Improving the Health Benefits of Wheat

P.R. SHEWRY[1], J.L. WARD[1], F. ZHAO[1], C. RAVEL[2], G. CHARMET[2], D. LAFIANDRA[3] and Z. BEDŐ[4]

[1]Rothamsted Research, Harpenden, AL5 2JQ Hertfordshire, UK; [2]INRA Clermont-Ferrand, 63039 Clermont-Ferrand, France; [3]University of Tuscia, 01100 Viterbo, Italy; [4]Agricultural Research Institute of the Hungarian Academy of Sciences, 2462 Martonvásár, Hungary; e-mail: peter.shewry@rothamsted.ac.uk

Abstract: Analysis of wheat lines in the HEALTHGRAIN diversity screen has shown wide variation in the content of phytochemicals, dietary fibre components and minerals. In some cases, notably dietary fibre components, alkylresorcinols, tocols and sterols, this variation is also highly heritable, indicating that the contents of these components could be increased by plant breeding. Lower heritability was observed for the contents of Fe and Zn, but this may still be sufficient to achieve some increases by plant breeding. By contrast, some other components, such as folates, phenolic acids and Se, exhibit low levels of heritability. Grain concentrations of iron and zinc were lower in modern semi-dwarf cultivars than in older tall cultivars but no relationship between the date of release and the contents of phytochemicals and dietary fibre components was found.

Keywords: dietary fibre; grain; health benefits; minerals; phytochemicals

Wheat is a major dietary source of essential minerals and vitamins and of other beneficial bioactive components (phytochemicals and dietary fibre components). However, most of these components are concentrated in the embryo and outer layers of the grain which are removed on milling and hence depleted in the white flour fraction which is widely used to make bread and other processed foods. Thus, the consumption of foods produced from white flour has consequences for health in both the developing world and in developed countries. In the former it can contribute to dietary deficiencies, notably of iron and zinc, while in the latter the over-consumption of highly refined foods contributes to a combination of diseases known as the "metabolic syndrome" (which include cardiovascular disease, obesity and type 2 diabetes).

The HEALTHGRAIN project was supported from 2006–2010 by the EU as part of the FP6 programme. It was focused primarily on improving the health of consumers in developed countries, by increasing the consumption of the bioactive components responsible for the health benefits associated with the consumption of wholegrain wheat products (Poutanen *et al*. 2008, 2010). However, many of the components studied have wider significance for human health globally. Further analyses were also carried out to determine the contents of minerals including iron and zinc which are of particular relevance to populations in developing countries.

Exploiting natural variation: the HEALTHGRAIN diversity screen

Feldman (1995) estimated the existence of over 25 000 genotypes of wheat, which provide a wide pool of genetic variation for exploitation in crop improvement. However, limited numbers of genotypes have been analysed for their contents of bioactive components, and even less have been compared for differences in composition when grown and analysed under defined conditions. The HEALTHGRAIN programme therefore established a "diversity screen", in which 150 bread wheat genotypes (130 winter habit and 20 spring habit) selected for their genetic diversity (based on geographical origin and release date) were grown together on a single site (Martonvásár in Hungary) in 2004–2005. Milled samples were then distributed to partners to determine the contents and compositions of dietary fibre components (arabinoxylan and β-glucan) and phytochemicals (tocols, sterols, phenolic acids, alkylresorcinols, folates). The detailed results are reported in a series of papers in Journal of Agricultural and Food Chemistry (2008, Vol. 56, 9710–9749) and summarised by Ward *et al*. (2008).

Based largely on these analyses, 26 wheat genotypes (including 23 from the initial diversity screen) were grown on the same site for two further years (2005–2006, 2006–2007) and a further three sites (in the UK, France and Poland) in 2006–2007 only, and subjected to the same series of analyses. Full results of these analyses are reported in a further series of papers in Journal of Agricultural and Food Chemistry (2010, Vol. 58, 9291–9383, and are summarised by Shewry *et al*. (2010). The availability of data for the same genotypes grown in six environments (ie site × year combinations) allowed the heritability of the components to be calculated as described by Lynch and Walsh (1998). The ranges of variation in the contents of bioactive components and their calculated heritabilities are summarised in Table 1.

Two types of variation are apparent; between genotypes and between samples of the same genotype grown in the different environments. The extent of variation also differs between groups of components, with tocols and sterols being particularly stable and phenolic acids particularly variable. Among the dietary fibre components, the total content of arabinoxylan (AX) is more stable than the content of water-extractable AX fraction.

Table 1. Ranges of variation in the contents of phytochemicals and dietary fibre components in 26 wheat genotypes grown in six environments (sites × years) and the calculated proportion of the variance due to genotype (heritability)

	Content	Heritability
Phytochemicals (wholemeal)		
Total sterols (inc stanols) (μg/g dw)	645–1039	0.57
Stanols (% sterols + stanols)	15–29	0.22
Tocols (μg/g dw)	32–89	0.77
Folates (ng/g dw)	323–889	0.24
Alkylresorcinols (μg/g dw)	281–981	0.63
Total phenolic acids (μg/g dw)	456–1171	0.28
Free phenolic acids (μg/g dw)	0.9–26.5	0.06
Conjugated phenolic acids (μg/g dw)	53–276	0.09
Bound phenolic acids (μg/g dw)	291–1005	0.26
Dietary fibre*		
Flour TOT-AX (% dw)	1.3–2.7	0.71
Flour WE-AX (% dw)	0.2–1	0.59
Bran TOT-AX (% dw)	12–22.6	0.39
Bran WE-AX (% dw)	0.3–0.9	0.48
Wholemeal β-glucan (%)	0.5–1.0	0.51

*TOT-AX – total arabinoxylan; WE-AX – water-extractable arabinoxylan

The contents of dietary fibre components vary in heritability, being particularly high for the flour total and water-extractable AX (ratios of genetic to total variance of 0.71 and 0.59, respectively) and lower for bran AX fractions (0.39, 0.48) and wholemeal β-glucan (0.51). High genotypic variance values were also calculated for total tocols, total sterols and alkylresorcinols (ratios of 0.77, 0.57 and 0.63, respectively). By contrast, phenolic acids (free, conjugated, bound and total fractions) were highly variable in amount and showed low heritability (ratios ranging between 0.06 and 0.28).

Mineral contents of the HEALTHGRAIN samples

Although the HEALTHGRAIN programme focused on phytochemicals and dietary fibre components, the samples from both experiments (the initial diversity screen and the multisite study) were also analysed for minerals. Three elements are of particular interest, with deficiencies of iron (Fe) and zinc (Zn) being widespread (each estimated to affect about a third of the world's population) and selenium (Se) deficiency being particularly significant in Western Europe.

The mineral contents of wheat grain are particularly sensitive to differences in soil composition and hence it is most valid to compare the mean contents for the 26 genotypes grown in the six environments. This showed variation in Fe from 28.6 ± 1.1 mg/kg to 42.5 ± 1.1 mg/kg and in Zn from 20.7 ± 2.4 mg/kg to 35.2 ± 1.4 mg/kg, compared with targets for biofortification of about 40 mg/kg and 60 mg/kg, respectively (Zhao *et al.* 2009). Similarly, the content of Se ranged from 33.8 ± 10.9 μg/kg to 90.6 ± 34.0 μg/kg (Zhao *et al.* 2009). The high standard errors on the Se analysis indicate strong effects of environment and this is confirmed by calculations of variance which showed that less that 1% of the variance in Se content could be assigned to the genotype. The corresponding values for genotypic variance for Fe and Zn content were ≈ 25% and 0.35%, respectively, indicated there is significant genetic control of mineral content which could be exploited by plant breeders.

The contents of both Fe and Zn were highly correlated with grain phosphorus content with correlation coefficients of 0.551 for Fe and 0.553 for Zn in the 150 wheat lines grown in 2005 (Zhao *et al.* 2009), indicating that both are largely bound to phytate.

Has intensive wheat breeding resulted in a decrease in beneficial components?

It has been suggested that higher yielding modern crop cultivars have lower contents of beneficial bioactive components due to negative impacts of selection during breeding (Morris & Sands 2006). Our analyses of the HEALTHGRAIN samples showed that the content of Zn was negatively correlated with yield ($r^2 = 0.439$) and that the decrease was particularly associated with the introduction of short strawed semi-dwarf wheats in the 1970s (Figure 1) (Zhao *et al.* 2009). Similar trends have been reported by Oury *et al.* (2006), Garvin *et al.* (2006) and Fan *et al.* (2008). A similar trend was also observed in the HEALTHGRAIN samples with Fe (Figure 1) but in this case the negative correlation between concentration and yield was not statistically significant ($r^2 = 0.151$).

In order to determine whether a similar decrease occurred in other bioactive components we compared the contents of phytochemicals and fibre components in the 130 winter wheat genotypes grown in the diversity screen with their release dates. The results are summarised in Figure 2 in which combined scores have been calculated for all of the phytochemical and dietary fibre components listed in Table 1.

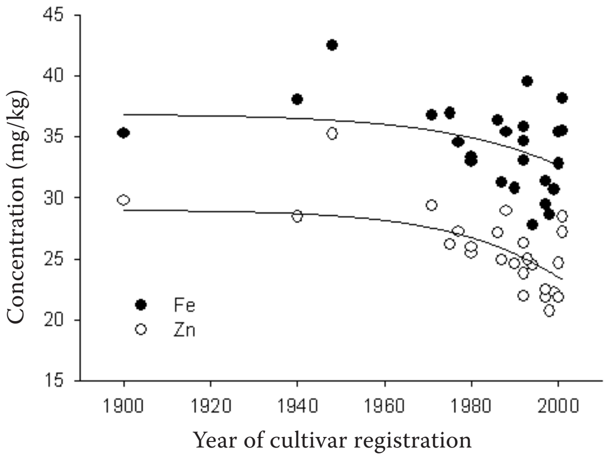

Figure 1. Trends of grain Zn and Fe concentrations (means of six trial sites/seasons) with the date of variety release; the curves are fitted with a logistic equation; taken from Zhao *et al.* (2009)

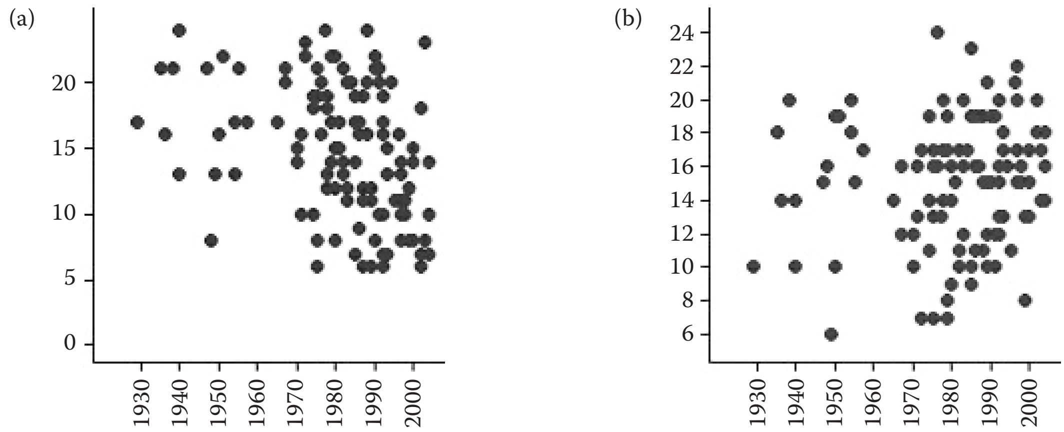

Figure 2. Relationships between the scores for (a) phytochemicals and (b) dietary fibre components in 130 winter wheat genotypes and cultivar release dates; the individual components contributing to the scores are listed in Table 1

This shows that there is no consistent relationship between the contents of dietary fibre and phytochemical components and the year of release, with modern cultivars varying widely in their contents of these components.

CONCLUSIONS

Analyses of phytochemicals, dietary fibre components and minerals in a series of wheat lines showed wide variation in content. This was related both to the environment and the genotype, with some components (notably arabinoxylan fibre, tocols, sterols and alkylresorcinols) showing sufficiently high heritability to be selected in plant breeding programmes. Although the contents of iron and zinc were lower in modern semi-dwarf wheats than in older tall varieties no relationships between cultivar release dates and the contents of other grain components were found.

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