Intestinal-Gas Production following Ingestion of Commercial Wheat Cereals and Milling Fractions[1]

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ABSTRACT

Human intestinal-gas production was increased over baseline levels following consumption of the wheat cereals 'All Bran' and 'Ralston', and the wheat milling fractions bran, red dog, and shorts. Endosperm, germ, and 'Cream of Wheat' resulted in only insignificant increases, as reflected in breath and flatus gas composition.

Whole-grain breads and cereals are often classified as high-residue foods which contribute to the bulk of human feces and to the regularity of stool evacuation. Fecal matter contains, primarily, indigestible material, microorganisms and their products, and secretions and shed cells from the alimentary tract (1). The indigestible material consists of varying amounts of cellulose, hemicellulose, lignin, pectic substances, gums, and mucin (2), some of which are present in whole wheat. Although the enzymes capable of breaking down cellulose, hemicellulose, and lignin are not present in the human gastrointestinal secretions, various bacterial enzymes are capable of their digestion (1). It has been assumed that indigestible residue contributes to intestinal motility by increasing the mass of bulk via moisture absorption, or by providing substrate for bacterial degradation to volatile fatty acids which are assumed to stimulate the bowel (1,3). However, few studies are available to document these pharmacological or distension effects on intestinal motility.

Certain food residues have been observed to undergo partial fermentation in the intestine with the production of, among other gases, hydrogen (H_2) and methane (CH_4) (4,5). Since these gases are virtually absent from room air and are not produced elsewhere in the body, their presence in expired air and flatus indicates gas formation in the gut. Breath H_2 and rectal flatus were used to compare intestinal-gas production from test meals of wheat cereals and wheat milling fractions.

MATERIALS AND METHODS

General

The voluntary subjects of study were healthy young men, free of known food allergy, who had no recent history of gastrointestinal disorders. Tests were conducted in random sequence over a period of several months and individual tests were separated by at least one nontest day. The subjects were requested to fast from 11 p.m. of the night preceding each test day. They received the test meal at 9 a.m. (zero time) and were required to complete the food in 30 min.

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The commercial cereals 'Cream of Wheat' (light farina), 'Ralston' (dark farina with 5% added wheat germ), and 'All Bran' were fed in 150-g. test doses and were cooked with 325 to 350 g. deionized water. These test dosages are about two to five times the normal serving and were set deliberately high for test purposes.

The individual wheat fractions, bran, germ, endosperm, and the combined red dog and shorts fractions were fed in amounts corresponding to their percent composition adjusted to 150-g. weight of whole wheat. Based on the original wheat at 15% moisture, these amounts were: bran, 11.5% (17.25 g.); germ, 0.5% (0.75 g.); endosperm, 74.3% (111.45 g.); red dog, 3.8% (5.25 g.); and shorts, 8.3% (12.45 g.). The endosperm fraction was obtained by blending patent flour and clear flour (3.9:1.1).

Each fraction was given as a separate test meal and was fed by incorporation into a wafer which included hydrogenated vegetable fat (Crisco®), partially hydrolyzed starch (Dextri-Maltose®), sucrose, wheat starch, glycerol, salt, saccharine, and cinnamon flavoring. Wheat-starch wafers were fed without the addition of the wheat fractions in order to assure that the added ingredients gave a low level of background-gas production. All wafers were baked at 350°F. (177°C.) for 12 to 15 min. before serving.

All test meals were adjusted to an 800-kcal. level (approximately 3,500 kjoules) by the addition of Swiss cheese and orange-flavored beverage base (Tang®) when necessary. Decaffeinated coffee (Sanka®, 2.5 g. dry solids) and enough deionized water to bring the total fluid intake to 1,000 g. were given with each test meal, and beverages were equalized between meals. A 600-kcal. (2,500-kjoule) serving of a nutritionally balanced formula (6) was given to the subjects at 1 and 5 p.m. and was also fed at the 800-kcal. level as a test meal to give an estimate of baseline gas production. The composition of the test meals is shown in Table I.

TABLE I. COMPOSITION OF TEST MEALS FED AT 9 A.M.

Test Item	Weight[a] of Test Food g.	Composition of Total Test Meal[a] kcal.	Protein g.	Fat g.	Carbohydrate g.
Formula	352	800	23.3	26.5	130
'Cream of Wheat', instant (Nabisco)	150	802	17.3	26.6	124
'Ralston', instant (Ralston-Purina)	150	797	19.8	26.2	132
'All Bran' (Kellogg)	150	802	31.4	16.3	139.4
Wheat starch wafers	68	800	4	26.5	149
Endosperm fraction[b]					
Patent flour	87	797	17.3	24.4	129
Clear flour	24.45				
Germ fraction	0.75	808	7.8	30.3	135.1
Red dog and shorts fractions					
Red dog	5.25	831	10.8	31.3	132.2
Shorts	12.45				
Bran	17.25	808	10.6	31.2	131

[a]Uncooked weight of test wheat fraction or cereal only. Does not include weight of other ingredients or added water. Meals included Swiss cheese and 'Tang' as needed to equalize caloric content.

[b]The wheat fractions and their proximate analyses were obtained through the courtesy of G. Kohler and R. Saunders of the USDA, ARS, Field Crops Laboratory, Albany, California.

Breath and Flatus Collection and Analysis

Breath samples were obtained before and at 30-min. intervals after the test meal until either 5 or 7:30 p.m. (8 to 10.5 hr. p.c.). Rectal flatus was collected from 10 a.m. through 5 or 6 p.m. (8 to 9 hr. p.c.). This was done by affixing to the shaved buttocks an adhesive colostomy patch with attached Tygon® tube. Both breath and flatus were collected in evacuated multilaminate plastic bags with a low coefficient of diffusion. Breath samples were analyzed chromatographically for concentration of H_2, as published previously (6). The total volume of flatus was measured manometrically and its content of O_2, N_2, CO_2, CH_4, and H_2 was determined chromatographically.

Breath-hydrogen-concentration data obtained from 2.5-hr. p.c. to the end of the test period were used to compute: 1) The time and magnitude of peak H_2 production, 2) the mean of the five highest H_2 values, and 3) total H_2 ventilated (mean breath-H_2 concentration X measured pulmonary ventilation per min. X 480 min.).

Flatulence due to test foods was evaluated by comparing total flatus volumes during the 6-hr. period from noon to 6 p.m. and by noting changes in the component gases as different test items were fed. CH_4 values were not included in the evaluation because they have been found to be characteristic of each individual and to show cyclic variation rather than to vary with the test meal (5). Finally, the total measured flatus H_2 was added to the calculated total breath-H_2 excretion following each test item.

RESULTS

Wheat Cereals

Breath and flatus values following consumption of the wheat cereals were compared with corresponding values observed after consumption of the baseline formula (Table II). Breath-H_2 values following 'Cream of Wheat' were equivalent to those following a formula meal: Peak concentration for both was 16 p.p.m. and the means of all breath-H_2 values were 9±4 and 8±2 p.p.m., respectively. Flatus total volume following 'Cream of Wheat' was about half that following the formula (72±40 vs. 142±62 ml.). Flatus CO_2 and H_2 volumes were also lower following 'Cream of Wheat' than formula. However, when the total breath-H_2 volume was added to the flatus-H_2 volume, there was little difference between the two (formula, 34±14 p.p.m.; and 'Cream of Wheat', 35±23 p.p.m.).

Breath and flatus values following 'Ralston', a whole-wheat cereal with 5% added wheat germ, were increased as compared to those following 'Cream of Wheat'. Peak breath-H_2 concentration was 35±15 p.p.m. and total breath-H_2 volume was 65±17 ml., almost double the respective values following 'Cream of Wheat'. Flatus total volume from 'Ralston' was also double that with 'Cream of Wheat' (158±160 and 72±40 ml., respectively). Flatus-CO_2 volume following 'Ralston' was 5±5 ml., which was an increase over that observed with 'Cream of Wheat' (2±2 ml.), but not more than that with the formula baseline (5±8 ml.). Flatus-H_2 volume following 'Ralston' was 6±9 ml., an increase over the respective values for both formula and 'Cream of Wheat' (2±6 and 0.2±0.4 ml.). Total H_2 output was 78±20 ml. following 'Ralston', as compared to 35±23 following 'Cream of Wheat'.

Breath values following consumption of 'All Bran' were similar to those

TABLE II. INTESTINAL-GAS PRODUCTION FOLLOWING MEALS OF COMMERCIAL BREAKFAST CEREALS AND A BLAND LABORATORY FORMULA

Measure	Test Item			
	Formula N=8	'Cream of Wheat' N=8	'Ralston' N=7	'All Bran' N=2
Breath H_2				
Peak				
Concentration, p.p.m.	16±4[a]	16.0±7.0	35±15	28±15
Time, hr. p.c.	8±2	6.0±2.0	5±1	5±2
Mean concentration, p.p.m.				
Five highest values	11±3	14.0±7.0	22±3	26±13
All values	8±2	9.0±4.0	15±4	14±5
Total breath H_2[b]				
ml. excreted/8 hr.	31±10	38.0 ±19.0	65±17	61±32
Flatus volume, ml./6 hr.				
CO_2 volume	5±8	2.0±2.0	5±5	55±15
H_2 volume	2±6	0.2±0.4	6±9	37±14
Air component	-135	-69	-151	-196
Total H_2, ml.				
Calculated breath-H_2 ventilation (8 hr.) + observed flatus H_2 (6 hr.)	34±14	35.0 ±23.0	78±20	99±46

[a]All values are plus or minus one standard deviation.

[b]Mean breath-H_2 concentration X measured pulmonary ventilation per min. X 480 min.

following 'Ralston', but flatus volume was not. The peak breath-H_2 value was 28±15 p.p.m. and total breath H_2 was 61±32 ml. Flatus total volume following the consumption of 'All Bran' was much larger than that following 'Ralston', as were the volumes of CO_2 and H_2. Respective values were: total volume, 289±36 ml. vs. 158±160 ml.; CO_2, 55±15 ml. vs. 5±5 ml.; and H_2 volume, 37±14 ml. vs. 6±9 ml. These comparisons clearly demonstrate that wheat fractions removed in milling include components that support increased bacterial activity in the intestine. Therefore, various milling fractions were tested to identify the causative portion(s) of the grain.

Wheat Fractions

Breath and flatus values following the wheat fractions were evaluated against corresponding values obtained with the wheat starch alone (Table III). There was a small increase in the peak, mean, and total breath-H_2 values following each wheat fraction as compared to the wheat starch. However, with the exception of the combined red dog and shorts fractions, there was no significant difference in the values among fractions. Peak H_2 concentration varied somewhat among fractions (endosperm, 15±6 p.p.m.; germ, 10±3 p.p.m.; and bran, 20±7 p.p.m.), but the means of the five highest H_2 values (endosperm, 12±5 p.p.m.; germ, 9±2 p.p.m.; and bran, 13±3 p.p.m.) and the total breath-H_2 values (endosperm, 31±15 ml.; germ, 28±6 ml.; and bran, 34±4 ml.) were quite similar. Breath-H_2 values following the combined red dog and shorts fractions were 50 to 100% higher than those following the other three fractions (peak H_2 concentration, 31±13 p.p.m.; mean of five highest H_2 values, 19±4 p.p.m.; and total breath H_2, 57±8 ml.).

TABLE III. INTESTINAL-GAS PRODUCTION FOLLOWING TEST DOSAGES OF WHEAT FRACTIONS EQUIVALENT TO THEIR OCCURRENCE IN 150 g. WHOLE WHEAT

Measure	Wheat Fractions				
	Starch N=3	Endosperm 111.45 g. N=5	Germ 0.75 g. N=4	Red dog + shorts 17.70 g. N=3	Bran 17.25 g. N=5
Breath H_2					
Peak					
Concentration, p.p.m.	8.0±4.0[a]	15.0± 6.0	10±3	31±13	20±7
Time, hr. p.c.	8.0±4.0	9.0± 1.0	8±2	6±3	6±2
Mean concentration, p.p.m.					
Five highest values	7.0±3.0	12.0± 5.0	9±2	19±4	13±3
All values	5.0±2.0	8.0± 4.0	6±2	13±2	9±2
Total breath H_2[b]					
ml. excreted/8 hr.	19.0±8.0	31.0±15.0	28±6	57±8	34±4
Flatus volume, ml./6 hr.					
CO_2 volume	4.0±0.8	3.0± 3.0	3±3	11±10	8±11
H_2 volume	0.5±0.7	0.6± 1.1	3±4	16±19	4±6
Air component	~185	~118	~75	~300	~145
Total H_2, ml.					
Calculated breath-H_2 ventilation (8 hr.) + observed flatus H_2 (6 hr.)	19.0±8.0	31.0±16.0	28±7	73±11	38±9

[a] All values are plus or minus one standard deviation.

[b] Mean breath-H_2 concentration X measured pulmonary ventilation per min. X 480 min.

Flatus-H_2 and CO_2 volumes were small and gave somewhat differing pictures of the effects of the wheat fractions on intestinal-gas production. CO_2 volume was highest for the combined red dog and shorts fractions (11±10 ml.) and for the bran fraction (8±11 ml.) and was produced in small but almost identical amounts following the endosperm (3±3 ml.), germ (3±3 ml.), and carrier starch (4±0.8 ml.). Flatus-H_2 volume was also highest for the combined red dog and shorts fractions (16±19 ml.) and was lower with the germ (3±4 ml.) and the bran (4±6 ml.) fractions. Only a very small amount of flatus H_2 was noted from the endosperm (0.6±1.1 ml.) fraction and the starch carrier alone (0.5±0.7 ml.). Total H_2 (breath plus flatus) volumes varied in a manner similar to the other breath and flatus values, with the combined red dog and shorts fractions being highest (73±11 ml.), followed by bran (38±9 ml.), endosperm (31±16 ml.), and germ (28±7 ml.).

Theoretically, the sum of the separate fraction H_2 values should approximate those following the whole-wheat cereal, since the fractions were fed in amounts corresponding to their content in a 150-g. dose of whole wheat. (A slight discrepancy would be expected in light of the 5% added wheat germ in 'Ralston'.) The starch-corrected means of the five highest H_2 values following the separate germ, endosperm, bran, and red dog plus shorts fractions are 2, 5, 6, and 12 p.p.m.; the total of these, 25 p.p.m., is quite like the 22 p.p.m. found with 'Ralston' (Table IV). The means of all breath-H_2 values also indicate that the effects of the fractions are additive (individual fractions 1, 3, 4, 8 = 16 p.p.m. vs. 15 p.p.m. with 'Ralston'). The calculated breath-H_2 values are similar, but not identical, for the combined fractions and 'Ralston' (74 vs. 65 ml.). However, the sum of the total H_2 volumes (breath plus flatus), 94 ml., was larger than the corresponding 'Ralston' value, 78±20 ml.

DISCUSSION

Total flatus volumes were recorded and corrected for air in collection-device deadspace. However, because of the large remaining N_2 and O_2 components, the only proved source of which is air (7), this total measure may not accurately reflect the effect of the test meal. Total volume includes unrelated factors such as the amount of air swallowed as such or as a component of air-containing foods. This is probably even more the case when total flatus volumes are small, such as those noted here with wheat, rather than with larger total volumes such as those noted following legume test meals (8). Thus, greater reliance is placed, in evaluating foods, on the components definitely due to intestinal factors, i.e., CO_2 and H_2.

'All Bran' definitely caused more intestinal gas of bacterial origin than any other sample at the dosages tested. Approximately nine times more 'All Bran' cereal (150 g.) was fed than wheat-bran fraction (17.25 g.), and flatus component-gas volumes were approximately eight times larger with 'All Bran'. However, breath-H_2 values were only slightly higher with 'All Bran' than with bran fraction. This suggests that the diffusion capacity (intestinal lumen to blood) for H_2 was exceeded following the consumption of 150 g. of 'All Bran', or that the larger dosage resulted in greater evolution of gas lower in the colon where diffusion would be poorer (5,6).

The small difference in gas production following consumption of the endosperm, germ, and bran fractions was surprising considering the marked differences in composition of the fractions. Their proximate carbohydrate composition (9) indicates a concentrating of starch in the endosperm, sugar in the germ, and cellulose and hemicellulose in the bran fraction. The red dog and shorts fractions contain varying amounts of bran and fine fibrous matter, pieces of germ (mainly scutellum), and flakes of endosperm (10).

Linko (11) has reported the component-sugar analysis of commercial wheat germ, using chromatographic techniques for separation of the individual sugars. Values were given as percent of total sugars (28.6 g. per 100 g. germ) present. Sucrose (55.9%) and raffinose (38.1%) are by far the most prevalent sugars. Since commercial wheat germ is contaminated with varying amounts of bran and endosperm, the fructose (2.8%), glucose (2.1%), and melibiose (1.1%) present are thought to be the result of contamination, or possibly of partial hydrolysis of sucrose and raffinose (9).

Saunders and Walker (12) have reported the sugars of Canadian hard wheat bran also as percent of total sugars (6.48 g. per 100 g. bran) present. As with wheat

TABLE IV. COMPARABILITY OF INTESTINAL H_2 PRODUCED FROM WHEAT FRACTIONS AND WHOLE-WHEAT CEREAL

Measure	Germ 0.75 g.	Endosperm 111.45 g.	Bran 17.25 g.	Red Dog + Shorts 17.70 g.	Total (150 g. whole wheat)	'Ralston' 150 g.
$\bar{X}$ Five highest H_2 values (p.p.m.)	9	12	13	19	...	...
minus starch baseline (7 p.p.m.)	2	5	6	12	25	22
$\bar{X}$ All H_2 values (p.p.m.)	6	8	9	13	...	...
minus starch baseline (5 p.p.m.)	1	3	4	8	16	15
Calculated breath H_2 (ml.)[a]	28	31	34	57	...	...
minus starch baseline (19 ml.)	9	12	15	38	74	65
Total H_2 : Breath + flatus (ml.)	28	31	38	73	...	...
minus starch baseline (19 ml.)	9	12	19	54	94	78

[a]Mean breath-H_2 concentration X measured pulmonary ventilation per min. X 480 min.

germ, sucrose is the predominant sugar (35.3%), with raffinose second in concentration (22.7%). Stachyose, which had not been previously reported in wheat, was also found to be present (2.6%). Using these reported sugar percentages, and assuming that the wheat fractions used in the study (North Dakota-grown No. 2-grade hard dark northern spring wheat) were comparable, it can be calculated that the 17.25 g. of bran contained 0.22 g. of raffinose and 0.02 g. of stachyose, whereas the 0.75 g. of germ contained only 0.07 g. of raffinose.

The endosperm fraction (clear flour plus patent flour) fed in this study contained approximately 2.3% sugar. However, a component-sugar analysis was not available for it nor for the red dog and shorts fractions. A sugar analysis of the latter two fractions would be interesting, since the combined weight of the two (17.70 g.) was almost identical to the weight of bran fed (17.25 g.), and yet the combined red dog and shorts fractions resulted in gas-production values that were 50 to 100% above those for the bran fraction.

Raffinose and stachyose, the primary nondigestible sugars present in foods, are thought to contribute importantly to the increased intestinal H_2 (6) and total gas (13) production due to bacterial action in the intestinal tract. If so, these were present in the endosperm, germ, and bran fractions in amounts too small to produce noticeable differences in intestinal-gas production in this study. In contrast, the amounts of these sugars or other factors found in 150 g. of 'All Bran' cereal, approximately nine times as much as fed in the bran fraction alone, could have been enough to result in a definite increase in intestinal-gas production. Gas production following the red dog and shorts fractions was higher than that following any of the other separate fractions and probably accounts for a large part of the intestinal-gas production associated with whole-wheat cereals.

Literature Cited

1. WEINSTEIN, L., OLSON, R. E., VAN ITALLIE, T. B., CASO, ELIZABETH, JOHNSON, DORIS, and INGELFINGER, F. J. Diet as related to gastrointestinal function. J. Amer. Med. Ass. 176: 935 (1961).
2. TURNER, DOROTHEA. Handbook of diet therapy, 4th ed. The University of Chicago Press: Chicago (1965).
3. WILLIAMS, R. D., and OLMSTED, W. H. The manner in which food controls the bulk of the feces. Ann. Intern. Med. 10: 717 (1939).
4. CALLOWAY, DORIS H., COLASITO, D. J., and MATHEWS, R. D. Gases produced by human intestinal microflora. Nature (London) 212: 1238 (1966).
5. CALLOWAY, DORIS H. Respiratory hydrogen and methane as affected by consumption of gas forming foods. Gastroenterology 51: 383 (1966).
6. CALLOWAY, DORIS H., and MURPHY, E. L. The use of expired air to measure intestinal gas formation. Ann. N.Y. Acad. Sci. 150: 82 (1968).
7. CALLOWAY, DORIS H. Gas in the alimentary canal. Chapter 137, Alimentary canal. Handb. Physiol. 5: 2839 (1968).
8. CALLOWAY, DORIS H., HICKEY, CAROL A., and MURPHY, E. L. Reduction of intestinal gas-forming properties of legumes by traditional and experimental food processing methods. J. Food Sci. 36: 251 (1971).
9. BECHTEL, W. G., GEDDES, W. F., and GILLES, K. A. Carbohydrates. In: Wheat: Chemistry and technology, ed. by I. Hlynka. American Association of Cereal Chemists: St. Paul, Minn. (1964).
10. JONES, C. R., and ZIEGLER, E. Principles of milling. In: Wheat: Chemistry and technology, ed. by I. Hlynka. American Association of Cereal Chemists: St. Paul, Minn. (1964).

11. LINKO, P., CHENG, Y., and MILNER, M. Changes in the soluble carbohydrates during browning of wheat embryos. Cereal Chem. 37: 548 (1960).
12. SAUNDERS, ROBIN M., and WALKER, H. G., Jr. The sugars of wheat bran. Cereal Chem. 46: 85 (1969).
13. STEGGERDA, F. R. Gastrointestinal gas following food consumption. Ann. N.Y. Acad. Sci. 150: 57 (1968).

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