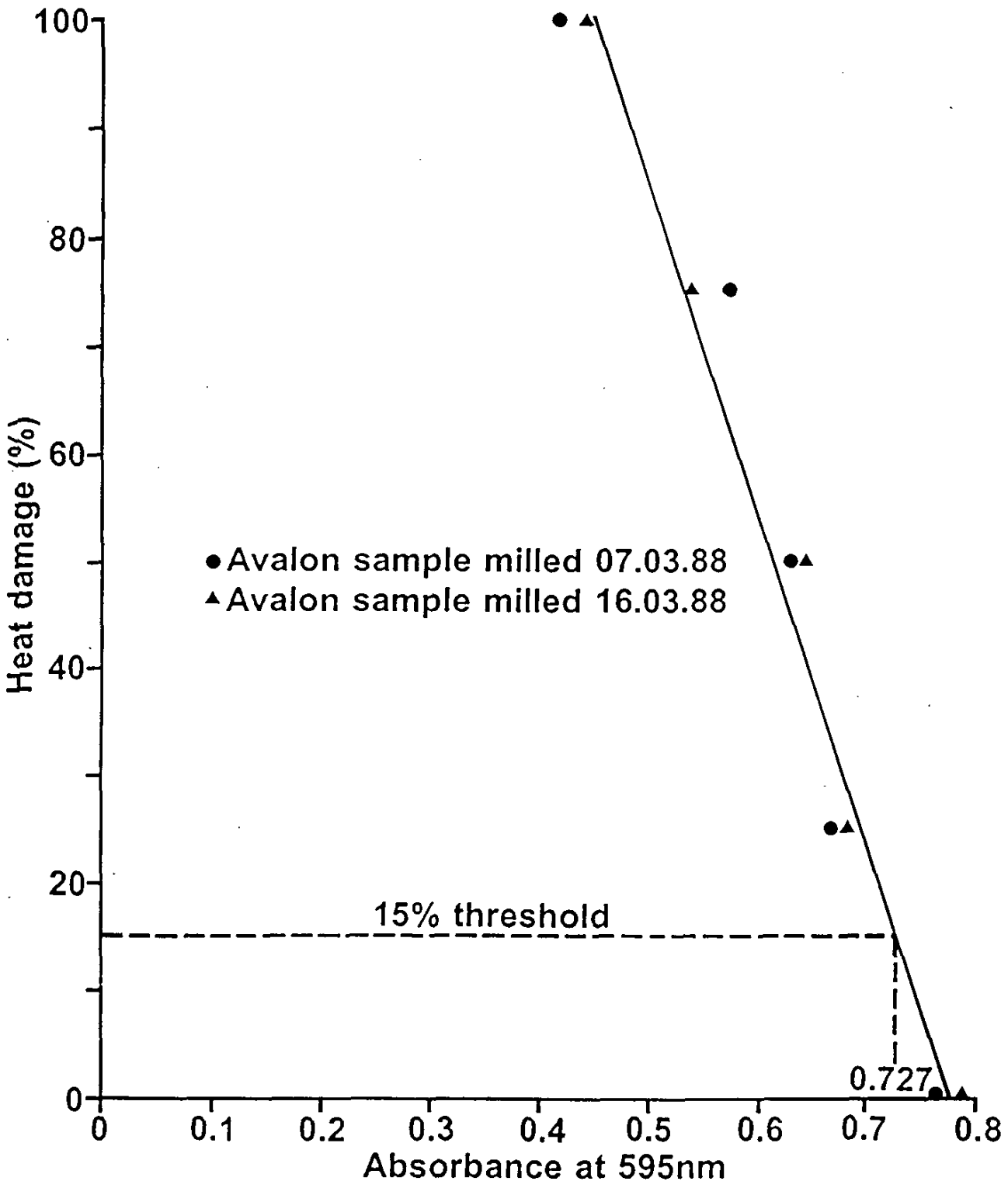

Figure 4: Calibration graph for the protein solubility test using different proportions of heat damaged wholemeal.

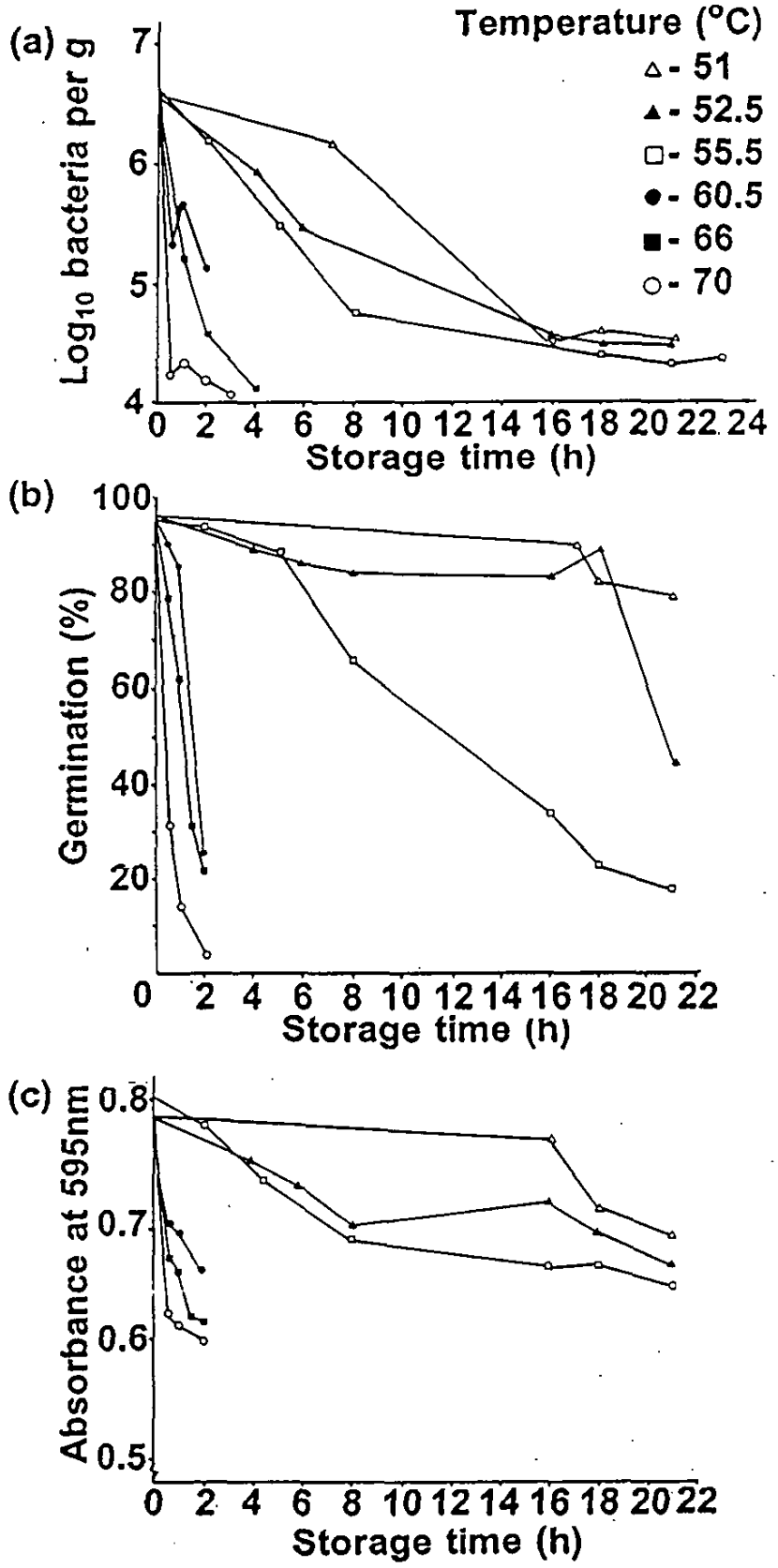

Figure 5: Changes in (a) bacterial count (b) germination rate and (c) absorbance in the protein solubility test during storage of wheat at different temperatures

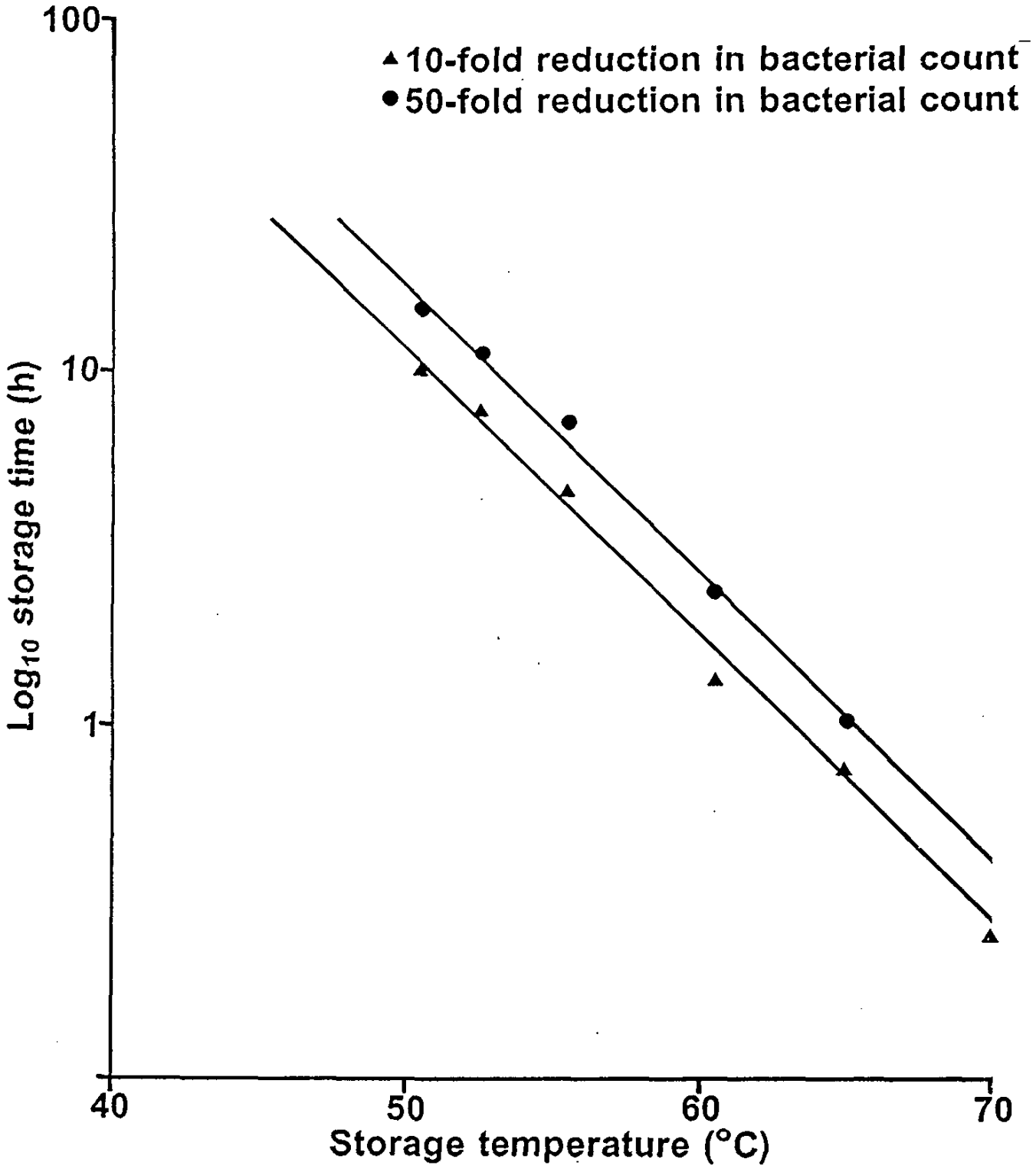

Figure 6: Storage times at different elevated temperatures estimated to give a 10 and 50-fold reduction in counts of bacteria in wheat

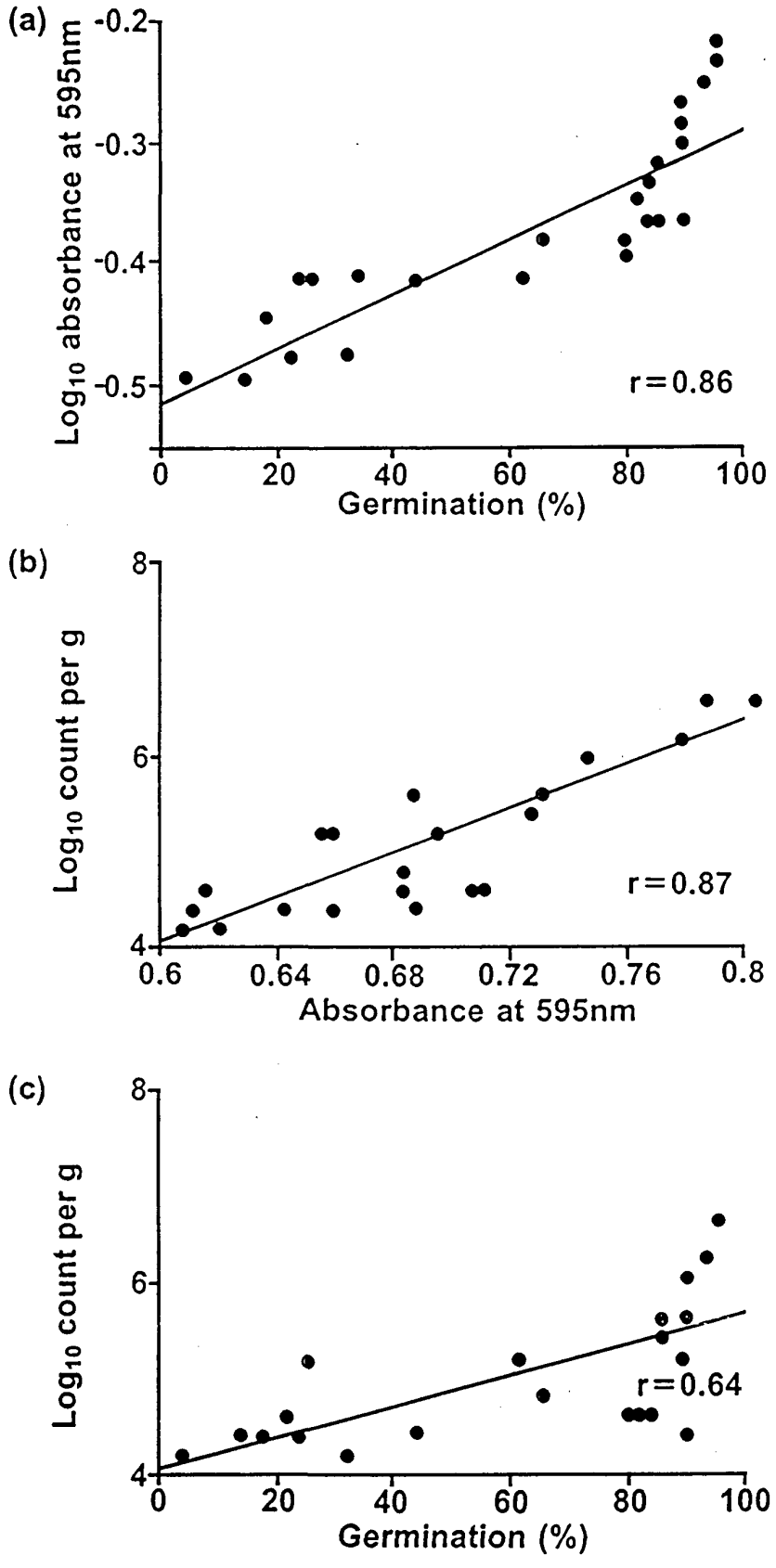

Figure 7: Relationships between (a) germination and absorbance (b) absorbance and bacterial count and (c) germination and bacterial count