



**PROJECT REPORT No. 102**

**CHEMICAL COMPOSITION OF  
WHEAT GRAIN:**

**I. SURVEY RESULTS;**

**II. EFFECTS OF COPPER  
AMENDMENT ON BREAD  
QUALITY**

**FEBRUARY 1995**

**PRICE £5.00**

**CHEMICAL COMPOSITION OF WHEAT GRAIN: I. SURVEY RESULTS;  
II. EFFECTS OF COPPER AMENDMENT ON BREAD QUALITY**

by

S. P. McGRATH AND A. M. CHAUDRI

IACR Rothamsted Experimental Station, Harpenden, Herts. AL5 2JQ

D. THACKER, S. E. SALMON,

K. LITTLE, S. DOUGLAS AND S. P. CAUVAIN

Flour Milling and Baking Research Association,

Chorleywood, Herts. WD3 5SH

This is the final report of a one year project which commenced in January 1993. The work was funded by a grant of £78,825 from the Home-Grown Cereals Authority (Project No. 0049/1/92).

The Home-Grown Cereals Authority (HGCA) has provided funding for this project but has not conducted the research or written this report. While the authors have worked on the best information available to them, neither HGCA nor the authors shall in any event be liable for any loss, damage or injury howsoever suffered directly or indirectly in relation to the report or the research on which it is based.

Reference herein to trade names and proprietary products without stating that they are protected does not imply that they may be regarded as unprotected and thus free for general use. No endorsement of named products is intended nor is any criticism implied of other alternative, but unnamed products.



## CONTENTS

	Page
ABBREVIATIONS	3
SUMMARY	4
OBJECTIVES	5
BACKGROUND	5
 <b>SECTION I:</b>	
CONCENTRATIONS OF COPPER AND OTHER ELEMENTS IN UK WHEAT	6
MATERIALS AND METHODS	6
RESULTS AND DISCUSSION	7
<i>Concentration of elements in grain</i>	7
<i>Correlations between elements</i>	8
<i>Varietal effects</i>	8
<i>Changes with time</i>	10
CONCLUSIONS OF SECTION I	11
 <b>SECTION II:</b>	
THE EFFECTS OF COPPER ON THE PERFORMANCE OF WHOLEMEAL AND WHITE FLOURS IN THE CHORLEYWOOD BREAD PROCESS	13
MATERIALS AND METHODS	13
Milling and flour analysis	13
Experimental details	13
Loaf quality assessment	13

RESULTS AND DISCUSSION	14
Wholemeal loaves	14
White loaves	18
General comments	19
CONCLUSIONS OF SECTION II	20
REFERENCES	21
APPENDIX 1.    Milling procedure.	22
APPENDIX 2.    Milling section test report.	23
APPENDIX 3.    Results of flour analysis.	24
APPENDIX 4.    Copper content of the flours used.	25
APPENDIX 5.    Results of the electrophoresis.	26
APPENDIX 6.    Test baking procedure No. 1AA.	27
APPENDIX 7.    Test baking procedure No. 7AA.	28
APPENDIX 8.    Subjective dough assessment.	29

**Note:**

Photographs were taken of the crumb surfaces of loaves produced using a range of varieties and with grain of different copper contents. Persons interested in the photographs may borrow a set of them from Professor S. P. McGrath, IACR Rothamsted Experimental Station, Harpenden, Hertfordshire, AL5 2JQ. (Tel: 0582 763133).

## ABBREVIATIONS

P	Phosphorus
K	Potassium
Ca	Calcium
Mg	Magnesium
Fe	Iron
Zn	Zinc
Cu	Copper
Mn	Manganese
ppm	parts per million (= $\mu\text{g g}^{-1}$ or $\text{mg kg}^{-1}$ )
$\mu\text{g g}^{-1}$	micrograms per gram
$\text{mg kg}^{-1}$	milligrams per kilogram
$\text{mg g}^{-1}$	milligrams per gram
$\text{t ha}^{-1}$	tonnes per hectare
CV	coefficient of variation
FMBRA	Flour Milling and Baking Research Association
CBP	Chorleywood Bread Process



## SUMMARY

1. Four hundred samples of wheat grain were collected by the Regional Cereals Officers of the Home-Grown Cereals Authority in 1992 from the major cereal growing areas in Britain. The samples were analysed in various ways as part of the annual Cereals Quality Survey. In this project, the concentrations of P, K, Ca, Mg, Fe, Zn, Cu and Mn in wholemeal flour sub-samples prepared from the grain, were measured.
2. The minimum and maximum concentrations were 0.44-4.55 mg P g<sup>-1</sup>; 2.27-6.70 mg K g<sup>-1</sup>; 0.41-1.44 mg Mg g<sup>-1</sup>; 0.17-0.90 mg Ca g<sup>-1</sup>; 1.49-7.34 µg Cu g<sup>-1</sup>; 7.48-52.38 µg Zn g<sup>-1</sup>; 9.93-40.88 µg Mn g<sup>-1</sup> and 12.07-73.62 µg Fe g<sup>-1</sup>. Mean concentrations of the elements in the grain decreased in the order K > P > Mg > Ca >> Fe > Zn = Mn > Cu.
3. There was a significant positive correlation between grain K and P ( $r = 0.56$ ) and between grain Mg and P ( $r = 0.68$ ). Similarly, a significant positive correlation existed between grain Zn and Mg ( $r = 0.54$ ).
4. Analysis of variance of the concentration data showed highly significant ( $P < 0.001$ ) varietal differences. The breadmaking varieties generally contained slightly larger concentrations of all elements, except K.
5. Six varieties were used, each from two sites, to assess the effect of Cu on the performance of wholemeal and white flours in the Chorleywood Bread Process (CBP). Wholemeal and white loaves were assessed for differences in loaf volume, crumb colour and structure, and softness with varying concentrations of total Cu added to the dough. The varieties used were Genesis, Spark, Hereward, Riband, Fresco and Mercia.
6. The results of the breadmaking assessment showed only slight effects of adding Cu on loaf quality. Reasons for this may be linked to site to site variations or other agronomic effects masking the effects of Cu, such as interaction with other elements. However,



the most likely and important reason may be the masking effect of the ascorbic acid which is added during the breadmaking process. Ascorbic acid is a powerful oxidising agent that may swamp the effects that Cu may have on breadmaking quality. It seems that the effects on bread quality due to variations in Cu content in the flour may be small in the UK, given the nature of the breadmaking process employed.

### **OBJECTIVES**

1. To determine the concentration of copper and other minerals in UK wheat (Section I below).
2. To establish the effects of copper on the performance of wholemeal and white flours in the Chorleywood Bread Process (Section II).

### **BACKGROUND**

With the ban on adding potassium bromate as an oxidant to flour, breadmakers have experienced much variability in the performance of flours and increasing incidences of machine handling problems in production. There is also a question mark over the use of azodicarbonamide in the UK (it is not permitted elsewhere in Europe), so the industry is now restricted to ascorbic acid as the sole oxidative improver.

Wheat grown on a copper deficient site in Australia gave flour with reduced quality dough and poor baking performance (Flynn *et al.*, 1987). These workers showed that by applying copper during wheat growth both yield and baking quality could be improved. Work carried out by FMBRA in which copper was added to flour resulted in improved dough handling ability. Also, copper added with a low level of ascorbic acid improved baking quality through enhanced oxidation. Since copper and other minor minerals may improve

baking quality and dough handling ability, it is important to establish whether the increased variability in these properties is due to the variability of copper and other minor minerals in the wheat grain.

## **I. CONCENTRATIONS OF COPPER AND OTHER ELEMENTS IN UK WHEAT**

### **MATERIALS AND METHODS**

Four hundred samples of wheat grain were collected by the HGCA in 1992 from the major cereal growing areas in Britain. The samples were milled by the Flour Milling and Baking Research Association (FMBRA) at Chorleywood. At Rothamsted, wholemeal flour sub-samples were dried at 80 °C for 12 h, before digesting with a mixture of perchloric-nitric acids (13%:87% v/v) in a Carbolite heating block. Ramp rates, dwell temperatures and dwell duration of digestion were controlled through an Eurotherm 818 Controller/Programmer following the procedures of Zhao *et al.* (1994). The concentrations of P, K, Ca, Mg, Fe, Zn, Cu, and Mn in the digests were determined on an ARL 34000 inductively-coupled plasma spectrometer.

The reliability of the analytical procedure was tested using NIST (National Institute of Standards and Technology) standard wheat flour samples (Anon., 1988). Variability of the measurements of each element was determined by analysis of nine replicate digests of the standard wheat flour sample. The agreement with the certified values was good (Table 1).

### **Data analyses**

The distributions of the concentration data were checked for normality using Genstat (Anon., 1987). Varietal differences were examined using analysis of variance.

**Table 1.** Means and coefficients of variation of elemental concentrations found in nine replicate digests of the Certified Wheat Flour Standard NBS 1567a (dry matter basis). Certified elemental concentrations are also included for comparison.

	mg g <sup>-1</sup>				µg g <sup>-1</sup>			
	P	K	Ca	Mg	Cu	Zn	Mn	Fe
Mean	1.36	1.36	0.19	0.39	1.95	11.08	8.96	14.31
CV (%)	1.68	2.39	2.65	1.84	8.21	3.62	1.77	9.38
Certified*	1.34	1.33	0.19	0.40	2.10	11.60	9.40	14.10
	±0.06	±0.03	±0.004	±0.02	±0.2	±0.40	±0.9	±0.5

\* ± 95% confidence limits

## RESULTS AND DISCUSSION

### *Concentration of elements in grain*

The mean, median and concentration ranges of P, K, Ca, Mg, Cu, Zn, Mn and Fe are represented in Fig. 1. In each case schematic plots (Tukey, 1977) are used to represent the distribution of the elements in the grain. The box represents the 25-75 percentile range, and the solid and dotted lines within it are the median and mean values respectively. The ends of the bars represent the 10-90 percentile range.

The concentrations of all the elements were found to be normally distributed. Eighty percent of the data were found to lie in a narrow range for P, K, Zn, Mn and Fe, and in even a smaller range for Ca, Mg and Cu (Fig. 1a and b). The minimum and maximum concentrations differed by factors of ten for P (0.44-4.55 mg g<sup>-1</sup>); three for K (2.27-6.70 mg g<sup>-1</sup>) and Mg (0.41-1.44 mg g<sup>-1</sup>); five for Ca (0.17-0.90 mg g<sup>-1</sup>) and Cu (1.49-7.34 µg g<sup>-1</sup>);

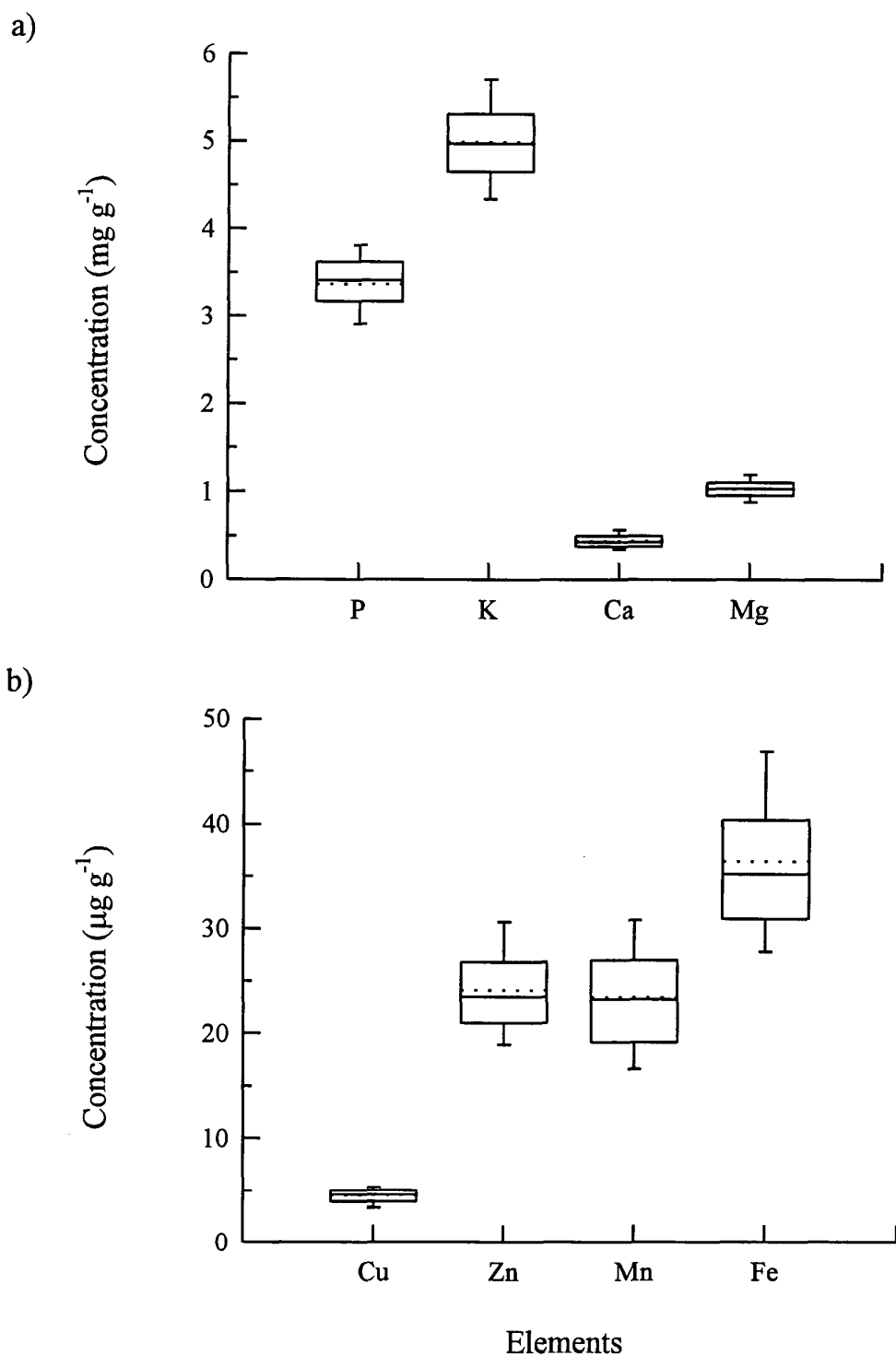
seven for Zn (7.48-52.38  $\mu\text{g g}^{-1}$ ); four for Mn (9.93-40.88  $\mu\text{g g}^{-1}$ ) and six for Fe (12.07-73.62  $\mu\text{g g}^{-1}$ ). The largest elemental concentrations in the whole wheat grain were those of K and P and the smallest was Cu. The mean elemental concentrations decreased in the order  $\text{K} > \text{P} > \text{Mg} > \text{Ca} \gg \text{Fe} > \text{Zn} = \text{Mn} > \text{Cu}$  (Fig. 1a and b).

#### *Correlations between elements*

There was a significant positive correlation between grain K and P ( $r = 0.56$ ), indicating a degree of constancy in the deposition of K and P in the grain (Table 2). A significant positive correlation was also found between grain Mg and P ( $r = 0.68$ ). Similarly, a significant positive correlation existed between grain Zn and Mg ( $r = 0.54$ ). Most elemental concentrations showed positive correlations.

#### *Varietal effects*

The analysis of variance of the concentration data showed highly significant ( $P < 0.001$ ) varietal differences (Table 3). The breadmaking varieties generally contained slightly larger concentrations of all elements than the other varieties, except K. The differences between individual varieties, although statistically significant because they are based on a large number of degrees of freedom, are not large enough to be agriculturally important (McGrath, 1985). These differences may arise as a result of variation in the elemental content of cereals due to both genetic and environmental factors. For example, small kernels caused by environmental stress or genetic factors may contain larger concentrations of elements than larger kernels. Varietal differences in mineral content may be best investigated in future by analysis of different varieties grown in the same locations. By doing this, any differences due to variety could be distinguished from the effects of soil and climate.



**Fig 1.** Concentrations of a) major and b) trace elements in the dry matter of wholemeal flour. Boxes indicate the range between the 25th and 75th percentiles; the horizontal solid and dotted lines mark the median and means respectively. The ends of the bars indicate the 10th and 90th percentiles.

**Table 2.** Correlation coefficients between the elements

	P	K	Ca	Mg	Cu	Zn	Mn	Fe
P	1.00	0.56	0.42	0.68	0.19	0.39	0.20	0.36
K	---	1.00	0.12	0.36	0.16	0.21	0.09	0.15
Ca	---	---	1.00	0.37	0.25	0.37	0.27	0.27
Mg	---	---	---	1.00	0.22	0.54	0.12	0.39
Cu	---	---	---	---	1.00	0.35	-0.09	0.21
Zn	---	---	---	---	---	1.00	0.28	0.47
Mn	---	---	---	---	---	---	1.00	0.15
Fe	---	---	---	---	---	---	---	1.00

*Changes with time*

The mean grain P and Cu concentrations in the 1992 survey were smaller than those in a survey carried out in 1982 by McGrath (1985). Similarly, there were slight decreases in the mean concentrations of grain Zn and Fe in 1992 compared to 1982. However, there were no differences in the mean concentrations of K, Ca, Mg and Mn in grain between the 1992 and 1982 surveys. It is possible that these reductions in the grain P, Cu, Zn and Fe concentrations in the 1992 survey may be due to increased yields resulting in growth dilution. For example, grain yields increased from about 6 t ha<sup>-1</sup> in 1983 (Spencer, 1983) to 7.25 t ha<sup>-1</sup> in 1991 (Anon., 1993). This idea would not explain why the concentrations of K, Cu, Mg and Mn

did not change.

### CONCLUSIONS OF SECTION I

1. The concentration ranges differed by factors of ten for P (0.44-4.55 mg g<sup>-1</sup>); three for K (2.27-6.70 mg g<sup>-1</sup>) and Mg (0.41-1.44 mg g<sup>-1</sup>); five for Ca (0.17-0.90 mg g<sup>-1</sup>) and Cu (1.49-7.34 µg g<sup>-1</sup>); seven for Zn (7.48-52.38 µg g<sup>-1</sup>); four for Mn (9.93-40.88 µg g<sup>-1</sup>) and six for Fe (12.07-73.62 µg g<sup>-1</sup>).
2. The largest concentrations in the wheat grain were those of K and P and the smallest was Cu. Mean grain concentrations decreased in the order K > P > Mg > Ca >> Fe > Zn = Mn > Cu.
3. There was a significant positive correlation between grain K and P ( $r = 0.56$ ) and between grain Mg and P ( $r = 0.68$ ). Similarly, a significant positive correlation existed between grain Zn and Mg ( $r = 0.54$ ).
4. Varietal differences were highly significant ( $P < 0.001$ ). The breadmaking varieties generally contained slightly larger concentrations of all elements, except K.
5. The mean grain P and Cu concentrations in 1992 were smaller than those in 1982. Similarly, there were slight decreases in the mean grain Zn and Fe concentrations in 1992 compared to 1982. There were no differences in the mean grain K, Ca, Mg and Mn concentrations between 1992 and 1982.

**Table 3.** Mean concentrations of elements in winter wheat grain dry matter. (Varieties with less than three samples were omitted).

Variety	n <sup>a</sup>	mg g <sup>-1</sup>				µg g <sup>-1</sup>			
		P	K	Ca	Mg	Cu	Zn	Mn	Fe
<u>Breadmaking varieties</u>									
Mercia	57	3.67	4.90	0.53	1.12	4.40	26	26	39
Hereward	33	3.29	4.85	0.44	1.01	4.03	24	23	39
Soissons	5	3.32	4.26	0.47	1.11	4.47	22	29	35
Tonic	4	3.90	5.10	0.51	1.27	4.13	31	32	37
Estica	3	3.52	4.92	0.41	1.20	3.36	20	23	30
Urban	3	3.78	4.96	0.43	1.19	4.04	29	29	47
Avalon	3	3.03	4.57	0.46	0.83	4.60	24	28	34
Mean		3.53	4.86	0.49	1.09	4.24	25	26	38
<u>Other varieties</u>									
Riband	108	3.23	4.81	0.44	0.96	4.22	21	21	32
Beaver	52	3.30	5.36	0.44	1.05	3.98	23	24	35
Haven	40	3.29	5.41	0.40	1.03	4.04	23	22	34
Apollo	25	3.43	4.92	0.41	1.06	4.04	24	22	41
Slejpner	17	3.48	5.19	0.41	0.99	4.73	24	22	41
Galahad	7	3.35	5.32	0.47	1.00	3.76	22	26	36
Hornet	3	3.35	4.99	0.44	1.03	2.93	20	24	32
Mean		3.30	5.07	0.43	1.00	4.13	21	22	35
F ratio <sup>b</sup>		2.57	3.51	3.86	5.37	2.39	4.57	2.97	2.87
Signif. <sup>c</sup>		***	***	***	***	***	***	***	***

<sup>a</sup>n = number of samples

<sup>b</sup>F ratio = variance ratio

<sup>c</sup> \*\*\* =  $P < 0.001$



## **II. THE EFFECTS OF COPPER ON THE PERFORMANCE OF WHOLEMEAL AND WHITE FLOURS IN THE CHORLEYWOOD BREAD PROCESS**

### **MATERIALS AND METHODS**

Six wheat varieties were chosen using two samples of each from different sites. A list of samples and their suppliers are given in Appendix 5.

#### **Milling and flour analysis**

Wheat samples were milled in the laboratory using a Buhler mill (see Appendices 1 and 2 for details) and analyzed for variety by electrophoresis, protein content, water absorption and falling number at Chorleywood, FMBRA. The copper contents of the white and wholemeal flours were determined at Rothamsted and the results are given in Appendix 3.

#### **Experimental details**

Doughs were produced from 1400 g of flour using FMBRA standard test baking procedures. In the tests, the flour had either no copper added ('as is') or was amended with copper sulphate powder to give 3, 6, or 9  $\mu\text{g Cu g}^{-1}$  flour, depending on the experiment. Details of the procedures used are given in appendix 6 and 7.

#### **Loaf quality assessment**

Loaves were stored overnight at 21 °C and assessment was carried out the next day. Loaf volume was measured by seed displacement, and crumb colour by Hunterlab Tristimulus Colorimeter using the Y value as a measure of whiteness. Crumb structure was assessed by expert examination of the cell size, uniformity and wall thickness scored up to

a maximum of 10 points.

Tables 1 and 2 give averages of replicates for mixing time, dough temperature, proving times, loaf volume, crumb score and colour for wholemeal and white flour respectively. The higher the Hunterlab Y-value the whiter the crumb. Subjective dough assessment results are given in Appendix 8. NOTE: In the Tables, 'ppm' denotes parts per million or  $\mu\text{g g}^{-1}$  (or  $\text{mg kg}^{-1}$ ).

## RESULTS AND DISCUSSION

### Wholemeal loaves

**Genesis** Site 2 produced a more uniform crumb structure than site 1. There was more side compression in the loaves with no added Cu than in the loaves with  $9 \mu\text{g}$  total Cu  $\text{g}^{-1}$  flour. Subjective assessment was carried out for crumb softness and the  $9 \mu\text{g g}^{-1}$  loaves were found to have softer crumbs. Small improvements at  $9 \mu\text{g}$  total Cu  $\text{g}^{-1}$  were noticed, but these were very slight.

**Spark** Crumb softness and structure results were as for Genesis. The loaves produced from site 1 were less dense than those from site 2.

**Hereward** Crumb softness and structure results were as for Genesis. The loaves from site 1 were all firmer than those from site 2.

**Riband** All loaves were of very poor quality. There were softness differences between sites, but not between Cu concentrations. All loaves from sites 1 and 2 suffered moulder damage. There was more loaf variation between sites than

Table 1. Averages of replicates for mixing time, dough temperature, proving times, loaf volume, crumb score and colour for wholemeal flour.

Wholemeal							
Variety	Cu level	Mix Time (m.s)	Dough Temp (°C)	Proof Time (min)	Loaf Volume (ml)	Crumb Score (max 10)	Crumb Colour Y-value
Genesis (site 1)	as is	3.13	30.6	39	1328	5.5	26.47
	9ppm	3.10	30.7	38	1354	6.0	26.55
Genesis (site 2)	as is	3.18	30.0	40	1296	5.5	24.45
	9ppm	3.13	30.1	40	1309	6.0	25.34
Spark (site 1)	as is	3.10	30.8	38	1396	7.5	28.21
	9ppm	3.26	30.8	38	1326	6.0	28.80
Spark (site 2)	as is	3.00	30.3	40	1268	5.0	25.52
	9ppm	3.02	30.4	40	1297	5.0	25.35
Hereward (site 1)	as is	3.04	30.7	40	1331	5.5	25.35
	9ppm	2.59	30.5	36	1367	6.0	26.15
Hereward (site 2)	as is	3.05	30.3	38	1431	7.0	26.74
	9ppm	3.05	30.0	40	1425	7.0	26.63
Riband (site 1)	as is	2.40	29.9	40	1206	3.0	25.84
	9ppm	2.35	30.8	40	1195	3.0	24.63
Riband (site 2)	as is	2.50	30.5	42	1194	3.0	24.57
	9ppm	2.56	30.1	41	1195	3.0	23.90
Fresco (site 1)	as is	3.18	30.7	39	1402	7.0	28.37
	9ppm	3.13	30.8	37	1442	8.0	28.37
Fresco (site 2)	as is	3.11	30.3	38	1422	6.0	28.12
	9ppm	3.10	30.3	37	1428	7.0	28.76
Mercia (site 1)	as is	3.07	30.1	38	1293	5.0	27.94
	9ppm	3.07	30.6	41	1298	5.0	27.89
Mercia (site 2)	as is	3.25	30.0	41	1359	5.5	30.65
	9ppm	3.23	30.0	45	1325	5.5	30.29

Table 2. Averages of replicates for mixing time, dough temperature, proving times, loaf volume, crumb score and colour for white flour.

White							
Variety	Cu level	Mix Time (m.s)	Dough Temp (°C)	Proof Time (min)	Loaf Volume (ml)	Crumb Score (max 10)	Crumb Colour Y-value
Genesis (site 1)	as is	3.07	30.0	40	1523	6.0	53.57
	3ppm	3.18	30.6	41	1533	6.0	54.10
	6ppm	3.07	30.4	39	1563	6.0	54.37
	9ppm	3.11	30.3	40	1582	6.5	54.09
Genesis (site 2)	as is	3.08	30.5	38	1502	5.5	53.12
	3ppm	3.05	30.0	40	1509	6.0	52.84
	6ppm	3.08	30.6	41	1523	6.5	52.67
	9ppm	3.06	30.3	39	1557	6.0	52.72
Spark (site 1)	as is	3.00	30.5	40	1594	7.0	57.36
	3ppm	3.00	30.1	37	1601	7.5	57.46
	6ppm	3.09	30.2	39	1621	7.0	57.26
	9ppm	3.08	30.4	38	1626	7.5	57.43
Spark (site 2)	as is	2.51	30.2	40	1447	5.0	52.38
	3ppm	2.54	30.8	39	1442	5.0	52.19
	6ppm	2.53	30.3	41	1506	6.0	52.85
	9ppm	2.51	30.6	39	1481	6.5	53.49
Hereward (site 1)	as is	2.41	30.0	43	1555	6.5	54.88
	3ppm	2.39	30.2	39	1492	6.5	55.01
	6ppm	2.34	30.1	40	1587	7.0	55.86
	9ppm	2.42	30.0	45	1609	8.0	55.91
Hereward (site 2)	as is	2.45	30.0	38	1586	7.5	56.06
	3ppm	2.49	29.9	40	1637	7.0	56.43
	6ppm	2.47	30.0	40	1641	7.5	56.74
	9ppm	2.50	30.4	36	1606	7.0	56.79
Riband (site 1)	as is	2.16	30.1	40	1297	4.0	48.43
	3ppm	2.19	29.9	39	1307	4.0	48.30
	6ppm	2.20	30.2	43	1317	4.0	48.95
	9ppm	2.21	30.1	41	1306	4.5	49.32
Riband (site 2)	as is	2.14	30.0	41	1281	4.0	49.29
	3ppm	2.20	31.0	38	1277	4.0	49.46
	6ppm	2.13	30.0	40	1302	4.5	49.47
	9ppm	2.17	30.4	42	1303	4.0	49.98

Table 2. continued

White							
Variety	Cu level	Mix Time (m.s)	Dough Temp (°C)	Proof Time (min)	Loaf Volume (ml)	Crumb Score (max 10)	Crumb Colour Y-value
Fresco (site 1)	as is	3.01	30.5	44	1619	7.0	56.41
	3ppm	3.00	30.2	42	1627	7.5	58.00
	6ppm	3.06	30.4	39	1616	7.5	57.59
	9ppm	3.04	30.1	41	1646	8.5	58.26
Fresco (site 2)	as is	2.59	30.0	42	1599	6.5	57.70
	3ppm	3.03	30.5	42	1584	7.0	57.18
	6ppm	3.01	30.1	40	1651	7.5	57.56
	9ppm	3.03	30.2	40	1640	6.0	57.50
Mercia (site 1)	as is	2.46	30.2	38	1413	5.0	53.41
	3ppm	2.39	30.4	41	1481	5.5	54.71
	6ppm	2.43	30.3	39	1466	6.0	55.41
	9ppm	2.42	30.2	39	1474	6.0	55.90
Mercia (site 2)	as is	3.10	30.5	37	1471	6.0	58.01
	3ppm	3.02	30.2	39	1540	7.0	58.82
	6ppm	2.56	30.1	39	1545	7.5	59.68
	9ppm	3.06	30.0	39	1637	7.0	59.67

between Cu concentrations.

**Fresco** Site 2 produced softer loaves than site 1 and the loaves were softer at 9 µg total Cu g<sup>-1</sup> flour from both sites. The results for crumb structure are the same as indicated for Genesis.

**Mercia** There was more site to site variation than there was between Cu concentrations. Site 2 produced loaves that were softer than site 1. The results for crumb structure are the same as indicated for Genesis.

## **White Loaves**

**Genesis** The loaves with no Cu addition from site 1 were better than those from site 2, but the improvements from site 1 were less noticeable with increasing Cu concentration. There was an improvement in crumb structure between loaves made with no added Cu and those made with 9  $\mu\text{g}$  total Cu  $\text{g}^{-1}$  flour. However, no improvement could be seen between the 0, 3 and 6  $\mu\text{g}$  total Cu  $\text{g}^{-1}$  treatments. All loaves had streaks in the crumb. The loaves with 9  $\mu\text{g}$  total Cu  $\text{g}^{-1}$  flour were softer from both sites.

**Spark** The results for softness were the same as for Genesis. From site 1, there was an improvement in crumb structure of loaves with 6  $\mu\text{g}$  total Cu  $\text{g}^{-1}$  flour, but not with 3  $\mu\text{g}$  total Cu  $\text{g}^{-1}$ . When the loaves with 9  $\mu\text{g}$  total Cu  $\text{g}^{-1}$  flour were examined, there was no improvement over the loaves with 6  $\mu\text{g}$  total Cu  $\text{g}^{-1}$ . For site 2, an improvement in crumb structure could only be seen in the loaves with 9  $\mu\text{g}$  total Cu  $\text{g}^{-1}$  flour.

**Hereward** The crumb of loaves with 9  $\mu\text{g}$  total Cu  $\text{g}^{-1}$  flour was softer than at other total concentrations of Cu. No site to site differences and no improvements were noted.

**Riband** All loaves were very poor in quality and no improvement in softness and crumb structure could be found. There was no cell compression at the crust.

**Fresco** The softness results were the same as for Hereward. The loaves produced had

a fine and even crumb structure which had a few streaks. A small improvement could be seen with the largest total Cu concentration, but not in loaves produced with smaller concentrations of total Cu.

**Mercia** Site 1 produced loaves with poor volume, an open structure and thick cell walls, whereas site 2 gave loaves that had a more uniform crumb structure. Streaks were visible in all loaves from site 2, but not in loaves from site 1. The improvements were the same as for Fresco and the softness results were as for Hereward.

#### **General comments**

Previous work indicated that adding Cu had a significant effect on loaf quality. The results from this project show little significant effect of adding Cu on loaf quality. Reasons for this lack of effect may be due to possible site to site variations, other agronomic effects masking the effect of Cu such as interaction with other elements, and the masking of the effect of Cu by the more significant oxidising effect of the ascorbic acid added in the recipe.

Previous work on the effect of Cu in breadmaking systems which contained no or small concentrations of ascorbic acid showed significant effects from variations in total Cu concentrations in the flour. It is possible that the effects from variations in total Cu concentrations in the flour on most of the UK bread quality will always be small given that the major breadmaking process employed includes addition of ascorbic acid.

## CONCLUSIONS OF SECTION II

1. Genesis wholemeal softness increased with the largest concentration of total Cu. Genesis white showed an improvement with a total Cu concentration of  $9 \mu\text{g g}^{-1}$  flour, but no improvement below this concentration.
2. Spark wholemeal from site 1 produced loaves with a more open crumb structure compared to site 2. Spark white displayed signs of improvement with  $6 \mu\text{g}$  total Cu  $\text{g}^{-1}$  flour, but not above or below this concentration.
3. Hereward wholemeal loaves were softer from site 2. No site to site variation was seen with Hereward white with regard to crumb structure, but an increase in softness was clear with a total Cu concentration of  $9 \mu\text{g g}^{-1}$  flour for both sites.
4. Riband wholemeal showed no signs of softness increase with increasing total Cu content, although site variation in softness was noted. Riband white displayed no signs of improvement and no site to site variation.
5. Softness increased in Fresco wholemeal from both sites with increasing total Cu concentrations. However, site 1 produced softer loaves compared to site 2. Small improvements in crumb structure could be seen in Fresco white at a total Cu concentration of  $9 \mu\text{g g}^{-1}$  flour.
6. There was more softness variation for Mercia wholemeal between sites than between total Cu concentration, with site 2 giving the softest loaves. For Mercia white, large site to site variations in crumb structure could be seen. Softness increased with the largest concentration of total Cu.
7. Hereward and Riband white were the only flours to show no improvement with a total Cu concentration of  $9 \mu\text{g g}^{-1}$  flour. The improvements that were seen were very slight.



## REFERENCES

- ANON. (1987). *Genstat 5 Reference Manual*. Oxford: Clarendon Press.
- ANON. (1988). National Institute of Standards and Technology (NIST). Gaithersburg, Maryland 20899, USA: U.S. Department of Commerce.
- ANON. (1993). *Agriculture in the United Kingdom (1992)*. Ministry of Agriculture, Food and Fisheries. London: HMSO Publication.
- FLYNN A. G., PANOZZO J. F. AND GARDNER W. K. (1987) The effect of copper deficiency on the baking quality and dough properties of wheat flour. *Journal of Cereal Science* **6**, 91-98.
- McGRATH S. P. (1985). The effects of increasing yields on the macro- and micro-element concentration and offtakes in the grain of winter wheat. *Journal of the Science of Food and Agriculture* **36**: 1073-1083.
- SPENCER B. (1983). Wheat production, milling and baking. *Chemistry and Industry* **15**: 591-596.
- TUKEY J. W. (1977). *Exploratory Data Analysis*. Reading, Massachusetts, USA: Addison Wesley.
- ZHAO F., McGRATH S. P. & CROSLAND A. R. (1994). Comparison of three wet digestion methods for the determination of plant sulphur by ICP-AES. *Communications in Soil Science and Plant Analysis* **25 (3 & 4)**, 407-418.

## APPENDIX 1

### Milling Procedure

Wheat samples were cleaned (through a Carter-Day dockage tester) and conditioned (to 15% m.c. if soft and 16% m.c. if hard) 18 - 24 hours prior to milling.

Flour samples were produced by a Buhler MLU 202 laboratory mill set to achieve an extraction rate of 75 % and a starch damage of 24 FU.

All milling operations were carried out in a temperature and humidity controlled environment. Extraction rate figures are quoted on a total recovered product basis.

APPENDIX 2  
MILLING SECTION TEST REPORT

Date of issue: 10 / 12 / 93

IDENTIFICATION TEST ITEMS

RESULTS OF ANALYSIS

BUHLER Milling  
Breakdown (%)

(These figures were calculated on mill feed to 1 st break basis, i.e. as a percentage of the total weight of milled wheat).

MR93/-	VARIETY	SITE	SR / ER	BRAN	OFFAL
1540 (1)	Genesis	Twyfords	74.1	16.2	6.9
1541 (2)	Genesis	Twyfords	74.7	15.3	7.2
1542 (1)	Spark	Nickersons	73.4	13.7	10.8
1543 (2)	Spark	Nickersons	70.0	13.0	12.9
1544 (1)	Hereward	PBI	77.7	14.1	6.5
1545 (2)	Hereward	PBI	76.6	14.7	7.0
1546 (1)	Riband	PBI	78.0	14.0	6.2
1547 (2)	Riband	PBI	77.6	14.2	6.2
1548 (1)	Fresco	PBI	77.7	13.8	6.5
1549 (2)	Fresco	PBI	77.4	14.2	6.1
1550 (1)	Mercia	PBI	76.3	14.6	6.3
1551 (2)	Mercia	PBI	75.6	15.3	6.7

N/B: SR = Straight Run

ER = Extraction Rate

The Spark wheat samples appeared to be immature, this could possibly account for the lower extraction rates.

### APPENDIX 3

#### Results of the flour analysis

Variety	MR93/	White Flour		
Protein		Falling	Water	
		Number	adsorption	%
<b>Twyford's</b>				
Genesis site 1	1540	373	59.6	9.3
Genesis site 2	1541	332	59.6	9.4
<b>Nickerson's</b>				
Spark site 1	1542	380	61.1	9.8
Spark site 2	1543	302	62.9	10.1
<b>PBI</b>				
Hereward site 1	1544	308	58.9	10.7
Hereward site 2	1545	314	56.8	9.9
Riband site 1	1546	200	49.6	8.6
Riband site 2	1547	199	48.5	8.7
Fresco site 1	1548	284	56.7	9.8
Fresco site 2	1549	302	56.8	9.9
Mercia site 1	1550	230	57.5	10.4
Mercia site 2	1551	355	58.2	10.1
<b>Wholemeal Flour</b>				
<b>Twyford's</b>				
Genesis site 1	1540	329	67.1	10.7
Genesis site 2	1541	306	65.4	10.6
<b>Nickerson's</b>				
Spark site 1	1542	337	67.5	10.8
Spark site 2	1543	302	62.9	10.1
<b>PBI</b>				
Hereward site 1	1544	285	65.0	11.6
Hereward site 2	1545	277	63.2	11.1
Riband site 1	1546	196	55.0	9.8
Riband site 2	1547	197	57.8	9.9
Fresco site 1	1548	284	56.7	10.9
Fresco site 2	1549	291	62.1	10.9
Mercia site 1	1550	214	64.3	11.6
Mercia site 2	1551	299	65.0	11.5

# APPENDIX 4

## Copper contents of the flours used

Variety Wholemeal and Supplier	MR93/	White	Cu ( $\mu\text{g g}^{-1}$ DM)
<b>Twyfords</b>			
Genesis site 1	1540	1.928	3.0427
Genesis site 2	1541	1.230	3.2745
<b>Nickersons</b>			
Spark site 1	1542	0.8205	1.5595
Spark site 2	1543	1.3888	3.6225
<b>PBI</b>			
Hereward site 1	1544	0.9133	2.5390
Hereward site 2	1545	1.0877	3.0065
Riband site 1	1546	1.8256	3.7776
Riband site 2	1547	1.6226	3.7132
Fresco site 1	1548	1.4708	3.5084
Fresco site 2	1549	1.3925	3.4445
Mercia site 1	1550	1.5423	3.4240
Mercia site 2	1551	1.7009	4.5440

## APPENDIX 5

### Results of the Electrophoresis

The tests were carried out on the white flour produced from the following wheat samples

MR93/	IDENTIFIED VARIETY	SUPPLIER
1540	Genesis	Twyfords seeds
1541	Genesis	Twyfords seeds
1542	Spark	Nickersons
1543	Spark	Nickersons
1544	Hereward	PBI
1545	Hereward	PBI
1546	Riband	PBI
1547	Riband	PBI
1548	Fresco	PBI
1549	Fresco	PBI
1550	Mercia	PBI
1551	Mercia	PBI

## APPENDIX 6

Test baking procedure No. 1AA

Breadmaking process : CBP

Bread type : 400g, white

Mixing machine : Morton

Control recipe :	% of flour weight	g/mix
Flour	100	1400
Yeast (compressed)	2.5	35
Salt	2.0	28
Water	As determined by Simon Extrusion Meter 10 min method	
Fat (Ambrex, slip point c.45°C)	1.0	14
Ascorbic acid (100 ppm AA)	0.01	0.14

The alpha-amylase activity of the flour is adjusted to 80 FU by the addition of fungal alpha-amylase.

### Dough processing :

Mixing machine	: Morton
Beater speed	: 300 rev/min
Work input	: 11 Wh/kg
Pressure	: Atmospheric
Dough temperature	: 30.5 +/- 1°C
Scaling	: By hand to 454g
First moulding	: Cylinder using Mono moulder
First proof	: 10 min at ambient temperature
Final moulding	: Single-piece cylinder, (R7, W5.5, P1.25)
Pan size	: Top 160mm x 98mm, 83mm deep
Shape	: Unlidded
Proving conditions	: 43°C, humidity to prevent skinning
Proving height	: 10cm
Baking temperature	: 244°C
Oven type	: Direct gas-fired reel 12 tray
Baking time	: 25 min
Baking humidity	: No steam injected
Cooling	: Open rack at room temperature
Storage	: Closed cupboard overnight at 21°C

## APPENDIX 7

Test baking procedure No. 7AA

Breadmaking process : CBP

Bread type : 400g, wholemeal

Mixing machine : Morton

Control recipe :

	%	
	of flour weight	g/mix
Flour	100	1400
Yeast (compressed)	2.5	35
Salt	2.0	28
Water	As determined by Simon Extrusion Meter 10 min method	
Fat (Ambrex, slip point c.45°C)	2.0	28
Ascorbic acid (100 ppm AA)	0.01	0.14

The alpha-amylase activity of the flour is adjusted to 80 FU by the addition of fungal alpha-amylase.

Dough processing :

Mixing machine	: Morton
Beater speed	: 300 rev/min
Work input	: 11 Wh/kg
Pressure	: Atmospheric
Dough temperature	: 30.5 +/- 1°C
Scaling	: By hand to 454g
First moulding	: Cylinder using Mono moulder
First proof	: 10 min at ambient temperature
Final moulding	: Single-piece cylinder, (R7, W5.5, P1.25)
Pan size	: Top 160mm x 98mm, 83mm deep
Shape	: Unlidded
Proving conditions	: 43°C, humidity to prevent skinning
Proving height	: 10cm
Baking temperature	: 244°C
Oven type	: Direct gas-fired reel 12 tray
Baking time	: 25 min
Baking humidity	: No steam injected
Cooling	: Open rack at room temperature
Storage	: Closed cupboard overnight at 21°C



# APPENDIX 8

## Subjective Dough Assessment

Flour Variety	Cu Content (ppm)	Mix 1	White	Mix 2
Genesis	0	OK		OK
MR93/1540	3	OK		OK
	6	OK		OK
	9	OK		OK
Genesis	0	OK		OK
MR93/1541	3	OK		OK
	6	OK		OK
	9	OK		OK
Spark	0	OK		OK
MR93/1542	3	OK		OK
	6	OK		OK
	9	OK		OK
Spark	0	OK		OK
MR93/1543	3	VSS		OK
	6	OK		OK
	9	OK		OK
Hereward	0	OK		OK
MR93/1544	3	OK		OK
	6	OK		OK
	9	OK		OK
Hereward	0	OK		OK
MR93/1545	3	OK		OK
	6	OK		OK
	9	OK		OK
Riband	0	OK		SS
MR93/1546	3	SS		Sticky\soft
	6	S		SS
	9	SS		SS
Riband	0	SS		OK
MR93/1547	3	SS		OK
	6	OK		OK
	9	SS		S
Fresco	0	OK		OK
MR93/1548	3	Soft		OK
	6	Soft		SS
	9	Soft		SS

VSS = Very slightly sticky

SS = Slightly sticky

S = Sticky

# APPENDIX 8 (contd)

## Subjective Dough Assessment

Flour Variety	Cu Content (ppm)	White	
		Mix 1	Mix 2
Fresco	0	Soft	OK
MR93/1549	3	OK	Soft
	6	OK	Soft
	9	Soft	OK
Mercia	0	S	SS
MR93/1550	3	Soft	Soft
	6	SS	SS
	9	SS	Soft
Mercia	0	SS	SS
MR93/1551	3	Soft	Soft
	6	Soft	SS
	9	Soft	Soft
		Wholemeal	
		Mix 1	Mix 2
Genesis	0	OK	OK
MR93/1540	9	OK	OK
Genesis	0	SS	SS
MR93/1541	9	OK	OK
Spark	0	OK	OK
MR93/1542	9	OK	OK
Spark	0	OK	OK
MR93/1543	9	OK	OK
Hereward	0	OK	OK
MR93/1544	9	OK	OK
Hereward	0	SS	OK
MR93/1545	9	OK	OK
Riband	0	SS	OK
MR93/1546	9	OK	SS
Riband	0	S	S
MR93/1547	9	Very sticky	S

VSS = Very slightly sticky  
 SS = Slightly sticky  
 S = Sticky

# APPENDIX 8 (contd)

## Subjective Dough Assessment

Flour Variety	Cu Content (ppm)	Mix 1	Wholemeal Mix 2
Fresco	0	OK	OK
MR93/1548	9	OK	OK
Fresco	0	OK	OK
MR93/1549	9	OK	OK
Mercia	0	SS	OK
MR93/1550	9	OK	OK
Mercia	0	SS	OK
MR93/1551	9	S	SS

VSS = Very slightly sticky  
 SS = Slightly sticky  
 S = Sticky