Oat Protein Concentrates from a Wet-Milling Process: Composition and Properties[1]

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ABSTRACT

Protein concentrates, starch, and residue fractions produced by a wet-milling process from ground oat groats with moderate- and high-protein contents were analyzed for amino acid composition, protein, starch, fat, fiber, ash, and various neutral carbohydrates. The concentrates, which have a bland taste, contain from 59 to 75% protein (nitrogen × 6.25) with 3.9 to 4.1 g. lysine and 3.3 to 4.3 g. total sulfur amino acids per 16 g. nitrogen. The concentrates are low in fiber (0.1 to 0.2%), have 3.5 to 4.5% ash, no starch, and from 2.2 to 23.3% total carbohydrate. Protein concentrate from Garland groats has 10.1% fat, whereas defatted Wyndmere groats give a protein concentrate with 0.3% fat. The starch fraction is essentially composed of pure starch without any other carbohydrate. Protein concentrate from defatted Garland groats has a nitrogen solubility of 83% at pH 2.1, a minimum solubility (15%) around pH 5, and 95% solubility at pH 11.4.

The estimated yearly market for 3.1 billion lb. of protein concentrates (1) means there is considerable room for protein supplements other than nonfat dry milk and soy flour. Such a new protein ingredient should possess high nutritive value, a bland taste, suitable solubilities, and potential for adequate production capacity to keep demands supplied. Among all these qualities, the most essential one for any product going into the protein ingredient market is freedom from objectionable taste.

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A wet-milling process has been developed to produce concentrates, starch, and residue fractions from ground oat groats of moderate- and high-protein contents (2). The good nutrient quality of oat proteins has been established by animal feeding studies and amino acid analysis (3-6). This paper reports the amino acid composition, protein, starch, fat, fiber, ash, and total neutral carbohydrates of oat protein concentrates, starch, and residue fractions, as well as the nitrogen solubility and other functional properties of the concentrates.

MATERIALS AND METHODS

Wyndmere oats with a moderate-protein content (14.2% d.b.) and Garland oats with a high-protein content (17.2% d.b.) were grown in 1970. The oats were dehulled and the resulting groats ground in a hammer mill. Some of the groats were defatted with 1-butanol after grinding. The butanol left in the groats was removed by a hexane wash. Butanol was used, rather than hexane because butanol is the better defatting solvent. The ground oat groats were mixed with 0.025N NaOH in a ratio of one part of groats to six parts of solvent. The slurry was passed through bolting cloth and the protein solution was separated from the fine starch particles by centrifuging. The preparation of protein concentrates, starch, and residue fractions has been reported in more detail (2).

Protein content was calculated from duplicate micro-Kjeldahl analyses by multiplying percent nitrogen by 6.25, and corrected to dry basis. Starch was measured by a polarimetric method (7). Total neutral carbohydrates of hydrolyzed samples were determined by gas-liquid chromatography (8). A cellulose fraction was also analyzed by the same chromatographic method (8) after other components in each sample were solubilized and removed. Fat, fiber, ash, nitrogen solubility index, and hydration capacity were determined by AACC Approved Methods (9).

Each sample for amino acid analysis was hydrolyzed in refluxing, constant-boiling HCl for 24 hr. The hydrolyzed sample was then evaporated to dryness, and the residue was dissolved in pH 2.2 citrate buffer. Amino acids in a fraction of the residue were separated by a Beckman Spinco Model 120 amino acid analyzer and ninhydrin peaks were integrated electronically. The amino acid data were computed automatically by an IBM 1130 computer (10). Tryptophan was determined separately (11). Emulsion stability was established by the method of Yasumatsu et al. (12) for a simple system except the protein-water-oil mixture was emulsified with a magnetic stirrer at 1,350 r.p.m. for 5 min.

RESULTS AND DISCUSSION

Composition

The protein, starch, fat, fiber, ash, and total neutral carbohydrate of Wyndmere and Garland oat protein concentrates, as well as by-products, are shown in Table I. Defatting Garland and Wyndmere groats by 1-butanol removed not only lipid, but also 11% of the total nitrogen. The nitrogen removed may include prolamins and lipoproteins. Defatted Garland and Wyndmere groats all have a lower protein content than the corresponding groats that have not been defatted. The concentrates have protein contents ranging from 59.1 to 75.0%. Concentrates from defatted oat groats have higher protein contents than those from nondefatted groats. Also, the higher protein groats (Garland) give concentrates with higher protein contents. Both the residue and starch fractions included some protein

TABLE I. COMPOSITION OF OAT PROTEIN CONCENTRATE AND BY-PRODUCTS (% dry basis)

Groats	Protein	Starch	Fat	Fiber	Ash	Neutral Total Carbohydrate of Hydrolysate
Wyndmere	18.9		7.4		2.2	
Protein concentrate	59.1	0	17.7		4.5	12.6
Residue on screen	19.6	22.4	8.0		4.8	61.6
Residue on cloth	2.4	75.0	3.9		2.4	98.2
Starch fraction	0.2	95.9	0.8		0.6	110.2
Defatted Wyndmere	16.8		0.1	1.8	2.4	
Protein concentrate	73.1	Trace	0.3	0.1	4.1	23.3
Residue on cloth	17.1	28.5	0.3	6.2	4.6	58.7
Starch fraction	0.8	94.4	0.1	0.2	1.6	106.3
Garland	23.3			2.0	2.2	
Protein concentrate	70.6		10.1	0.2	3.5	2.2
Residue on cloth	17.4		1.3	6.8	4.3	64.6
Starch fraction	0.8		0.2	0.3	1.2	92.9
Defatted Garland	20.6		0.6		2.3	
Protein concentrate	75.0		1.9		3.6	19.5
Residue on cloth	20.2		1.1		5.7	58.7
Starch fraction[a]	2.4		0.4		1.2	106.6

[a]A small yellowish top layer included in this starch fraction but not in other starch fractions.

solution so that the protein content of the dried residues and starches in Table I is high. The protein content of the residue and starch fractions can be reduced considerably by a water wash (2). Also if a small yellowish layer above the starch is removed, the protein content of the starch fraction is greatly reduced. In preparing Wyndmere protein concentrate the residue on screen (40 mesh) has 19.6% protein, and the residue on cloth (160 mesh) has only 2.4% protein. For later preparations, the screening step was eliminated. The starch fraction is essentially pure starch, as shown by the low protein and fat content and high-starch content for both Wyndmere and defatted Wyndmere starch fraction (Table I).

The fat contents of Garland and Wyndmere protein concentrate are 10.1 and 17.7%, respectively, and are considerably higher than those of the residue and starch fractions. Apparently the fat in oat groats tends to concentrate in the oat protein fraction. Protein concentrate from defatted Wyndmere and Garland groats, on the other hand, has only 0.3 to 1.9% fat. The fiber content of the two protein concentrates is low (0.1 to 0.2%) and their ash content varies between 3.5 and 4.5%. Total neutral carbohydrates range from 2.2 to 23.3%, but the concentrates are essentially free of starch. The total neutral carbohydrate of Wyndmere residue on screen and defatted Wyndmere residue on cloth constitutes close to 60% of the solids; less than half of this carbohydrate is starch.

Neutral Carbohydrate

The neutral carbohydrate analysis of hydrolysates of oat protein concentrates and by-products is found in Table II. The percentage of each aldose is based on residue weights to permit conversion of aldose to polysaccharide. It is not clear why some of the total neutral carbohydrate percentages for starch exceed 100. The predominant sugar is D-glucose in all protein concentrates, except the Garland,

TABLE II. NEUTRAL CARBOHYDRATE FROM HYDROLYSATES OF OAT PROTEIN CONCENTRATES AND BY-PRODUCTS (% dry basis)

Fraction	L-Arabinose	D-Xylose	D-Mannose	D-Galactose	D-Glucose	Total
Wyndmere						
Protein concentrate	0.5	0.3	0	2.0	9.8	12.6
Residue on screen	2.5	5.5	0.2	0.5	52.9	61.6[a]
Residue on cloth	0	0	0	0	98.2	98.2
Starch	0	0	0	0	110.2	110.2
Defatted Wyndmere						
Protein concentrate	0.6	0.6	0.1	1.8	20.2	23.3
Residue on cloth	2.0	4.8	0.5	0.2	51.2	58.7[b]
Starch	0	0	0	0	106.3	106.3
Garland						
Protein concentrate	0.1	1.8	0	0	0.3	2.2
Residue on cloth	1.9	5.5	0	0	57.2	64.6[c]
Starch	0	0	0	0	92.9	92.9
Defatted Garland						
Protein concentrate	0.4	0.6	0.1	1.4	17.0	19.5
Residue on cloth	3.4	7.6	0.2	0.4	47.1	58.7[d]
Starch	0	0	0	0	106.6	106.6

[a]Includes a 1.7% cellulose fraction of which 1.5% is D-glucose and 0.2% is D-xylose.
[b]Includes a 2.5% cellulose fraction of which 2.3% is D-glucose and 0.2% is D-xylose.
[c]Includes a 3.2% cellulose fraction of which 2.9% is D-glucose and 0.3% is D-xylose.
[d]Includes a 6.7% cellulose fraction of which 5.9% is D-glucose and 0.8% is D-xylose.

which has a low total neutral carbohydrate content but a relatively high D-xylose content. There is no cellulose in protein concentrates or starch fractions and only a small amount (1.7 to 6.7%) in the residue fractions. About 90% of the cellulose fraction is derived from D-glucose while xylose accounts for the remaining weight.

Oats contain some gum, a β-D-glucan, that is soluble in water at room temperature, has $[\alpha]_D$- of +6° in 1N NaOH, and gives only D-glucose upon hydrolysis (13). Since there is neither starch nor cellulose in an oat protein concentrate, the D-glucose percentage probably represents oat gum. Part of the difference between D-glucose and starch percentages for residue fraction is probably also due to oat gum because the amount of cellulose is low. The starch content, as determined by a polarimetric method, is not significantly influenced by the small amount of gum that may be present because the $[\alpha]_D$ of oat starch is close to +200°. Since only D-glucose is obtained from the starch fraction and since cellulose is absent, the conclusion may be drawn that the starch fraction is essentially pure starch. Apparent pentosan content, which can be calculated from the sum of L-arabinose and D-xylose, varies from 0.8 to 1.9% for protein concentrates and from 6.8 to 11.0% for residue fractions, except for the residue-on-cloth fraction from Wyndmere that is free of pentosan.

Amino Acid Composition

The amino acid composition of groats, protein concentrates, and residues from Wyndmere and Garland oats is given in Table III. In general, there is not much difference in amino acid composition between groats, protein concentrates, and residues. Garland protein concentrate has 4.1 g. lysine and 4.3 g. total sulfur amino acids per 16 g. nitrogen and has a good amino acid distribution. Wyndmere protein concentrate has 3.9 g. lysine and 3.3 g. total sulfur amino acids per 16 g. nitrogen

TABLE III. AMINO ACID COMPOSITIONS OF GROATS, PROTEIN CONCENTRATES, AND RESIDUES (g. amino acid per 16 g. nitrogen)

	Garland Variety, Defatted			Wyndmere Variety		
Amino Acid	Groats	Protein concentrate	Cloth residue	Groats	Protein concentrate	Screen residue
Lysine	4.1	4.1	4.5	4.5	3.9	3.4
Histidine	2.2	2.3	2.3	2.5	2.1	2.2
Ammonia	2.6	3.0	2.3	3.1	2.8	3.2
Arginine	7.0	7.6	6.9	8.1	7.1	7.7
Aspartic acid	8.1	8.4	8.1	8.3	8.5	8.1
Threonine	3.3	3.4	3.5	3.3	3.3	3.4
Serine	4.6	4.8	4.7	5.0	5.1	4.9
Glutamic acid	20.9	22.8	19.0	22.3	23.0	20.5
Proline	6.1	5.7	4.7	5.5	4.1	5.0
Glycine	4.8	4.8	5.2	5.1	5.0	5.5
Alanine	4.4	4.7	5.0	4.8	4.8	5.1
Half-cystine	1.9	2.5	1.6	1.3	2.0	1.3
Valine	5.2	5.5	5.2	5.3	5.5	5.4
Methionine	1.7	1.8	1.8	1.1	1.3	1.0
Isoleucine	3.8	4.0	3.7	3.8	4.0	3.8
Leucine	7.4	7.8	7.2	7.8	8.0	7.6
Tyrosine	3.9	4.2	3.7	3.5	3.9	3.2
Phenylalanine	5.3	5.7	5.0	5.2	5.5	5.0
Tryptophan[a]		1.1	1.2	1.0	1.0	0.6

[a]Determined separately (11).

and has a good amino acid composition. Garland protein concentrate not only has a higher total sulfur amino acid content than the Wyndmere protein concentrate, but also is higher in protein. Also, the Garland residue fraction has higher protein and higher lysine, tryptophan, and total sulfur amino acids than the Wyndmere residue. The amino acid composition of Wyndmere groats in Table III agrees well with the amino acid composition of Wyndmere oats from a different location and crop year (6). The amino acid composition of defatted Garland groats is in general agreement with that of Garland groats from a different location and crop year (4) except that the half-cystine value in Table III is considerably higher, and proline and tyrosine values are somewhat higher.

Storage Stability of Concentrates

Garland protein concentrate, defatted Garland and Wyndmere protein concentrates, and most of the nondefatted Wyndmere protein concentrates have no rancid smell after a few months of storage at room temperature. One batch of Wyndmere protein concentrate, however, deteriorated. The difference in storage stability of the Wyndmere protein concentrates prepared under identical conditions cannot be readily explained because only one batch of the protein concentrate developed a rancid smell. Apparently the two Garland protein concentrates contain enough antioxidant to prevent the lipid from becoming rancid. For a protein concentrate from Wyndmere, it may be necessary to defat the groats, to add such antioxidants as BHA (butylated hydroxyanisole) or BHT (butylated hydroxytoluene) commonly used in food, or to prevent the lipid from becoming rancid by other methods, such as inactivation of lipid hydrolase and oxidase.

Nitrogen Solubility of Concentrates at Various pH Values

The solubility of oat protein concentrates at various pH values was determined

by mixing from 0.1 to 0.3 g. of defatted Garland groat protein concentrate with 10 ml. of water and by adjusting the pH from 1.6 to 11.4 by HCl or NaOH. After stirring and centrifuging at 1,500 r.p.m., the supernatant was analyzed for nitrogen by the micro-Kjeldahl method. The percentage of nitrogen soluble at various pH values is plotted in Fig. 1. Maximum solubility of the oat protein concentrate is observed at pH 11.4 where 95% of the nitrogen is soluble. This concentrate is also very soluble between pH 2 and 3, the solubility of nitrogen being 83% at pH 2.1. The minimum solubility of the protein concentrate is around pH 5 where only 15% of the nitrogen is soluble.

Effect of Ionic Strength on Solubility

The defatted Garland groat protein concentrate nitrogen is 83% soluble at pH 2.12, 37% soluble at pH 2.15 in 0.1M NaCl, and 9% soluble at pH 2.19 in 1M NaCl. The large decrease in nitrogen solubility of the protein concentrate with increasing ionic strength indicates minimum salt is best if good solubility around pH 2 is desired.

Hydration Capacity and Emulsion Stability

The hydration capacity of Garland protein concentrate was 3.1 (weight of sediment per weight of dry sample). Defatted Garland protein concentrate gave a sediment that was too loosely packed in the centrifuge tube under the same experimental conditions and gave a value of 2.4. The 2.4 value represents a lower limit for hydration capacity, because some of the solid was aspirated off with the water. The emulsion stability of Garland protein concentrate, defatted Garland protein concentrate, and Promine D (soybean protein isolate) at pH 2.2 was 55, 57, and 56%, respectively, while the corresponding figure at pH 8.6 was 47, 83, and 47%. The emulsified layers for defatted Garland protein concentrate at both pH values and for Promine D at pH 8.6 were very stable and did not flow when the centrifuge tubes were inverted. The emulsion stability of the Garland protein concentrate equals that of Promine D, while that of defatted Garland protein concentrate is better than the soybean protein isolate.

Taste Testing of Protein Concentrate

Ten people participated in taste testing a 1% Garland protein concentrate slurry in water at pH 5.73 and 1% defatted Garland protein concentrate slurry in water at pH 5.97. Both concentrates are essentially bland without undesirable flavor. Seven out of the ten preferred the Garland protein concentrate, which corresponds to a significance at 1% level.

GENERAL DISCUSSION

The composition and properties of Garland and Wyndmere protein concentrates, as well as defatted Garland and Wyndmere concentrates prepared from a wet-milling process,were evaluated for possible food uses. Hischke et al. (4) reported the PER (protein efficiency ratio; i.e., g. gain in body weight per g. of protein intake) of Garland oats for weanling white rats as 2.37, whereas six other oat varieties had a PER from 2.25 to 2.38. Since the amino acid compositions of Wyndmere groats and concentrate, as well as defatted Garland groats and concentrate (Table III), are close to those reported by Hischke et al., presumably

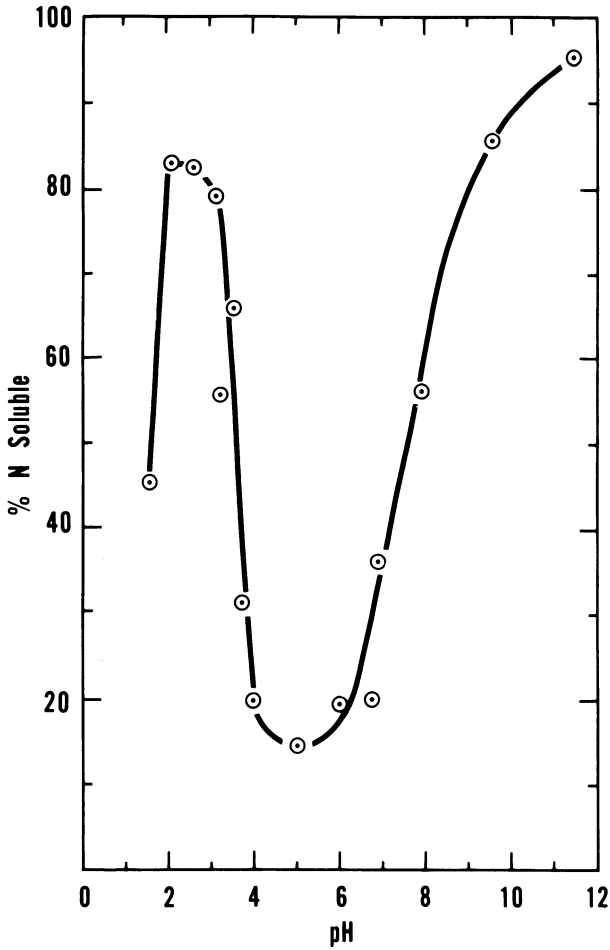

Fig. 1. Nitrogen solubility of defatted Garland groat protein concentrate at various pH values. From 0.1 to 0.3 g. of the protein concentrate was stirred with 10 ml. of water at different pH values by addition of HCl or NaOH.

our oat protein concentrates will have PER values similar to theirs, especially for Garland. The nutritional values of oat protein concentrate for food will have to be determined by feeding tests with humans.

Oat protein concentrate has good nitrogen solubility around pH 2.5 and above 8, bland flavor, good amino acid composition, reasonable hydration capacity, and emulsion stability. The net cost to make oat protein concentrate depends to a large extent on the values of the starch and cloth residue fractions that are also produced. Further improvement on the yield of protein concentrate is possible. Oat protein concentrate may find application in foods.

Garland groats (a high-protein oat) gave a protein concentrate with higher protein content (Table I), higher yield (6), better total sulfur amino acids (Table

III), and better storage stability than a protein concentrate from Wyndmere groats (a moderately high-protein oat). Since high-protein oats give better protein concentrates and higher yields, active research on high-protein oats becomes more meaningful. If oats with a higher protein content than those available commercially at present are developed, then the cost of oat protein concentrate will likely lower and an even better protein concentrate may result than described here.

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