Alkylresorcinols in U.S. and Canadian Wheats and Flours

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ABSTRACT

Wheat samples from the United States and Canada and flours from those wheats were analyzed for alkylresorcinols. Alkylresorcinols in wheats ranged from 317.5 to 655.0 μg/g dry weight. Flours contained very small amounts of alkylresorcinols and the values ranged from 0.025 to 14.45 μg/g dry weight. Generally, hard wheats had higher protein and lower alkylresorcinols; soft wheat had lower protein and higher alkylresorcinols. Linear regression analysis between protein and alkylresorcinol content indicated that they are negatively correlated. Wheat type had no effect on flour alkylresorcinol content. Patent percentage of flours was shown to be positively correlated with the amount of alkylresorcinols. Both kernel maturity and cereal types influenced the amount of alkylresorcinols. As maturity increased, alkylresorcinol content decreased.

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A group of compounds known to inhibit growth in several animal species has been isolated from cereal grains (Wieringa 1967, Evans et al 1973, Pawlik 1979, Sedlet et al 1984) and identified as resorcinol derivatives with hydrocarbon chains at the fifth position. Cereal alkylresorcinols were found to be mixtures of saturated, monoenoic, and dienoic homologs with 13–29 carbon side chains (Wieringa 1967; Kozubek 1984b, 1987a; Seitz and Love 1987). The C21, C23, C25, C27, and C29 homologs were observed in rye oil (Briggs 1974). In wheat bran, the C25 and C27 components were found to be predominant (Wenkert et al 1964). Wieringa (1967) states that factors such as soil type, fertilization, and weather may influence the content of alkylresorcinols. Cereal grains grown under the same agronomic and climatic conditions during consecutive crop years showed only slight variations from year to year. However, Verdeal and Lorenz (1977) found that alkylresorcinol content decreases in rye and triticale as the grains mature. Alkylresorcinols are present quite early in kernel development, and the apparent decrease in proportion of alkylresorcinols may be a dilution effect, partly due to deposition of starch and protein in developing grain kernels.

By milling wheat, rye, and triticale into bran, shorts, and flour fractions, and subsequent analysis, Verdeal and Lorenz (1977) and Salek (1978) showed the bran to contain the highest alkylresorcinol level. Intermediate values were found in the shorts, whereas the flour fractions produced relatively low values. This indicates that a gradient exists with the highest amounts of the compounds in the pericarp, intermediate amounts in the aleurone layer, and relatively small but detectable amounts in the endosperm portion of cereal grain kernels. Seitz and Love (1987) suggested that analyses of alkylresorcinols in milling fractions could be a useful measure of bran contamination in flours. Generally, the amount of alkylresorcinols in cereals is highest in rye, lower in wheat and triticale, and very low in other cereals such as oats, barley, and corn (Verdeal and Lorenz 1977, Musehold 1978, Kozubek and Demel 1980). However, some varieties of wheat have an alkylresorcinol content similar to that of rye. Selection of cultivar progeny was effective in increasing or decreasing alkylresorcinol content (Evans et al 1973).

Thus far, these compounds have only been suspected to be detrimental factors in animal nutrition, although concern has occasionally been raised about possible ill-effects on humans in European countries with high rye bread consumption (Anonymous 1974). There are no established human toxicity levels for these compounds. In model studies, alkylresorcinols were shown to cause red blood cell hemolysis, permeability changes of erythrocytes and liposomes to small solutes, and DNA strand scission, and to be involved in many pathological conditions (Kozubek 1984a, 1987b; Kozubek and Demel 1980; Kozubek et al 1988).

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It was the purpose in this study to determine 1) the effect of wheat types (hard, soft, and mixed) on alkylresorcinol content of wheat grains; 2) the effect of types of flour (hard, soft, and mixed wheat flour) and patent percentage on alkylresorcinol contents of commercial wheat flours; and 3) the effect of kernel maturity and cereal species on alkylresorcinol content.

MATERIALS AND METHODS

Wheat samples (Table I) that differed in hardness and origin were analyzed. These samples were grouped into wheat classes: A, hard red winter wheat; B, hard red spring wheat; C, white wheat; D, soft red winter wheat; and E, unclassified or mixed wheat. Canadian wheat, i.e., Alberta red winter, was included in group A; Alberta red spring and Western (Canada) red spring were included in group B; and Ontario soft winter and Alberta soft white spring were included in group C. Flour samples commercially milled from these wheats were divided into six major categories depending on the end use. The extraction rate, patent percentage, and protein content are shown in Table I.

The study of the effect of cereal type and kernel maturity on alkylresorcinol content included one wheat, four triticales, two ryes, and two durums. The wheat cultivar, Colano, was a hard red spring type selected from the CIMMYT program and released by Colorado State University. Two of the four triticales, 6TA204 and 6TA206, were tall spring types obtained from the Jenkins Research Foundation. Triticale RF720009 and RF720011 were semidwarf spring selections from the Armadillo cross obtained from the CIMMYT program. The two durums, RF710066 and RF710222, are spring semidwarf selections from the CIMMYT program.

Grains were seeded in plots 24 rows wide, with a row length of 3.05 m, and 25.4 cm between rows. The plots were planted at the Colorado State University Agronomy Research Center, Fort Collins, CO. These plots were on summer fallow ground and no fertilizer was added. The plots received three irrigations of approximately 6.35 cm each prior to the initial harvest.

Several rows of each cultivar were harvested one and two weeks before final kernel maturity and at full maturity. After harvesting, all the grain kernels were removed from the heads by hand. The grains were stored in plastic containers under nitrogen at −10° F until analysis.

Moisture and Protein Analyses

Moisture of the grains and flours was determined using AACC method 14-15A and protein by method 46-12 (AACC 1969).

Fluorometric Determination of Alkylresorcinol Contents

The method used was a modification of that described by Verdeal and Lorenz (1977). A sample of 1.25 g of whole grain or 2.5 g of flour was soaked at room temperature with an equal amount of acetone by weight in a Pyrex screw-cap tube. After 24 hr, the extract was filtered through No. 1 Whatman paper and then saved. The grain or the flour was again immersed in

TABLE I
Sample Identification, Composition, and Alkylresorcinol Content of Wheats and Flours

Sample No.	Wheat: Origins and Types[a]	Wheat Class[b]	Protein (% db)	AR[c] Content (μg/g, db)	Flour: Extraction Rate (%)	Patent (%)	Protein (% db)	Flour Type[d]	AR[c] Content (μg/g, db)
1	100% KS-HW	A	NA[e]	NA	74.0	85.0	11.31	AP	5.42 ± 0.03
2	100% MN-HW	B	11.67	384.5 ± 0.7	74.1	96.8	11.47	AP	9.27 ± 0.24
3	100% AZ-HW	A	12.51	378.5 ± 1.3	73.5	100.0	12.57	AP	0.09 ± 0.00
4	100% TN-SRW	D	9.22	533.0 ± 42.4	75.0	82.0	ND	AP	NA
5	100% ID-HW	E	11.65	308.0 ± 4.2	70.0	100.0	12.02	AP	0.08 ± 0.00
6	60% IL-HW, 40% KS-HW	A	11.31	569.0 ± 15.6	74.0	90.0	11.09	AP	NA
7	66% MT-HW, 16% IL-HW, 18% IN-SW	E	12.01	582.0 ± 1.4	75.3	91.0	11.60	AP	0.06 ± 0.00
8	100% TX, OK-HYW	A	11.83	495.0 ± 17.0	74.0	95.0	11.62	AP	0.05 ± 0.00
9	80% ND-HS, 20% MN-HS	B	13.73	402.0 ± 5.7	75.0	96.0	13.79	AP	3.91 ± 0.00
10	70% IN-SRW, 30% SC-SRW	D	10.43	478.0 ± 0.0	70.0	50.0	9.75	AP	2.56 ± 0.12
11	100% WRS	B	13.92	472.0 ± 18.4	73.0	56.0	13.88	AP	3.24 ± 0.01
12	100% WRS	B	14.00	437.0 ± 2.8	73.0	80.0	14.04	AP	10.42 ± 0.13
13	100% WRS	B	13.71	457.5 ± 17.7	73.0	52.0	13.64	AP	3.68 ± 0.14
14	100% WRS	B	13.95	471.0 ± 2.8	74.6	26.0	13.45	AP	11.42 ± 0.14
15	67% IS-HW, 33% MN-HS	E	13.76	454.5 ± 9.2	74.0	100.0	13.33	BP	14.42 ± 0.60
16	50% KS-HW, 50% ND-HS	E	14.36	332.5 ± 12.0	74.0	80.0	14.48	BB	8.31 ± 0.42
17	100% KS, NE-HW	A	12.99	NA	74.0	94.0	12.89	BB	11.09 ± 0.41
18	100% KS-HW	A	13.34	NA	75.0	95.0	13.26	BB	6.82 ± 0.01
19	90% NE-HW, 10% SD-HS	E	NA	450.5 ± 3.5	78.0	95.0	13.14	BB	NA
20	100% MT-HW	B	14.06	413.0 ± 33.9	74.0	94.8	13.72	BB	0.12 ± 0.00
21	10% ND-HS, 60% CO-HW, 15% WY-HW, 15% NE-HW	E	13.35	442.5 ± 2.1	74.0	95.0	13.47	BB	0.10 ± 0.00
22	40% MN, SD-HS, 50% OH-HW, 10% ?-SR	E	13.24	400.0 ± 15.6	74.1	88.0	13.16	BB	0.11 ± 0.00
23	60% TX-HW, 40% KS-HW	A	13.69	426.5 ± 12.0	74.5	95.0	13.43	BB	0.09 ± 0.00
24	100% ND-HS	B	16.30	409.5 ± 2.1	75.0	100.0	16.08	BB	0.10 ± 0.00
25	100% ND-HS	B	15.01	449.5 ± 10.6	73.0	98.0	14.62	BB	0.06 ± 0.00
26	29% ND, SD-HS, 71% SD, NE-HW	E	12.94	350.5 ± 23.3	73.0	80.0	12.73	BB	0.05 ± 0.00
27	30% ND-HS, 35% OK-HW, 35% KS-HW	E	13.11	490.0 ± 21.2	74.8	94.0	12.94	BB	0.10 ± 0.01
28	100% KS, NE-HW	A	12.72	386.5 ± 0.7	74.1	96.0	12.67	BB	10.02 ± 0.48
29	100% MN, ND-HS	B	15.56	394.5 ± 10.6	74.0	98.0	14.88	BB	3.93 ± 0.25
30	100% KS-HW	A	13.49	433.0 ± 7.1	72.0	96.0	13.43	BB	6.07 ± 0.23
31	100% Pacific NW-HS	B	13.73	439.5 ± 6.4	75.0	96.0	14.28	BB	5.09 ± 0.02
32	100% Pacific NW-HS	B	14.01	378.0 ± 12.7	75.0	100.0	13.56	BB	6.77 ± 0.00
33	100% MN-HS	B	13.94	317.5 ± 3.5	74.0	76.0	13.75	BB	4.26 ± 0.00
34	100% ARS	B	14.84	410.0 ± 2.8	75.5	NA	14.68	BB	11.27 ± 0.02
35	100% WRS	B	14.92	421.0 ± 2.8	72.0	100.0	14.67	BB	9.97 ± 0.25
36	100% WRS	B	14.38	394.5 ± 3.5	74.0	96.0	14.39	BB	12.66 ± 0.11
37	100% WRS	B	15.02	500.5 ± 7.8	72.0	59.0	15.12	BB	7.35 ± 0.21
38	100% WRS	B	14.48	398.5 ± 17.7	75.5	71.5	14.54	BB	8.11 ± 0.52
39	80% ?-HW, 20% ?-HS	E	14.07	390.0 ± 0.0	NA	NA	NA	BB, HB	NA
40	100% MN-HS	B	16.33	449.5 ± 10.6	74.5	100.0	16.16	HB	11.42 ± 0.01
41	100% SD-HS	B	15.32	414.0 ± 12.7	75.2	100.0	15.90	HB	14.47 ± 0.01
42	100% SD, ND-HS	B	16.06	377.0 ± 5.7	72.2	100.0	16.16	HB	5.93 ± 0.25
43	90% ND-HS, 10% MT-HW	E	14.00	410.5 ± 0.7	72.0	80.0	13.95	HB	3.93 ± 0.24
44	100% WRS	B	17.06	412.5 ± 0.7	76.0	ND	16.76	HB	11.65 ± 0.01
45	100% WRS	B	15.41	444.5 ± 24.7	72.0	59.0	14.75	HB	10.15 ± 0.01
46	100% OH, IN-SR	D	8.92	418.0 ± 4.2	74.0	35.0	8.91	C	9.04 ± 0.01
47	100% IL, IN-SRW	D	9.27	517.0 ± 12.7	76.0	65.0	9.05	C	0.04 ± 0.00
48	100% ID-SW	C	9.19	655.0 ± 7.1	75.7	50.3	9.10	C	0.03 ± 0.00
49	100% OH-SR	D	9.87	393.0 ± 2.8	75.5	49.6	9.65	C	0.11 ± 0.01
50	100% VI-SRW	D	9.10	559.5 ± 0.7	70.0	20.0	8.87	C	2.10 ± 0.12
51	100% WA-S	C	9.28	513.5 ± 27.6	70.5	58.5	8.85	C	0.34 ± 0.00
52	90% ASWS, 10% ARW	E	9.83	587.0 ± 1.4	71.0	25.0	9.82	C	1.24 ± 0.00
53	50% ASWS, 50% ARW	E	10.69	447.5 ± 10.6	75.0	67.0	10.43	C	11.85 ± 0.74
54	100% OSW	E	9.38	405.5 ± 6.4	75.0	100.0	9.31	C	2.22 ± 0.13
55	60% OSW, 40% ASWS	E	10.24	475.5 ± 3.5	77.2	100.0	10.44	S,P,C	8.89 ± 0.12
56	100% MO-SRW	C	10.73	629.5 ± 10.6	74.0	100.0	10.14	S	11.56 ± 0.35
57	100% OH-SRW	D	10.03	NA	70.0	35.0	10.05	S	8.11 ± 0.22
58	100% MI-SWW	D	9.95	467.5 ± 10.6	72.0	100.0	9.77	S	9.05 ± 0.03
59	100% OH, IN-SR	D	10.38	NA	74.0	100.0	10.36	S	0.11 ± 0.00
60	80% WA, ID, MT-SWW, 20% MT-HW	E	10.97	573.5 ± 37.5	76.1	ND	10.10	S	2.26 ± 0.12
61	70% OH-SRW, 30% MI-SWW	D	10.19	NA	74.8	92.0	9.95	S	0.04 ± 0.00
62	100% IN, KY, TN-SRW	D	9.90	429.0 ± 19.8	72.0	ND	9.75	S	3.46 ± 0.12
63	60% ARW, 40% OSW	E	11.57	433.0 ± 1.4	72.0	70.0	11.39	S	9.56 ± 0.13
64	100% OSW	E	10.26	431.5 ± 17.7	70.0	100.0	10.44	S	9.32 ± 0.01
65	100% ID-HS	E	14.88	456.5 ± 4.9	ND	71.6	13.38	P	0.12 ± 0.00

[a] Origins: AZ = Arizona, CO = Colorado, IA = Iowa, ID = Idaho, IL = Illinois, IN = Indiana, KS = Kansas, KY = Kentucky, MI = Michigan, MN = Minnesota, MO = Missouri, MT = Montana, NE = Nebraska, ND = North Dakota, OH = Ohio, OK = Oklahoma, SC = South Carolina, TN = Tennessee, TX = Texas, WA = Washington, WY = Wyoming, VI = Virginia, ? = Unknown. Types: HW = hard red winter, HYW = hard yellow winter, ARW = Alberta red winter, HS = hard red spring, ARS = Alberta red spring, WRS = western (Canada) red spring, SWW = soft white winter, SW = soft white, OSW = Ontario soft winter, ASWS = Alberta soft white spring, SRW = soft red winter, SR = soft red.

[b] Wheat class groupings: A = HW, HYW, ARW; B = HS, ARS, WRS; C = SWW, SW, OWS, ASWS; D = SRW, SR; E = Unclassified or mixed-region wheat.

[c] Alkylresorcinol.

[d] Flour types: AP = All-purpose, BB = baker's bread, HB = hearth bread, C = cake, S = cookies and crackers, P = pasta.

[e] Not analyzed.

TABLE II
Protein and Alkylresorcinol (AR) Content of Hard, Soft, and Mixed Wheat Grains from the United States and Canada (% dry basis)[a]

Wheat Class Groupings[b]	Hard Wheats Protein (%)	Hard Wheats AR[b] Content (μg/g)	Soft Wheats Protein (%)	Soft Wheats AR Content (μg/g)	Mixed Wheats Protein (%)	Mixed Wheats AR Content (μg/g)
A (HW, HYW, ARW)	12.64 ± 0.35	448.1 ± 24.9	...[c]	...	...	...
B (HS, ARS, WRS)	14.57 ± 0.20	417.5 ± 12.7	...	...	...	...
C (SWW, SW, OWS, ASWS)	...	...	9.76 ± 0.42	535.8 ± 27.3	...	...
D (SRW, SR)	...	...	9.71 ± 0.30	474.4 ± 21.6	...	...
E (unclassified)	13.41 ± 0.33	408.6 ± 19.3	10.26 ± 0.00	431.5 ± 0.0	11.36 ± 0.38	503.8 ± 24.9

[a] Mean ± SEM.
[b] Type abbreviations as in Table I.
[c] No sample in that category.

TABLE III
Average Patent Percentage and Alkylresorcinol (AR) Content in Flours of Hard, Soft, and Mixed Wheats (μg/g dry basis)[a]

Wheat Class Groupings[b]	Hard Wheats Patent (%)	Hard Wheats AR[b] Content (μg/g)	Soft Wheats Patent (%)	Soft Wheats AR Content (μg/g)	Mixed Wheats Patent (%)	Mixed Wheats AR Content (μg/g)
A (HW, HYW, ARW)	94.5	4.96 (8)	...[c]	...	...	...
B (HS, ARS, WRS)	83.2	7.18 (23)	...	...	...	...
C (SWW, SW, OWS, ASWS)	...	...	63.8	4.61 (5)	...	...
D (SRW, SR)	...	...	60.7	3.43 (10)	...	...
E (unclassified)	87.6	3.39 (8)	...	...	68.2	4.56 (5)

[a] Mean of the number of observations in parentheses.
[b] Abbreviations as in Table I.
[c] No sample in that category.

the same amount of acetone and filtered after 24 hr. Filtrates were combined with previous extracts. Grains were dried and ground, and the ground grain or the flour was soaked again with acetone in the proportion 1:5, filtered after 24 hr, and this filtrate added to the previous extract. The volume of collected extracts was made up to 25 ml with acetone. Two aliquots of 2.0 ml each were transferred to Teflon-lined Pyrex screw-cap tubes, and the acetone was removed in a water bath at 85°C. After cooling to room temperature, the residue was dissolved in 0.4 ml of chloroform. Following the addition of 0.1 ml of 75% ethanol and 0.1 ml of 75% KOH, the tube was capped tightly, placed in a shaker bath at 45°C, and agitated every 2–3 min. After 20 min, 1.0 ml of distilled water was added followed by 8.4 ml of 95% ethanol. The total volume of 10 ml was shaken and allowed to stand for 30 min. Prior to measuring the fluorescence on a Hitachi Perkin-Elmer MPF-2A spectrofluorometer (Perkin-Elmer, Norwalk, CT), the tube was shaken again. The excitation and emission wavelengths were 420 and 520 nm, respectively. A standard curve was prepared from 5-pentadecylresorcinol (Aldrich, Milwaukee, WI) with each set of samples.

Statistical Design and Analysis

For wheat grain, a completely randomized design was used to determine the effects of wheat types (hard, soft, and mixed) on alkylresorcinol and protein contents. All the results are the average values of two replicates of 62 samples. Pearson correlation analysis was also employed to determine the correlation between protein contents and alkylresorcinol contents of these wheats.

A randomized complete block design was used to determine the effects of wheat types (hard, soft, and mixed) on alkylresorcinol contents of the flour samples. The correlation between patent percentage and the amount of alkylresorcinol was analyzed by Pearson correlation analysis. Tests of significance among treatment means were performed by least significance difference. All of the data were analyzed by using the Statistical Package for the Social Sciences (SPSS 1988).

A factorial design was used to determine the effects of grain types and kernel maturity and their interaction on alkylresorcinol contents. The effect of different grain types at only the fully mature stage was analyzed separately by a completely randomized design. All the values are reported as means of the two replicates. One way analysis of variance (LSD) was employed to determine if differences in means were statistically significant. All analyses were also done by SPSSX.

TABLE IV
Alkylresorcinol Content of Different Types of Cereals at Different Harvest Times (μg/g)[a]

Sample	Two Weeks Before Full Maturity	One Week Before Full Maturity	Fully Mature
Prolific rye	488.5 ± 7.8 a[b]	416.0 ± 0.0 b	335.0 ± 0.0 c
Balboa rye	587.0 ± 1.4 a	398.0 ± 1.4 b	405.0 ± 12.7 b
Durum RF710066	281.5 ± 0.7 a	251.5 ± 7.8 b	210.5 ± 13.4 c
Durum RF710222	330.0 ± 28.8 a	334.0 ± 9.9 a	334.5 ± 9.2 a
Triticale 6TA204	384.5 ± 10.6 a	330.0 ± 25.5 b	294.0 ± 5.7 c
Triticale 6TA206	436.5 ± 0.7 a	305.0 ± 0.0 b	318.0 ± 11.3 b
Triticale RF720011	382.5 ± 10.6 a	322.5 ± 0.7 b	357.5 ± 26.2 c
Triticale RF720009	384.5 ± 5.0 a	347.0 ± 11.3 b	352.5 ± 0.7 b
Colano spring wheat	380.0 ± 11.3 a	375.0 ± 9.9 a	310.0 ± 1.4 b

[a] Mean ± SEM.
[b] Means not sharing common letter for the same row are significantly different (least significant difference), $P < 0.05$.

RESULTS AND DISCUSSION

Alkylresorcinol Content in U.S. and Canadian Wheat Grains and Flours

Results of grain analyses expressed as micrograms per gram of sample on a dry basis are presented in Table I. Alkylresorcinol (AR) contents in wheat grains ranged from 317.5 to 655.0 μg/g of wheat, or approximately 0.03 to 0.065%. This range is in agreement with the values obtained in a study of variability in alkylresorcinol content in rye grains compared with several cultivars of wheat by Kaczmarek and Tluscik (1985).

Verdeal and Lorenz (1977) showed hard red spring Chris wheat from two crop years (1972 and 1973) to have average AR contents of 0.062 and 0.065% and HRS Colano wheat from two crop years (1974 and 1975) to have an average AR content of 0.067%. A recent study by Gohil et al (1988), in which ARs in three samples of wheat variety Holme grown in Sweden were analyzed, showed 0.06% AR. In the present study of 59 samples of wheats from all over the United States and Canada, only a few samples (nos. 48, 56, and 60) had AR contents as high as those reported in previous studies.

Generally, the hard wheat samples (HW, HYW, ARW, HS, ARS, and WRS types in Table I) had lower average AR contents than the soft wheats (SWW, SW, OWS, ASWS, SRW, and SR). Therefore, in order to see the effects of wheat type (hard, soft, and mixed) on AR content of wheat, the data in Table I were summarized in Table II. Since hard and soft wheats are known to have different protein levels with generally higher levels in hard wheat, the protein data of all wheats studied were also summarized in Table II. The interrelationship between wheat types, protein contents, and AR contents is apparent.

White wheat (SWW, SW, OWS, and ASWS, group C) has the highest average AR content of 535.8 μg/g wheat. Even though the average AR content in soft red winter wheat (SRW and SR, class D) is lower than found in white wheats, it is still higher than in hard red spring wheat (B) or hard red winter wheat (A). Unclassified wheat was found to have the lowest AR content.

Statistical analyses of the effects of wheat types (hard, soft, and mixed) showed significant differences in AR contents between different wheat types ($P = 0.001$). Further analysis of differences among means of hard, soft, and mixed wheat by least significant difference shows differences between hard and soft and between hard and mixed but not soft and mixed. In general, hard wheats have a higher protein content and a lower AR content than soft wheats.

There were no significant differences in AR contents among the wheat class groupings A and B of the hard wheats. Within the soft wheats, the AR content of wheat classes in groups C and D were also not significantly different.

An interrelationship among wheat types, AR content, and protein content obviously exists. As previously mentioned, hard wheats have a higher protein and a lower AR content than soft wheats; soft wheats have a lower protein content and a higher AR content. Thus, it is clear that there is an inverse relationship between the amount of AR and protein. The Pearson correlation analysis produced a correlation coefficient of $r = -0.4802$ ($P < 0.0005$).

Flour samples contained very small amounts of AR. The values ranged from 0.025 to 14.47 μg/g for 56 samples in this study. This indicates that ARs are mainly found in the bran fraction of wheat milled into flour. The results thus support the findings by Wieringa (1967), Seitz and Love (1987), and Verdeal and Lorenz (1977) that ARs are present mainly in the bran fraction and the finding of Tluscik (1978) that ARs occur exclusively in the outer cuticle of rye and wheat, not in the germ and starchy endosperm.

Flour samples milled from the wheats had an average extraction rate of 73.6%, with a range of 70.0–78.0%. Patent percentage and wheat types, e.g., hard, soft, and mixed flours, and how they affect AR content were studied. The average patent percentages from different wheats and average AR values of the flours from these wheats are shown in Table III.

Flours from hard wheats have higher average AR contents than flours from soft wheats. This is different from the results of grain samples. However, statistical analyses show no significant differences in AR content of flours from hard, soft, and mixed wheats ($P = 0.228$). Since the amount of ARs in flours is very low, the accuracy of measurement or the higher variations within sample might affect the analyses, even though the fluorometric method chosen for the analyses is very sensitive, allowing detection of very small quantities of these compounds.

The desired patent percentage of a flour depends on the end use of the flour or flour type. Hard wheats milled to all-purpose, bread, pasta, and hearth flours have a higher patent percentage than soft wheats, which are milled into cake, cookie, and cracker flours. The results in Table III indicate that hard wheat flours that have a higher average patent percentage are higher in average AR content than soft wheat flours. Mixed wheat flours, with an average patent percentage value between hard and soft wheat flours, thus have AR content values between hard and soft wheat flours. When the correlation coefficient between patent percentage and AR content of flours was analyzed, the Pearson correlation coefficient (r) of 0.5265 ($P < 0.0005$) indicated a positive correlation between patent percentage and AR content.

Effects of Cereal Types and Kernel Maturity on Alkylresorcinol Content

Table IV shows AR contents of different types of cereals at different stages of maturity. Generally, ARs are highest in rye, intermediate in triticales and wheat, and lowest in durum. At final maturity, Balboa rye had the highest average AR value, followed by triticale RF720011, triticale RF720009, Prolific rye, durum RF710222, triticale 6TA206, Colano spring wheat, triticale 6TA204, and durum RF710066, respectively. The analysis of variance of the effects of cereal types and harvest time on AR content of the grains showed significance at $P < 0.0005$.

Most of the previous studies on AR content in different types of cereal were done by comparing AR content either in wheat and rye or in wheat, rye, and triticale. Rye was always shown to contain the highest AR content, as in this study. Kaczmarek and Tluscik (1985) stated that wheat is about twofold lower in AR content than rye. In this study, at full maturity only durum wheat RF710066 had an AR content about half of Balboa rye, which had the highest AR content. However, the other wheats, e.g., Colano spring wheat and durum wheat RF710222, had ARs close to that of triticale 6TA206 and Prolific rye, and statistical analyses showed no significant differences ($P > 0.05$).

Two triticales, RF720011 and RF720009, had higher AR contents than Colano spring wheat and durum RF710222. This is in agreement with results reported by Gohil et al (1988) in that AR content in triticale is significantly higher than in wheat. However, the other two triticales, 6TA204 and 6TA206, have AR contents lower than that of Colano spring wheat and durum RF710222. At full maturity, Prolific rye was also shown to have an AR content lower than that of triticales RF720011 and RF720009. This is contrary to the report by Gohil et al (1988), probably because the ryes, wheats, and triticales are normally grown under different agronomic and climatic conditions.

The amount of AR at the fully mature stages of rye, wheat, durum, and triticale in this study are about half of that reported by Verdeal and Lorenz (1977). The disagreement could be due to the differences in crop year. As indicated by Wieringa (1967), environmental conditions, which are different from year to year can affect AR content.

Table IV shows average AR contents of all grains at different stages of maturity. In general, AR content decreases during maturation. Statistical analysis showed significant differences ($P < 0.05$) in AR content at all different maturity stages, i.e., two weeks and one week before full maturity and fully mature. This supports the finding by Verdeal and Lorenz (1977) that ARs decrease during maturation. These compounds are believed to be present quite early in kernel development; therefore, the apparent decrease in AR content is a dilution effect partly due to deposition of starch and protein during kernel development while alkylresorcinol amounts remain constant.

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