Digestibility of Complex Carbohydrates and Protein in Wheat Breads[1]

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ABSTRACT

These studies examined the apparent digestibility (on young adult rats) of dry matter, protein, fat, ash, dietary fiber, and available carbohydrates in wheat breads. Five types of breads were made: flour bread, starch bread, reconstituted (starch and gluten combined) flour bread, gluten bread, and starch bread-plus-gluten. Results showed that the apparent digestibility of dry matter (96.3–98.1%) and of available carbohydrates (98.6–99.8%) was almost complete. Digestibility of protein, fat, and ash was also quite high. A portion of the dietary fiber was also digested. Indirect evidence suggested that the microbial degradation of available carbohydrates was probably minimal.

Complex carbohydrates (fiber and starches) and protein are the major components of most bread products. When bread is consumed, some of the fiber may undergo digestion that is mostly microbial (Bond and Levitt 1978, Van Soest 1978), but only the starch and protein components are extensively broken down. Food preparation, such as cooking and baking, improves the digestibility of starches and protein (El-Harith et al 1976, Fleming and Vose 1979). However, disagreement exists on the extent to which starches and protein in wheat and wheat products such as bread may be digested in man and monogastric animals and on how the starches and protein might interact (Anderson et al 1981, El-Harith et al 1976, Hickey et al 1972).

This study was designed to obtain information on the digestibility of major bread components with particular emphasis on available carbohydrates (mainly starches) and protein (mainly gluten). Young adult rats were used as test models.

MATERIALS AND METHODS

White flour obtained from hard red winter wheat, and the starch and gluten components prepared from it, were used to make five types of test breads (Table I). Information on bread formulas and on bread-making procedures is presented in Table II and Table III, respectively. Baked breads were either air-dried (breads A, C, and D) or freeze-dried (bread B) and then finely ground before the analytical and animal-feeding phases of the study were done.

Gluten used in test breads was prepared by the standard AACC method (1961) and then freeze-dried. Starch was isolated from the rinse water used in gluten preparation. Settled starch was recovered, centrifuged (top pentosan/gluten layer scraped off), remixed with water, recentrifuged, air-dried, and put through a fine sieve.

Six-week-old Sprague-Dawley rats (10 rats per bread group), initially averaging about 140 g, were housed individually in clear-plastic metabolism cages with a controlled environment (75° F, 50% rh, 12-hr light-dark cycle). Distilled-deionized water was provided ad libitum. Each rat was offered 7 g (breads B and D) or 10 g (breads A, C, and E) of bread per day for the two- to three-week test period. Feces were collected quantitatively at the end of each 24-hr period, pooled for the test period, air-dried, finely ground, frozen, and stored until needed for analysis.

The standard AACC methods (1977) were used to determine Kjeldahl protein, fat (ether extract), ash, and moisture contents in breads and feces. The standard AACC method (1977) was also used to determine the dietary fiber content in breads. Dietary fiber in the fecal material was determined by the method of Robertson and Van Soest[2]. The content of available carbohydrates (nitrogen-free extract) in breads and feces was obtained by calculation (Table IV). Apparent digestibilities were calculated based on intakes and fecal losses of various bread components.

RESULTS AND DISCUSSION

Five types of breads were tested (Table I). Bread A was made with white wheat flour, bread B with prepared starch, and bread C with reconstituted flour. In reconstitution, only the starch and gluten fractions were combined (starch, 86%; gluten, 14%). To minimize variables, starch and gluten were prepared from the same wheat as was used in bread A. To facilitate breadmaking by improving water retention properties, prepared starch was mixed in a 10:1 ratio with 95% damaged starch. Bread D was made with prepared gluten. Bread E was the same as starch bread, with gluten later added to the finely ground bread.

All breads were made by the straight dough procedure (Table III). Based on preliminary test bakes, various baking parameters

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[2]J. B. Robertson and P. J. Van Soest. 1977. Presented at the 69th meeting of the Am. Soc. Animal Sci., Univ. of Wisconsin, Madison, July 23–27.

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TABLE I
Test Breads

Bread	Main Ingredient
A (flour bread)	Wheat flour (protein in flour, 11.5%)
B (starch bread)	Starch (protein in starch, 0.2%)
C (starch + gluten bread)	Starch and gluten
D (gluten bread)	Gluten (protein in gluten, 82.8%)
E (bread B + gluten)	Bread B + gluten (gluten added to the bread after baking)

TABLE II
Bread Formula

Ingredients (g)	Bread A (flour)	B (starch)	C (starch + gluten)	D (gluten)
Flour	100	···	···	···
Starch[a]	···	100	86.0	···
Gluten	···	···	14.0	100.0
Sucrose	6	6	6	6
Salt (NaCl)	2	2	2	2
Shortening	3	3	3	3
Yeast (compressed)	3	3	3	3
Yeast food	0.5	0.5	0.5	0.5
Water	65	180	65	70

[a]Contained 9.1% damaged starch. Extent of damage, 95%.

were altered (Tables II and III) to produce acceptable products. Thus mixing times, mixing speeds, fermentation, proofing, and baking times and temperatures between test breads all varied, some quite significantly (Table III).

The proximate composition of test breads is shown in Table IV. The protein contents of breads A, C, and E were similar, but breads B and D represented the extremes. Other measured components in breads A, C, and E were also similar. Consequently, the calculated values for available carbohydrates in these three breads differed little (Table IV). Starch bread (bread B) contained the highest amount of available carbohydrates.

The types of available carbohydrates in breads were not determined, but starch, undoubtedly, was the predominant component, with simple sugars constituting about 3–4%. At the level used (Table II), about 50% of the sugar (sucrose) in bread remains unfermented. Sugars naturally occurring in wheat flour and those originating through amylolytic activity during breadmaking probably also contributed a small amount to the test breads. Raffinose and stachyose, the primary nondigestible sugars, are normally present in insignificant amounts in wheat flour (Hickey et al 1972).

The apparent digestibility values of the major bread components are presented in Table V. Initially, each animal was offered 10 g of bread per day. Rats on starch and gluten breads (breads B and D), however, were unable to consume this amount and therefore were offered 7 g of bread per day. For these two groups, the study period was extended by another week (total of three weeks) so that the bread consumption per rat was equal in all groups (total of 143 g). Because of slight differences in the moisture contents of breads (Table IV), the dry matter intake of rats differed slightly among groups.

All test breads except the starch bread adequately supported the body weight, but not normal growth, of rats during the test period. The starch bread contained virtually no protein and, thus, rats in that group lost more than 30 g in individual body weight during the three-week period.

Over 96% (more, if corrections are made for microbial and sloughed cells in fecal matter) of the dry matter in all test breads was digested by the rats (Table V). This alone suggests that the predominant components of bread (starch and/or protein) were quite available. Of the individual proximate components examined, the digestibility of protein in gluten-containing breads (breads A and C–E) ranged from 91.8 to 97.6%; relatively low digestibility of protein in bread E may have been because this bread contained raw gluten, in contrast to breads A–D. In the nongluten bread (bread B), the digestibility of protein was probably even higher, if the 0.78 g fecal protein is considered to have originated from nondietary (metabolic) sources. Such an assumption is realistic; on low-protein diets, fecal protein is almost exclusively of metabolic origin. Extending such an assumption to include all breads would mean that the "true" digestibility of protein was almost 100%. Significant amounts of fat and ash in test breads were also digested. These amounts could conceivably be higher if "true" digestibilities (accounting for endogenous losses) were determined.

Digestibilities of fiber and available carbohydrates presented a divergent picture. Breads contained about 2% dietary fiber, a significant amount of which apparently was digested through microbial degradation in the large intestine (Bond and Levitt 1978, Van Soest et al 1978). Because methods used to determine fiber in bread and feces differed (bread method appeared inoperative for fecal material), some error may have been introduced in calculations of fiber digestibilities. Certain gases, such as hydrogen and methane, and volatile fatty acids, which provide utilizable energy, are the major end products of bacterial degradation of fiber as well as of available carbohydrates.

Available carbohydrates (mainly starches) were almost completely digested; calculations showed fecal material to contain virtually no available carbohydrates (Table V). This and the absence of starch granules in feces precluded the need to undertake starch analysis of fecal material. The small intestine possesses high absorptive capacity for simple sugars (Riesenfeld et al 1980). Simple sugars, the components of available carbohydrates, probably were completely absorbed before reaching the colonic flora. Some starch, however, may have reached the colonic flora. Because germ-free animals were not used, microbial degradation of starch, if any occurred, could not be assessed. Indirect evidence suggested that this was probably inconsequential.

Based on measurements of breath hydrogen in humans, recent studies of bread and macaroni (Anderson et al 1981) indicated that 10–20% of the carbohydrates (presumably starches) in wheat flour was not digested. In addition, the consumption of breads made with low-gluten flour (with or without extra gluten added), in contrast to all-purpose flour, resulted in complete absorption of the carbohydrates. Physical and chemical interactions between starch and gluten in the native flour are the probable causes of malabsorption of starches in all-purpose flour. Our studies revealed no significant differences in the digestibility of available carbohydrates, whether bread flour, nongluten flour, or reconstituted flour was used to make breads (Table V). For each test bread, the digestibility of available carbohydrates was almost 100%, which agrees with several other studies done with human and animal subjects. For example, Hickey et al (1972) studied intestinal gas production in young men fed wafers made with wheat endosperm (starch and gluten in native state) and showed only insignificant increases in breath and flatus gas composition. De Vizia et al (1975) showed that young children almost completely absorbed cooked wheat starch administered in the form of a biscuit or macaroni. Working with laboratory rats, Fleming and Vose (1979) reported that cooked starches of wheat were nearly 100% digested. In chickens fed cornstarch, Riesenfeld et al (1980) showed that about 97% of the cornstarch was digested as it traveled through

TABLE III
Bread-making Procedure for Straight Dough[a]

	Bread			
	A (flour)	**B (starch)**	**C (starch + gluten)**	**D (gluten)**
Hook or paddle[b]	Hook	Paddle	Hook	Hook
Mixing (min)				
Speed one	1	2.5	1	3
Speed two	2	···	15.5	···
Speed three	10	···	4.5	···
Fermentation (min)	90	90	90	30
Speed one mixing (min)	···	1	···	1
Scaling	Yes	Yes	Yes	Yes
Rounding	Yes	···	Yes	Yes
Intermediate proofing (min)	20	···	20	···
Molding/pouring	Molding	Pouring	Molding	···
Pan proofing (min)	46	60	63	300
Baking				
Time (min)	20	75	20	45
Temperature (°F)	430	350	430	430

[a] All ingredients added at the same time except in bread B, in which yeast was presoaked before addition.
[b] Used with Hobart A120 mixer and McDuffy bowl (12-qt mixing bowl used for bread B).

TABLE IV
Proximate Composition of Breads

	Bread				
Components	**A (flour)**	**B (starch)**	**C (starch + gluten)**	**D (gluten)**	**E (bread B + gluten)**
Protein (N × 5.7)	10.69	0.68	11.08	69.33	9.82
Fat (ether extract)	2.76	1.81	3.11	2.38	1.86
Ash	2.25	2.16	2.02	2.08	1.95
Moisture	12.48	12.23	12.39	11.53	11.81
Fiber (dietary)	2.09	1.84	1.98	1.33	1.88
Carbohydrates[a] (available)	69.73	81.28	69.42	13.35	72.68

[a] By difference (100 − sum of other five components listed).

TABLE V
Apparent Digestibilities of Major Bread Components[a]

	Bread				
	A (flour)	B (starch)	C (starch + gluten)	D (gluten)	E (bread B + gluten)
Test Period (week)	2	3	2	3	2
Body weight (g)					
Initial	138 ± 10	138 ± 7	138 ± 7	138 ± 7	138 ± 8
Final	148 ± 9	107 ± 11	147 ± 6	133 ± 9	149 ± 6
Dry matter					
Consumed (g)	125.2 ± 0.0	125.5 ± 0.0	125.3 ± 0.0	126.5 ± 0.0	126.1 ± 0.0
In feces (g)	3.7 ± 0.7	2.6 ± 0.6	2.4 ± 0.5	4.7 ± 0.2	3.8 ± 0.5
Digestibility (%)	97.0 ± 0.6	97.9 ± 0.5	98.1 ± 0.4	96.3 ± 0.2	97.0 ± 0.4
Protein					
Consumed (g)	15.29 ± 0.00	0.97 ± 0.00	15.84 ± 0.00	99.14 ± 0.00	14.04 ± 0.00
In feces (g)	1.20 ± 0.20	0.78 ± 0.26	0.77 ± 0.16	2.41 ± 0.10	1.15 ± 0.12
Digestibility (%)	92.1 ± 1.3		95.1 ± 1.0	97.6 ± 0.1	91.8 ± 0.9
Fat					
Consumed (g)	3.95 ± 0.00	2.59 ± 0.00	4.45 ± 0.00	3.40 ± 0.00	2.66 ± 0.00
In feces (g)	0.36 ± 0.07	0.30 ± 0.09	0.22 ± 0.07	0.56 ± 0.35	0.22 ± 0.05
Digestibility (%)	90.9 ± 1.8	88.4 ± 3.3	95.1 ± 1.6	83.5 ± 1.0	91.7 ± 2.0
Ash					
Consumed (g)	3.21 ± 0.00	3.08 ± 0.00	2.88 ± 0.00	2.98 ± 0.00	2.79 ± 0.00
In feces (g)	0.18 ± 0.06	0.15 ± 0.03	0.10 ± 0.02	0.19 ± 0.01	0.17 ± 0.05
Digestibility (%)	94.5 ± 2.0	95.2 ± 1.1	96.6 ± 0.8	93.7 ± 0.4	93.9 ± 1.8
Dietary fiber					
Consumed (g)	2.99 ± 0.00	2.63 ± 0.00	2.83 ± 0.00	1.90 ± 0.00	2.69 ± 0.00
In feces (g)	1.71 ± 0.50	1.12 ± 0.40	1.04 ± 0.24	1.25 ± 0.1	1.88 ± 0.34
Digestibility (%)	42.8 ± 16.6	57.3 ± 15.1	63.4 ± 8.6	34.3 ± 6.9	30.0 ± 12.5
Carbohydrates (available)					
Consumed (g)	99.76 ± 0.00	116.24 ± 0.00	99.29 ± 0.00	19.14 ± 0.00	103.93 ± 0.00
In feces (g)	0.29 ± 0.19	0.27 ± 0.13	0.24 ± 0.13	0.27 ± 0.12	0.40 ± 0.15
Digestibility (%)	99.7 ± 0.2	99.8 ± 0.1	99.8 ± 0.1	98.6 ± 0.6	99.6 ± 0.1

[a]Mean ± standard deviation (ten rats per bread type).

the duodenum, jejunum, and ileum.

Present studies provide only indirect evidence on the completeness of starch digestion (discussed in terms of available carbohydrates) in bread. More convincing evidence could result when studies are conducted under germ-free conditions or when starch is recovered before it reaches the colonic bacteria. Such studies are planned.

LITERATURE CITED

AMERICAN ASSOCIATION OF CEREAL CHEMISTS. 1977. Approved methods of AACC. Methods 08-01, 30-25, 38-10, 44-40, and 46-12, approved April 1961; Method 32-20, approved October 1977. The Association, St. Paul, MN.

ANDERSON, I. H., LEVINE, A. S., and LEVITT, M. D. 1981. Incomplete absorption of the carbohydrates in all-purpose wheat flour. N. Eng. J. Med. 304:891.

BOND, J. H., and LEVITT, M. D. 1978. Effect of dietary fiber on intestinal gas production and small bowel transit time in man. Am. J. Clin. Nutr. 31:S109.

DE VIZIA, B., CICCIMARRA, F., DECICCO, N., and AURICCHIO, S. 1975. Digestibility of starches in infants and children. J. Pediatr. 86:50.

EL-HARITH, A. E., DICKERSON, J. W. T., and WALKER, R. 1976. On the nutritive value of various starches for the albino rat. J. Sci. Food Agric. 27:821.

FLEMING, S. E., and VOSE, J. R. 1979. Digestibility of raw and cooked starches from legume seeds using the laboratory rat. J. Nutr. 109:2,067.

HICKEY, C. A., MURPHY, E. L., and CALLOWAY, D. H. 1972. Intestinal-gas production following ingestion of commercial wheat cereals and milling fractions. Cereal Chem. 49:276.

RIESENFELD, G., SKALAN, D., BAR, A., EISNER, U., and HURWITZ, S. 1980. Glucose absorption and starch digestion in the intestine of the chicken. J. Nutr. 110:117.

VAN SOEST, P. J. 1978. Dietary fibers: Their definition and nutritional properties. Am. J. Clin. Nutr. 31:512.

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