THE OAT CROP

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Production and utilization

Edited by

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CHAPTER 10

The chemical composition of oats

Robert W. Welch

10.1 Introduction

The oat crop provides a range of products which are utilized in animal feed, for human foodstuffs or as industrial raw materials. These products, which may be derived from different parts of the crop and may be taken at various stages of growth, include whole crop silage, straw, grain and grain derivatives.

As with all natural materials there are variations in the composition of these products. These variations arise from differences between production environments, variations in the genotype of the crop and from interactions between environment and genotype. Environmental differences will include variations in climate, the soil and agronomic practices. Genotypic variation includes the differences between winter- and spring-sown crops and the differences between individual genotypes.

There will also be variations in composition arising from differences in harvesting conditions, postharvesting treatments and in the various processes that the crop is subjected to prior to its utilization as feed, food or for other purposes. Further apparent differences in composition may arise through variations in the analytical methods used.

Oat products such as oat silage, whole crop oats and oats used for grazing are discussed in Chapters 8 and 11. The first part of this chapter reviews the composition of oat straw, grain, hulls, groats and bran. Data have been taken from a variety of sources worldwide and sampling and analytical techniques are evaluated where appropriate. In the second part of the chapter, the groat constituents, including protein, lipid, carbohydrate, fibre, minerals, vitamins and other important, but quantitatively minor, components are described together with production and processing factors which may influence their composition.

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10.2 COMPOSITION OF OAT CROP DERIVATIVES

Classical feed analysis gives six proximate constituents – water, protein (measured as crude protein), oil (ether extract), ash (inorganic matter), fibre (measured as crude fibre) and nitrogen free extractives (chiefly carbohydrates, measured by difference) (McDonald *et al.*, 1988). Lignin, which is a fibrous constituent found mainly in straw and hull, is sometimes reported separately. Although some of the techniques have been modified and superseded, data from proximate analyses enable overall composition to be evaluated and comparisons to be made.

10.2.1 Straw

Cereal straw is the above-ground part of the cereal crop which remains at harvest after the crop has been threshed. The main components of oat straw are stem, leaf, sheath and the residue of the panicle (Staniforth, 1979). Straw is high in fibre and generally low in digestible nutrients. The value of oat straw in animal nutrition is reviewed in Chapter 11.

Data on the composition of oat straw are summarized in Table 10.1. All three sources indicate that oil and protein are minor straw constituents and that the main constituents of straw are carbohydrate and fibre. However, the relative proportions of the carbohydrate and fibre constituents vary substantially between reports and this is due mainly to differences in the analytical methods used. In the two older reports in Table 10.1 fibre was analysed as crude fibre and the carbohydrate content was calculated by difference. However, crude fibre involves a very rigorous extraction and gives low values in comparison with more modern methods. Direct analysis of carbohydrate as starch plus sugars shows that the content of digestible carbohydrates is very low (Table 10.1; MAFF, 1992). The more modern detergent methods of fibre analysis yield much higher fibre values which are compatible with the low carbohydrate values obtained by direct analysis.

The lignin content of oat straw is substantial (Table 10.1) and the high degree of lignification of the fibre limits the digestibility of straw and its value in animal nutrition. Lignin levels show variation between sources as a result of both analytical and sample differences. Even greater variability has been reported and Theander and Åman (1978) found 23% lignin in Swedish oat straw samples. These workers also found straw cellulose and hemicellulose contents of 30% and 22% respectively, and they reported the presence of fructose, glucose, sucrose and the sugar alcohols, arabinitol and mannitol in oat straw. However, the sum of these low molecular weight carbohydrates was only 1%.

The ash content of straw is relatively high (Table 10.1). Silica represents a major proportion of the ash but other minerals present include potassium

Table 10.1 *Composition of oat straw – mean values and ranges (% dry basis)*

	Crude protein	Oil	Carbo-hydrate	Fibre	Lignin	Ash
Mean[a]	4.1	1.4	46.4[d]	41.4[e]	–	6.8
Range	(1.9–7.6)	(0.6–2.1)	(42.8–49.5)	(37.5–45.4)		(4.9–9.2)
Mean[b]	2.8	2.0	49.7[d]	39.8[e]	14.7	6.2
Range	(2.2–3.4)	(1.7–2.2)	(49.3–50.1)	(39.4–40.2)	(11.0–17.5)	(5.7–7.2)
Mean[c]	3.4	1.4	2.0[f]	52.3[h]	9.2	6.6
Range	(2.0–4.8)	(0.8–2.1)	–[g]	(50.0–53.8)	(9.0–9.3)	(6.3–7.4)
				74.9[i]		
				(58.7–80.4)		

[a] 108 trial samples; three spring cultivars; six sites; two fertilizer levels; three seasons; Dent (1957).
[b] Compiled from various sources in Staniforth (1979).
[c] Six samples, winter and spring, MAFF (1992).
[d] Nitrogen-free extractives, by difference.
[e] Crude fibre.
[f] Sum of starch and sugars.
[g] No range given.
[h] Acid detergent fibre.
[i] Neutral detergent fibre.

(1–2% of the dry matter), phosphorus (0.1–0.2%) and calcium (0.1–0.4%) (Staniforth, 1979).

The composition of oat straw will vary substantially between samples. Although cultivar differences exist, environmental effects are reported to be by far the most significant factor (Dent, 1957). Although the nutritive value of oat straw is poor, alkali treatment can greatly enhance its digestibility (Chapter 11).

10.2.2 Grain

The oat grain of the normal covered crop consists of a husk or hull enclosing the groat. The husk, or hull as it will be referred to throughout this chapter, is derived from the lemma and palea of the floret. The hull, which consists mainly of fibrous material, protects the groat. The groat, known botanically as the caryopsis, is also referred to as the kernel. The term groat will be used throughout this chapter. Naked oats thresh free of the hull and thus, in the absence of any residual hull material, will comprise only groats. The term oat grain should only be used for the covered grain in the form in which it is harvested.

Unfortunately some reports use the term grain inappropriately or fail adequately to define the samples under discussion. Ideally any sample description should name the cultivar, give an indication of the conditions under which it was grown and state the anatomical or milling fraction. Analytical results should also indicate whether they are expressed on a dry matter (moisture free) or on an 'as is' basis.

The proximate composition of oat grain from a number of sources is summarized in Table 10.2. Mean protein and oil contents are similar across the reports but there are substantial variations between samples from the same report. The level of oil and protein in the hull is very low (section 10.2.3) and thus these variations reflect both differences in groat:hull ratio and differences in groat composition. Carbohydrate is the major grain constituent (Table 10.2). However, the review data (Wainman, 1976) and the data from Welsh samples (Morgan, 1968a) report carbohydrate as 'Nitrogen free extractives' (NFE). NFE is not a direct measure of carbohydrate but is calculated by difference following the analysis of the other constituents. NFE includes material which analyses as fibre when modern fibre analysis techniques are employed. Consequently much lower carbohydrate values are given by the more recent reports where direct measures of digestible carbohydrate constituents (starch and sugars) have been undertaken (Table 10.2). Fibre, which is given as crude fibre in the two earlier reports, also shows substantial variation between samples from the same report. The two more recent studies give 'Total fibre' and 'Neutral detergent fibre' (Table 10.2) which yield much higher values than the crude fibre method (Table 10.2). The inorganic constituents (ash) show the least variation both between and within reports.

10.2.3 Hull

The proportion of hull in whole oat grain will vary substantially depending on environmental and genetic factors and oat hull contents ranging from 20 to 36% of the grain have been reported (Hutchinson *et al.*, 1953; Salo and Kotilainen, 1970; Welch *et al.*, 1983). The hull is derived from the lemma and palea of the floret and the hull has a structure and composition which is radically different from the groat of the grain which it encloses. The function of the hull is to protect the groat. Hulls are very fibrous in texture and are composed primarily of cell wall material. Table 10.3 summarizes data on the major constituents of oat hull. Hemicellulose and cellulose are present in approximately equal proportions and both lignin and ash make significant contributions. Fibre analyses often give variable values for oat hull (Welch *et al.*, 1983). Frølich and Nyman (1988) found 79–84% total fibre in a Norwegian oat hull sample; the soluble fibre content was negligible and the lignin content was high (20%). The major monosaccharides in the insoluble fibre were glucose and xylose (50% and 38% of total) with arabinose, galactose and uronic acids present in minor amounts (Frølich and Nyman, 1988).

Table 10.2 *Composition of oat grain – average values and ranges (% dry basis)*

	Crude protein	Oil	Carbo-hydrate	Fibre	Ash
Median[a]	12.9	5.2	66.8[e]	12.1[f]	3.5
Range	(9.8–14.5)	(1.8–6.8)	(60.2–75.4)	(7.5–16.5)	(2.4–5.2)
Mean[b]	9.8	5.2	68.9[e]	13.0[f]	3.1
Range	(7.2–12.6)	(1.9–8.0)	(63.8–74.2)	(9.0–17.9)	(2.4–4.1)
Mean[c]	11.6	5.7	47.4[g]	32.3[h]	3.0
Range	(8.7–16.1)	(4.5–7.2)	(39.1–57.2)	(19.9–37.6)	(2.1–3.6)
Mean[d]	10.8	4.1	48.2[g]	31.5[i]	2.7
Range	(10.6–13.4)	(1.6–7.2)	(42.8–55.1)	(25.5–36.4)	(2.2–3.8)

[a] 38 analyses from 20 reports: Germany, USA, UK; 1873–1975: Wainman (1976).
[b] 171 farm samples: three seasons: Wales: 10 cultivars included; winter and spring types: Morgan (1968a).
[c] 121 samples, spring types including 42 cultivars, 15 sites, four seasons; Sweden; Aman (1987).
[d] 21 samples, winter and spring, MAFF (1992).
[e] Nitrogen-free extractives, by difference.
[f] Crude fibre.
[g] Sum of starch and sugars.
[h] Total fibre.
[i] Neutral detergent fibre.

Table 10.3 *Composition of oat hulls (% dry basis)*

Region	Cell wall	Hemi-cellulose	Cellul-lose	Lignin	Ash
Finland[a]	–	37	32	13.7	7.3
UK[b]	85–93	31–37	30–37	2.3–9.7	3.3–9.3
Australia[c]	–	–	38–41	0.8–7.6	0.9–2.9[d]

[a] One trial sample, Salo and Kotilainen (1970).
[b] Range for 29 samples including diverse genotypes, trial samples and oatmill samples, mostly hand separated, Welch *et al*. (1983).
[c] Range for 75 samples including seven cultivars from up to 16 sites; machine separated hand cleaned, Crosbie *et al*.(1985).
[d] Insoluble ash.

The protein content of hull is very low. UK samples which included diverse genotypes and cultivars from trials contained 2.0–4.9% protein (Welch *et al.*,1983) and samples from North Dakota (Wu *et al.*, 1972) and from Wisconsin (Pomeranz *et al.*, 1976) were also within this range. The amino acid composition of oat hulls has been investigated (Wu *et al.*, 1972; Draper, 1973; Pomeranz *et al.*, 1976). However, there was poor agreement between these studies. For example, glutamic acid was the major amino acid present in all cases but values ranged from 8 to 16%. The percentage recoveries of nitrogen as amino acids were low (46% and 62%; Wu *et al.*, 1972 and recalculated from Draper, 1973) which indicates that a significant proportion of the nitrogen in oat hull is in the form of non-protein nitrogen.

The contents of starch, oil, and water-soluble carbohydrate were very low in hand separated hulls from various sources and ranges were: starch, 0.3–1.8%; oil, 0.09–0.47% and water-soluble carbohydrate, 0.2–0.8% (Welch *et al.*, 1983). However, substantially higher levels of starch (up to 12%) were found in industrially separated hull samples. This reflects a significant degree of groat contamination and indicates that analyses of commercial hull samples may overestimate the nutritive value of the hull.

10.2.4 Groats

Oat milling which is described in detail in Chapter 12 involves the removal of the hull to produce a clean, sound groat. The groat is then subjected to cutting and/or rolling to yield various grades of rolled oats and oatmeal. The groat requires stabilization during the milling process in order to inactivate enzymes. Milling involves the loss of the trichomes (hairs) from the surface of the groat by abrasion, and also possibly losses of fine particles (fines) formed on cutting and rolling. However, the composition of the finished oatmeal or rolled oat will closely resemble that of the original groat.

Table 10.4 compares the proximate constituents of oatmeal and rolled oat samples from various regions. The values for protein and oil are broadly similar across the various samples. Protein and oil are generally present at higher levels in groats than they are in grain (Table 10.2). This difference is to be expected when the low protein and oil contents of the hull are taken into account.

Carbohydrate is the major groat constituent. However, the data show considerable variability which chiefly reflects differences in analytical methods. Different procedures have also been used for fibre analysis and this accounts for the wide variations between the samples in Table 10.4. The higher values are more appropriate and groat fibre content and composition is further discussed in section 10.4.4(d). Other groat constituents are described in greater detail in sections 10.3 and 10.4.

Table 10.4 *Composition and energy values for oatmeal and rolled oats (data from Food Tables)*

Region	Water	Protein	Oil	Carbo-hydrate	Fibre	Ash	Energy (kcal/ 100 g[e])
	(g/100 g fresh weight)						
UK[a]	8.9	12.4	8.7	72.8	6.8[f]	n	401
UK[a]	8.2	11.2	9.2	66.0	7.1[f]	n	375
USA[b]	8.8	16.0	6.3	67.0	5.6[g]	1.9	384
E. Asia[c]	11.5	13.5	4.8	68.4	1.1[h]	1.3	369
Australia[d]	9.2	13.8	7.8	69.9	8.0[f]	n	388

[a] Oatmeal and quick oatmeal; Holland *et al.*(1988).
[b] Oats, regular, quick and instant; Douglass *et al.*(1982).
[c] Oatmeal or rolled oats; Leung *et al.*(1972), Rao and Polacchi (1972).
[d] Oatmeal, rolled oats; Cashel *et al.* (1989).
[e] Multiply by 4.184 to convert to kJ.
[f] Total non-starch polysaccharide.
[g] Insoluble fibre.
[h] Crude fibre.
n = no value given.

10.2.5 Bran

Bran is the term applied to the outer layers of the caryopses of cereals. However, the bran fraction of oats is not as structurally distinct as the bran of wheat. The structure of wheat enables it to be milled to yield well-defined flour and a fibre-rich bran fraction. However, oat groats are softer than wheat grains and have a different structure and thus cannot be milled to yield such clearly defined flour and bran fractions. It is possible to mill oats so that a coarse fraction is obtained which is enriched in the outer bran layers (Paton and Lenz, 1993). This bran fraction still contains a substantial proportion of the inner endosperm material but nevertheless has a higher protein content and a higher fibre content than the parent groat. Interest in oat bran has focused on its fibre component and in particular the soluble fibre which appears to be the main agent responsible for the cholesterol lowering effects of dietary oats (Chapter 14). Because the bran of oats is not as well defined anatomically as wheat bran it has been necessary to produce a definition for oat bran for use in commerce and in dietary descriptive work. The definition devised by a Committee of the American Association of Cereal Chemists (Anon. 1989) states, in essence, that oat bran is produced by grinding oat groats or rolled oats and separating a bran fraction that is not more than 50% of the starting material and has a total β-glucan content of at least 5.5% of dry weight and a total dietary fibre content of at least 16% of dry weight with the result that at least one-third of the total fibre is soluble.

Table 10.5 *Composition of oat bran: data from commercial samples and other sources (% fresh basis)*

Source	Water	Protein	Oil	Carbo-hydrate[a]	Dietary fibre[a]	Ash
USA[b]	n	21.4	7.1	46.4	14.2	n
UK[c]	n	17.0	9.0	65.0	15.0[h]	n
USA[d]	10.0	20.8	7.2	42.0	–[i]	3.0
USA[e]	8.8	19.9	7.6	43.6	16.2	3.1
Norway[f]	nil	17.1	7.7	n	16.4	2.6
Norway[g]	nil	16.8	8.6	n	15.2	2.3

[a] Various methods used.
[b] Quaker oat bran, manufacturer's data.
[c] Jordans oat bran, manufacturer's data.
[d] Analysis of commercial oat bran, Welch *et al.* (1988).
[e] Analysis of commercial oat bran, Shinnick *et al.* (1988).
[f] Coarse bran, laboratory milled, Frølich and Nyman (1988).
[g] Fine bran, laboratory milled, Frølich and Nyman (1988).
[h] Non-starch polysaccharide; Englyst method; 8.5% soluble, 6.5% insoluble.
[i] 6.5% β-glucan.
n = no value given.

Studies have reported analyses of bran fractions that have been produced by grain dissection or other means (e.g. Youngs, 1972; Ma, 1983). However, since commercial oat bran is not a distinct anatomical fraction its composition may vary depending on the source of the oats processed and on the precise processing conditions. Marlett (1993) has comprehensively reviewed the fibre composition of oat bran and other brans and cereal products. The composition of oat bran from commercial and other sources is summarized in Table 10.5. The essential feature in bran production is the reduction in the amount of starchy endosperm which results in increases in the levels of protein and fibre components. Thus despite the disparities in the sources of the samples, comparison of oat bran composition (Table 10.5) with the composition of oatmeal, rolled oats and groats (Table 10.4) shows that the protein and fibre contents are substantially higher in the bran samples.

10.3 INORGANIC CONSTITUENTS

10.3.1 Total ash

Ash content of the oat grain averages about 3% (Table 10.2). The ash comprises the inorganic (mineral) constituents. Koivistonen *et al.* (1974b) were able to account for 31% of oat ash as major and trace elements (K, P, Mg, Ca, Na, Mn, Fe and Zn). The residue of the ash comprises oxygen in combination with these minerals, other trace elements, such as Cu or Se, and substantial quantities of silica.

10.3.2 Grain minerals

Mineral composition data for oat grain from surveys and trials in Europe and North America are summarized in Table 10.6. Comparison of the ranges and standard deviations shows that most of the elements have a greater than twofold range in content. The mean levels of the major minerals were broadly similar in all studies and K > P > Mg > Ca. Owen *et al.* (1977) commented that the K and Ca levels found in their Canadian study were lower than other published values but their data for these elements are only marginally lower than more recent data from Finland (Table 10.6).

The trace (or minor) elements show greater variations in concentration. For example both Mn and Zn show over threefold ranges in the Welsh samples and the standard deviations indicate similar large ranges in the samples from the other two regions (Table 10.6). There also appear to be regional differences in trace elements with the Finnish samples showing the highest levels of Cu and Mn. The availability of trace elements such as Cu to the growing oat crop is controlled by the level present in the soil and by other soil characteristics (Cheshire *et al.*, 1967, Tähtinen, 1976). Thus the variability in trace element levels probably results from variations in geological or other edaphic factors.

Levels of other essential trace elements have also been reported for oat grain. These include cobalt at a mean levels of 5 μg/100 g (range 2–17) (Morgan, 1968b) and 50 μg/100 g (range 20–90) (Yli-Halla and Palko, 1987) the latter being a very high level for this element. Owen *et al.* (1977) reported selenium at 26±20 μg/100 g.

10.3.3 Groat minerals

Table 10.7 shows the mineral contents of oat groats from two experimental trials and for oatmeal samples from tables of food composition from various sources. The levels of the major and trace elements are broadly similar to the mean levels found in whole grain (Table 10.6). Despite the widely varying provenances of the groat and oatmeal material, the variation between the mineral contents of these samples is much less than the variation found between grain samples from the same region (Table 10.6). This is because the data in Table 10.7 are mean values from a large number of samples or are analyses of samples derived from bulked grain. Although there is evidence of some consistent regional variation (for example the two samples from the USA have the highest P and Mg contents) and there are small differences in moisture content, the mineral composition of the

Table 10.6 *Mineral content of oat grain: data from surveys and trials*

	Na	K	Ca	Mg	P	Fe	Cu	Zn	Mn
					(mg/100 g[e])				
Mean[a]	20	470	110	130	380	–	0.47	3.7	4.5
Range	(4–60)	(310–650)	(70–180)	(100–180)	(290–590)	–	(0.30–0.82)	(2.1–7.0)	(2.2–7.9)
SD	9.6	80	20	17	40	–	0.08	1.0	1.3
Mean[b]	8.6	418	67	147	371	5.0	1.33	3.9	7.2
SD	3.2	43	12	13	41	1.2	0.79	0.6	2.3
Mean[c]	–	440	57	140	370	9.2	0.72	4.2	4.2
SD	–	57	11	17	59	3.2	0.29	1.2	0.7
Mean[d]	8.1	481	58	145	364	14.2	0.53	4.0	13.6
Range	(1.4–77)	(380–620)	(41–82)	(120–170)	(290–450)	(6–30)	(0.37–1.5)	(2.8–5.4)	(4.8–20.0)
SD	17	44	11	12	36	4.6	0.18	0.57	3.2

[a] Wales; 171 farm samples; three seasons; 10 cultivars included; winter and spring types; Morgan (1968b).
[b] Finland; 114 farm samples; 14 cultivars; Koivistoinen *et al.* (1974b).
[c] Saskatchewan, Canada, two cultivars, 16 sites, five seasons; Owen *et al.* (1977).
[d] Finland; 35 samples; one season, acid sulphate soils; Yli-Halla and Palko (1987).
[e] Dry basis.
SD = standard deviation.

Table 10.7 *Mineral composition of oatmeal, rolled oats or oat groats: data from Food Tables and experimental trials*

Region	Na	K	Ca	Mg	P	Fe	Cu	Zn	Mn
	(mg/100 g[h])								
Finland[a]	2	319	64	139	426	5.4	0.66	4.2	5.2
USA[b]	–	440	54	185	545	4.7	0.48	3.6	4.6
USA[c]	4	350	52	148	474	4.2	0.34	3.1	3.6
UK[d]	33	370	55	110	380	4.1	0.23	–	3.7
UK[e]	9	350	52	110	380	3.8	0.49	3.3	3.9
E. Asia[f]	5	–	30	–	360	3.4	–	–	–
Australia[g]	4	354	55	–	371	4.1	–	–	–

[a] Rolled oat flakes, means for 32 samples; Koivistoinen *et al.* (1974a).
[b] Groats; means for six cultivars, one site, one or two seasons; Peterson *et al.* (1975).
[c] Oats, regular, quick and instant; Douglass *et al.* (1982).
[d,e] Oatmeal and quick oatmeal; Holland *et al.* (1988).
[f] Oatmeal or rolled oats; Leung *et al.* (1972); Rao and Polacchi (1972).
[g] Oatmeal, rolled oats; Cashel *et al.* (1989).
[h] Dry weight basis for data from Finland[a]; all other data on fresh weight basis, samples contain 8.2–11.5% moisture (Table 10.4).

samples from these diverse regions shows a high degree of consistency. Trace amounts of boron (0.28 mg/100 g), barium (0.25 mg/100 g, and selenium (3 μg/100 g) have also been reported in groat and oatmeal samples (Peterson *et al.*, 1975; Holland *et al.*, 1988). The presence of phytic acid and phytates may render P and other minerals nutritionally unavailable (section 10.4.8).

10.4 ORGANIC CONSTITUENTS

The following pages describe quantitative and qualitative characteristics of the groat constituents. In view of the very close similarity of groat, oatmeal and rolled oats the data are applicable to all such samples. Furthermore, much of the ensuing qualitative data on oat constituents will also apply to oat bran.

10.4.1 Protein

Oat grain protein content varies substantially in farm and survey samples (Table 10.2). There are small consistent differences in grain protein content within cultivars from the same region (Welch and Yong, 1980). However, the variation in the cultivated crop is primarily environmental in origin, reflecting the availability of soil nitrogen and other factors. The application of nitrogen fertilizer will increase oat protein content (Peterson, 1976; Eppendorfer, 1977) and is particularly effective if applied late, at heading (Welch and Yong, 1980). The protein content of the hull is very low (section 10.2.3) and thus variations in grain protein will be reflected primarily in variations in groat protein (Hutchinson and Martin, 1955b).

The protein of oats and other cereal grains have been characterized in two principal ways, by analysis of amino acid composition and by investigation of the protein fractions separated by solubility and other criteria.

Amino acid composition is of importance in human and animal nutrition where protein sources must provide adequate essential amino acids (Chapters 11 and 14). Lysine tends to be the first limiting essential amino acid in cereals and this deficiency is exacerbated if the protein content of a cereal is increased, for example by fertilizer application. However, the amino acid balance of oats is generally superior to other cereals (Chapter 14; Frey, 1977).

(a) Amino acid composition

The nutritionally superior amino acid composition of oats has been confirmed in a comparison of the amino acid composition of caryopses (groats) of grass and cereal species which indicated that the Aveneae, which includes oats, had higher levels of all the essential amino acids (cysteine, histidine, isoleucine, leucine, lysine, methionine, phenylalanine, threonine, tryptophan, tyrosine and valine) than the Triticeae which includes wheat, rye and barley (Yeoh and Watson, 1981).

Data for the amino acid composition of oatmeal and groat samples have been compiled in Table 10.8. These data are from Food Tables from different regions and from two studies which investigated genetic and environmental influences on amino acid composition. Despite the widely different sources these data show broad agreement and similar results have also been reported by other workers (Peterson and Smith, 1976; Zarkadas *et al.*, 1982). The ranges observed in the samples grown at different fertility levels arise from both environmental and genetic factors (Table 10.8; Peterson, 1976). However, greater ranges were reported by Robbins *et al.* (1971) who evaluated the genetic variation in groat amino acid composition by analysis of 289 diverse cultivars of oats (Table 10.8). In this study correlations were computed between total protein and each constituent amino acid. Significant positive correlations were found between total protein and glutamic acid, phenylalanine and histidine levels. Significant negative correlations were found between total protein and a number of amino acids (lysine, threonine, serine, proline, glycine, alanine, valine, methionine, leucine). Although these correlations indicated that protein

Table 10.8 *Amino acid composition of oatmeal and groat samples*

	Food Table data			Experimental data	
	Oatmeal (g/16 gN)			Groats (means and ranges) (g/100 g recovered amino acid)	
	E. Asia[a]	UK[b]	USA[c]	USA[d]	USA[e]
Lysine	3.2	3.7	3.8	4.2 (3.2–5.2)	4.6 (4.4–4.8)
Histidine	2.1	2.1	2.1	2.2 (2–3.1)	2.6 (2.5–2.7)
Arginine	5.0	6.2	7.0	6.9 (6.2–7.8)	7.7 (7.5–7.9)
Aspartic acid	9.3	7.7	8.2	8.3 (8.9–9.9)	9.1 (8.6–9.8)
Threonine	3.5	3.4	3.2	3.3 (3.0–3.5)	3.0 (2.9–3.1)
Serine	4.3	4.6	4.4	4.2 (3.8–4.8)	4.1 (4.0–4.4)
Glutamic acid	20.8	21.0	21.4	23.9 (21.9–26.9)	22.0 (21.5–22.7)
Glycine	5.1	4.6	5.1	4.9 (4.4–5.5)	4.7 (4.5–5.0)
Alanine	5.0	4.5	5.0	5.0 (4.2–5.5)	5.1 (5.0–5.3)
Cysteine	2.6	2.7	2.3	1.6 (0.6–2.6)	2.0 (1.7–2.1)
Valine	5.3	5.1	5.5	5.3 (4.9–5.7)	5.7 (5.6–5.8)
Methionine	1.8	1.8	1.6	2.5 (1.0–3.3)	2.3 (1.6–2.6)
Isoleucine	3.8	3.8	4.3	3.9 (3.4–4.1)	4.0 (3.9–4.2)
Leucine	7.7	7.2	7.4	7.4 (4.8–7.8)	7.7 (7.5–7.9)
Tyrosine	4.0	3.4	3.3	3.1 (2.3–4.4)	3.4 (3.2–3.7)
Phenylalanine	5.8	5.0	5.1	5.3 (4.9–5.7)	5.7 (5.2–6.4)
Proline	5.4	5.1	5.3	4.7 (3.8–5.8)	3.6 (3.3–4.0)
Tryptophan	1.1	1.3	1.3	–	–
Protein[f]	16.4	14.5	18.8	17.1 (12.4–24.4)	–

[a] Recalculated from Leung *et al.* (1972).
[b] Recalculated from Paul and Southgate (1978).
[c] Recalculated from Douglass *et al.* (1982)
[d] 289 cultivars; Robbins *et al.* (1971).
[e] Three cultivars, five fertilizer levels, Peterson (1976).
[f] N × 6.25; dry matter basis.

quality declined with increasing protein content within oat genotypes, the correlation coefficients were low indicating that there may be scope for selecting within this material for high protein lines without a significant loss of protein quality (Robbins *et al.*, 1971).

Rigorous studies of the relationship between N fertility, grain protein and amino acid composition were reported by Eppendorfer (1977, 1978). In these studies oats were grown in pots and subjected to a wide range of fertilizer treatments. In one experiment in which grain protein increased from 6.4 to 16.3% of dry matter, the lysine decreased from 4.6 to 4.1% of the protein (Eppendorfer, 1977). In another experiment grain protein increased from 6 to 24% and was accompanied by a decrease in lysine from 4.6 to 3.9% of protein. Total grain protein was significantly negatively correlated with the lysine, threonine, cysteine and methionine content indicating a decline in protein quality with increasing protein concentration. However, this decline was much less than that found for either rye or wheat which were also grown in these experiments.

Thus oats have higher protein quality than other cereals and the decline in protein quality at higher protein levels is less pronounced in oats than other cereals. This effect is associated with the relative contribution of the various protein solubility fractions to oat total protein.

(b) Protein solubility fractions

The protein of cereal grain and of other grain crops can be fractionated on the basis of solubility characteristics. These solubility fractions were first characterized by Osborne (1924). The fractions and their respective solvents are: albumins (water); globulins (dilute aqueous salt solutions); prolamins (aqueous alcohol); glutelins (dilute acid or alkali). The differences in the solubility of the fractions are reflected in differences in amino acid composition (Lüers and Siegert, 1924; Waldschmidt-Leitz and Zwisler, 1963; Wu *et al.*, 1972; Draper, 1973). Variations in the fractionation and analytical procedures have resulted in considerable differences between reports. However, the results of Draper (1973) who analysed oat grain and Wu *et al.* (1972) who analysed oat flour were broadly similar. The results from Wu *et al.* (1972), summarized in Table 10.9, show substantial differences in the amino acid compositions of the fractions. For example, the contents of lysine and threonine are highest in the albumin fraction and lowest in the prolamin fraction whereas glutamic acid is lowest in the albumin fraction and highest in the prolamin fraction.

Clearly variations in the relative proportions of these fractions can influence overall amino acid composition. Early work indicated that the prolamin fraction, which is generally high in glutamic acid and proline and low in essential amino acids, is the major seed protein fraction in most cereals (Brohult and Sandegren, 1954; Mossé, 1968). Furthermore, it is this fraction that is chiefly increased in other cereals as protein is raised by genetic or environmental changes. This accounts for the marked decline in protein quality observed with cereals such as barley, maize or wheat as protein is increased (Mossé, 1968).

However, earlier work indicated that prolamins did not predominate in oats but that globulins (Brohult and Sandegren, 1954) or glutelins (Mossé, 1968) were the major protein fraction present. The situation was resolved by Peterson (1976) who studied the relationship between total protein and the relative amounts of the groat protein fractions in samples which included a range of cultivars and fertilizer treatments. The mean concentrations of the protein fractions, recalculated as a percentage of the total recovered protein, were: albumins, 14.4–20.1%; globulins, 47.1–53.2%;