Effect of Available Soil Phosphorus and Environment on the Phytic Acid Concentration in Oats[1]

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ABSTRACT

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Groat phytic acid concentration (GPA) was found to be positively correlated with available soil phosphorus (ASP) in seven oat (*Avena sativa* L.) cultivars in 1977 and 1978. Regression of GPA on ASP indicated that the amount of GPA synthesis with increasing ASP was not significantly different among cultivars within each year but was significantly different between years. GPA concentration differed significantly among cultivars within each year and was, on the average, significantly higher for each cultivar in 1978 than in 1977. Individual cultivar GPA-ASP relationships were similarly and significantly altered by environment.

Phytic acid is the hexaphosphate of myoinositol and the major storage form of phosphorus (P) in seeds (Roberts and Loewus 1968). It is nutritionally important because mineral deficiencies can be induced by phytic acid in humans and monogastric animals whose diets consist predominantly of whole grains and legumes high in phytic acid. Phytic acid chelates calcium (Anonymous 1967a, Taylor 1965), magnesium (Davies and Nightingale 1975), and zinc (Anonymous 1967a, Davies and Nightingale 1975) in the intestinal tract and reduces their absorption. Milling can remove most phytic acid, which is located predominantly in the aleurone layer of small grains and in the germ of corn (O'Dell et al 1972). Whether iron deficiencies associated with whole grain are induced by bran, phytic acid, or both is uncertain (Anonymous 1967b, Morris and Ellis 1976).

A positive correlation exists between available soil phosporus (ASP) and seed P in oats (Larson et al 1952, Moore et al 1957) and wheat (Bains 1949, Boatwright and Haas 1961, Srivastava et al 1955). ASP is positively correlated with phytic acid in wheat (Bains 1949, Srivastava et al 1955), and this correlation probably exists in many plant species; the ratio between seed phytic acid and P is fairly constant in oats (Ashton and Williams 1958, Lolas et al 1976), barley, wheat, soybeans, and beans (Lolas et al 1976). This information suggests that seed phytic acid and P are largely a function of ASP.

Phosphorus concentration in the seed varies significantly among cultivars of the same species for wheat, barley, and soybeans grown at one ASP level (Kleese et al 1968). Furthermore, in the same experiment, seed P concentration was not significantly affected by environment over the two years and locations in which the experiment was conducted. In another experiment, Ashton and Williams (1958) found no significant differences among the groat phytic acid (GPA) concentrations of six oat cultivars grown at one ASP level. The present study was undertaken to establish whether oat (*Avena sativa* L.) cultivars differ in their GPA-ASP relationship and whether environment affects this relationship.

MATERIALS AND METHODS

Field Design

Field studies were conducted during the 1977 and 1978 growing seasons at the University of Wisconsin Experimental Farm near Arlington on a plano silt loam (typic Arginidolls fine silty, mixed mesic). A split plot design was used with six replications. Main plot treatments were 0,20,78, and 157 kg of P per hectare (P_0,P_1,P_2, and P_3, respectively) in 1977. Main plots were reused in 1978, and the only P added was 49 kg/ha to the P_3 main plot. Phosphorus was hand-applied as 0-44-0 P_2O_5 fertilizer and incorporated before planting. ASP analyses were conducted before planting and after harvest at the University of Wisconsin Testing Laboratory by the method described by Liegel and Schulte (1977).

Seven oat cultivars (Wright, Garry, Dal, Orbit, Otter, Chief, and Stout) comprised the subplots, which were randomized within main plots. These cultivars could be commercially grown in Wisconsin but originated in different areas of the northern United States and Canada. Subplots were 0.3 m apart and had four 4.3-m long plant rows, of which only the center two were harvested.

Phytic Acid Analyses

The method of Miller et al (1980) was used to measure GPA.

Statistical Analyses

The statistical methods described by Draper and Smith (1966) were used. For each year, GPA was regressed on ASP within individual cultivars to determine whether a statistically significant relationship existed between these variables. Individual cultivar correlations were also run between these two variables. To determine whether slopes or intercepts or both were significantly different among cultivars, the following regression equations were used:

$$\text{GPA} = \beta_0 + \beta_1 (\text{ASP}) + \alpha_{01}Z_1 + \alpha_1 (\text{ASP}) + \alpha_{02}Z_2 + \alpha_2 (\text{ASP}) + \ldots + \alpha_{06}Z_6 + \alpha_6 (\text{ASP}) + \epsilon \quad (1)$$

$$\text{GPA} = \beta_0 + \beta_1 (\text{ASP}) + \alpha_{01}Z_1 + \alpha_{02}Z_2 + \ldots + \alpha_{06}Z_6 + \epsilon \quad (2)$$

$$\text{GPA} = \beta_0 + \beta_1 (\text{ASP}) \quad (3)$$

where ϵ represents experimental error and Z is a dummy variable having the values 0 or 1.

In equation 1, β_1 and α_1–α_6 are seven cultivar slopes. For equations 1 and 2, β_0 and α_{01}–α_{06} are seven cultivar intercepts. In equations 2 and 3, β_1 is the combined slope for seven cultivars, and β_0 is the combined intercept in equation 3. Cultivars significantly different in slopes are significantly different in their increase in GPA per unit of ASP, and cultivars having significantly different intercepts are on the average significantly different in GPA at any given ASP.

Data from 1977 and 1978 were analyzed separately. Input for each equation consisted of all GPA values (the dependent variable) for the seven cultivars and their corresponding main plot ASP values (the independent variable). Because each main plot contained seven subplots, each main plot ASP value was used seven times in each regression equation. The extra sum of squares principle was used to determine whether significant differences existed among slopes or intercepts or both (Draper and Smith

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TABLE I
Comparison of the Relationship of Percent Groat Phytic Acid and Available Soil Phosphorus for Seven Oat Cultivars in 1977 and 1978

Cultivar	Percent Groat Phytic Acid			r	Intercept
	Average	Range	Difference[a] (%)		
1977[b]					
Chief	1.04	0.95–1.13	18.9	0.78[c]	0.948 a[d]
Otter	1.07	0.98–1.13	15.3	0.71[c]	0.974 b
Stout	1.08	0.01–1.16	14.9	0.66[c]	0.985 b
Orbit	1.12	1.04–1.21	16.3	0.59[c]	1.029 c
Garry	1.13	1.03–1.21	17.5	0.74[c]	1.032 c
Dal	1.18	1.09–1.28	17.4	0.82[c]	1.083 d
Wright	1.20	1 11–1.29	16.2	0.77[c]	1.106 e
1978[e]					
Chief	1.25	1.17–1.31	12.0	0.73[c]	1.193 a
Otter	1.29	1.24–1.34	8.1	0.50[f]	1.236 b
Stout	1.31	1.20–1.37	14.2	0.39	1.254 bc
Garry	1.31	1.17–1.38	17.9	0.66[c]	1.253 bc
Orbit	1.31	1.23–1.39	13.0	0.49[f]	1.256 c
Dal	1.34	1.28–1.39	8.6	0.49[f]	1.285 d
Wright	1.37	1.33–1.41	6.0	0.52[c]	1.314 e

[a]Difference between upper and lower values of groat phytic acid.
[b]n = 24; equation 2 common slope = 0.0014; standard error of slope = 0.0001; standard error of intercept = 0.0098.
[c]$P = 0.01$.
[d]Intercepts followed by the same letter are not significantly different at the 5% level.
[e]n = 22–24; equation 2 common slope = 0.0008; standard error of slope = 0.0001; standard error of intercept = 0.0093.
[f]$P = 0.05$.

TABLE II
Comparison of Equations 1, 2, and 3 for 1977 and 1978[a]

Equation	1977				1978			
	SSR[b]		MSE[d]		SSR		MSE	
	df[c]	Value	df	Value	df	Value	df	Value
1	13	0.6853 a	154	0.00100	13	0.2640 a	145	0.00976
2	7	0.6754 a	160	0.00112	7	0.2567 a	151	0.00099
3	1	0.1932 b	166	0.00399	1	0.0637 b	157	0.00218

[a]L = larger regression model; S = smaller regression model. $[(SSR_L - SSR_S)/df_L - df_S)]/MSE_L$. The table value used for comparison is $F(df_L - SSR_S, df\ MSE)$.
[b]Sum of squares due to regression. Values followed by the same letter are not significantly different at the 5% level.
[c]Degrees of freedom.
[d]Error mean square.

1966). Equation 1 has seven slopes and intercepts, whereas equation 2 has only one slope and seven intercepts. If significant differences exist among cultivar slopes, equation 1 will predict GPA better than equation 2 and the equation 1 sum of squares due to regression (SSR) will be significantly larger than the equation 2 SSR. If slopes are not significantly different, an overall slope, as in equations 2 and 3, can be used and the SSRs of equations 2 and 3 can be compared to determine whether cultivar intercepts are significantly different. In the case of no differences, equation 2 with seven intercepts will not predict GPA better than equation 3 with one intercept. Therefore, equation 3 can be used for all cultivars if no significant difference is found among cultivar ASP-GPA relationships.

RESULTS AND DISCUSSION

The range of ASP was 34–106 kg/ha and 37–134 kg/ha in 1977 and 1978, respectively. The 1978 upper limit increased because of the additional application of P to P_3 main plots in 1978.

In both years, all correlations were positive, indicating that an increase in ASP was associated with an increase in GPA (Table I). In 1977, all correlations were significant at the 1% probability level. In 1978, three correlations were significant at the 1%, three at the 5%, and one (Stout) at the 10% probability level. All correlations were higher in 1977 than in 1978.

Within each year, individual cultivar slopes were not significantly different, as indicated by the lack of a significant difference each year between the SSRs of equations 1 and 2 (Table II). Equation 2 slopes were 0.0014 and 0.008% phytic acid per kg of ASP per hectare in 1977 and 1978, respectively (Table I), and were significantly different at the 1% probability level, indicating that more phytic acid was being produced in 1977 than in 1978 for a given increase in ASP. The smaller overall slope value in 1978 does not mean that the total uptake of P was less; almost all GPA values were higher in 1978 than in 1977 (unpublished data and Table I, columns 2 and 3). This suggests that at lower ASP levels, GPA was already quite high and increased very little with additional ASP. The fact that all 1978 intercepts were higher than 1977 intercepts also supports this suggestion.

Significant differences existed among individual cultivar intercepts within both years, as indicated by significantly different SSRs for equations 2 and 3 for both years (Table II). More significant differences among intercepts occurred in 1977 than in 1978, and by definition, cultivars having significantly different intercepts had on the average significantly larger GPA values over the range of ASP values used (Table I).

ASP significantly increased the amount of phytic acid produced by oat groats, although the regression equation describing this relationship varied among cultivars and between years. Environmental factors other than ASP significantly affected these relationships; the 1977 and 1978 rates of GPA production (equation 2 slopes) were significantly different, and the 1978 intercepts were all significantly larger than the 1977 intercepts at the 5% probability level. Because little difference was found between the 1977 and 1978 main plot ASP values except when additional P was added (unpublished data), ASP could not be responsible for these differences. In addition, average GPA ranking of cultivars remained the same each year except for Garry and Orbit (Table I). This suggests that within a year, environmental factors other than ASP affected GPA similarly for each cultivar.

A single multiple regression equation could possibly predict GPA from ASP if it included independent variables for cultivar and environment. The multiple regression equations used in this study were not intended to be predictive but to determine whether individual cultivar results were significantly different.

Our conclusion that GPA differs significantly among cultivars does not agree with that of Ashton and Williams (1958), but it does agree with Moore et al (1957) and Larson et al (1952). Although the latter two research groups measured groat P and GPA, the constant ratio between GPA and groat P determined by Lolas et al (1976) suggests that this conclusion can be drawn. Kleese et al (1968) noted that GPA differed significantly within cultivars of wheat, barley, and soybeans. Contrary to their results, we found that seed P, as GPA, was significantly affected by environment, ie, year. Because the two experiments were conducted in different years and on different species, their results are not directly comparable to ours. However, we hypothesize that oats, wheat, and barley respond similarly. Therefore, further research of a similar nature over more years is needed to determine how much the effect of environment on GPA varies.

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