EFFECTS OF NITROGEN FERTILIZER ON MALTING QUALITY OF WIDELY VARYING BARLEY CULTIVARS[1]

Y. POMERANZ[2], N. N. STANDRIDGE[3], E. A. HOCKETT[4], D. M. WESENBERG[5], and G. D. BOOTH[6]

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ABSTRACT

Two hull-less and three hulled barley cultivars were grown for 2 years at two locations and treated with three nitrogen fertilizer levels (none, optimum, and twice optimum). The barleys were malted under laboratory conditions and the barleys and malt were analyzed. Barley and malt parameters over the five cultivars were relatively consistent for three of four year-location combinations. The means were affected by drought in one year-location combination. Cultivar means varied widely for most barley and malt parameters; the hulled malting cultivars were superior to the hull-less cultivars. Increasing barley protein, as a result of nitrogen fertilization, decreased fine grind extract and increased diastatic power. Variety × fertilizer level interactions were significant for several barley and malt parameters. Barley protein was highly correlated with practically all malt parameters. Out of 43 highly significant correlations among barley and malt parameters, eight were with barley protein. Of the remaining 35 simple correlations, only six continued to be highly significant if the barley protein were held constant.

The effects of nitrogen fertilizers (N-fertilizers) on malting quality of barley have been the subject of several investigations. Lejeune and Parker (1) found that barley protein increased if N-fertilizer was added to the soil in excess of the amount required for maximum yield in relation to other soil nutrients and environmental conditions. Phosphorus, in combination with nitrogen, generally increased kernel plumpness and malt extract. Phosphorus may under certain conditions minimize or counteract undesirable effects of excess nitrogen.

Atkins *et al.* (2) reported that malting characteristics of barley produced under conditions of high response to fertilization generally were not significantly altered. N-fertilizer, applied in excess of that required for maximum yield per acre, resulted in an undesirable increase in protein content and a reduction in malt extract. Phosphorus fertilizer improved malting quality by increasing kernel weight and malt extract, and had no deleterious effects on other parameters of malting quality.

Reisenauer and Dickson (3) studied the effects of nitrogen and sulfur fertilizer

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[2]Chemist in Charge, Barley and Malt Laboratory, USDA, and Professor, Agronomy Department, University of Wisconsin, Madison. Present address: Director, Grain Marketing Research Center, ARS, USDA, Manhattan, KS 66502.

[3]Chemist, Barley and Malt Laboratory, ARS, USDA, Madison, Wis.

[4]Research Agronomist, ARS, USDA, Bozeman, Mont.

[5]Research Agronomist, ARS, USDA, Aberdeen, Idaho.

[6]Mathematical Statistician, ARS, USDA, Ames, Iowa.

on yield and malting quality of barley grown in the Palouse area of eastern Washington. Barley yields were increased by nitrogen and sulfur fertilization with a significant nitrogen × sulfur yield interaction. The higher rates of N-fertilization decreased kernel size and increased barley, malt, and wort protein. While N-fertilization increased amylolytic activities, it reduced overall malting activity. More recently, Zubriski *et al.* (4) found that, whereas kernel plumpness was not affected to a large degree by N-fertilizer, grain protein increased with fertilizer level. The effect of N-fertilizer depended on date of seeding and application of potassium fertilizer.

This study was conducted to determine the effects of N-fertilization on the malting characteristics of five widely varying barley cultivars. Specifically, we hoped to answer the following questions: 1) Are fertilizer treatments significant, despite year-to-year and location effects? 2) Are cultivar differences significant, despite year-to-year and location differences? 3) If there are cultivar differences in response to fertilizer treatments, are those differences significant for different barley genotypes? 4) Assuming that barley protein governs many variables, how are these variables affected by protein (*i.e.*, what are the regression lines of those variables on protein)? 5) Would there be a correlation among the barley and malt parameters if protein were held constant?

MATERIALS AND METHODS

Locations

The trials reported here were grown in 1971 and 1973 at Aberdeen, Idaho, and Ft. Ellis, Montana. Aberdeen is irrigated, and Ft. Ellis is a nonirrigated or dryland station. Aberdeen averages about 8.5 cm of precipitation during the growing season *vs.* 15.0 cm for Ft. Ellis. Both stations have relatively high elevations—Aberdeen, 1341 m, and Ft. Ellis, 1512 m. Typically, Ft. Ellis is planted about 30 days later in the spring than Aberdeen, and cultivar heading dates differ, similarly. Grain yields under irrigation at Aberdeen often exceed nonirrigated yields at Ft. Ellis by a factor of two or more. For example, during

TABLE I
Experimental Factors and Their Levels Studied[a]

Factors	Levels				
	1	2	3	4	5
Year	1971	1973	...	...	...
Location	Aberdeen, Idaho	Ft. Ellis, Montana	...	...	...
Variety[b]	Hiproly (HL)	CI 4362 (HL)	Larker (H)	Firlbecks III (H)	Conquest (H)
Fertilizer treatment	None	Optimum or recommended	Twice optimum	...	...

[a]Three replications for each treatment combination (2 × 2 × 5 × 3 = 60 treatment combinations).
[b]Two types of barley: (HL) = hull-less; (H) = hulled.

the test period (1971 and 1973), 21 entries grown in the Western Two-Row Barley Nursery averaged 6086 kg/ha at Aberdeen *vs.* 2185 kg/ha at Ft. Ellis.

The 1971 Ft. Ellis growing conditions for this experiment differed greatly. In 1971, the nursery suffered from drought and average yields were 1835 kg/ha. In 1973, the nursery was grown on an area which was subirrigated and average yields were 3346 kg/ha. In the 1971 and 1973 Western Two-Row Barley Nursery, grain produced at Aberdeen was higher in plump barley %, test weight, and protein content than grain produced at Ft. Ellis. Protein content for the same 21 entries averaged 12.9% at Aberdeen *vs.* 11.5% at Ft. Ellis, but malt extract levels averaged about the same.

Barley Cultivars

The five spring barley cultivars grown in each trial were Larker, Conquest, Firlbecks III, Hiproly, and CI 4362. Larker and Conquest are six-rowed, hulled, malting barleys. Larker has a white aleurone and Conquest has a blue aleurone. Firlbecks III is a two-rowed, hulled, white aleurone, malting barley. Hiproly and CI 4362 are two-rowed, hull-less, white aleurone barleys that are not acceptable for malting. They are morphologically similar and often considered as an isogenic pair. Both are rich in protein, but Hiproly has shrivelled seed, lower yield, and substantially more lysine in the protein compared with CI 4362. Neither Hiproly nor CI 4362 is grown commercially, but Larker, Conquest, and Firlbecks III are important cultivars in the U.S. and Canada.

Fertilizer Treatments

The experiments in both locations were set up as a split plot with varieties as main plots and fertilizer levels as subplots. The main plots were in a randomized block design. The nitrogen treatments were applied just prior to planting at Ft. Ellis and at seedling emergence at Aberdeen. Three fertilizer levels were used: none, the optimum amount recommended on the basis of soil analysis, and twice

TABLE II
Environment Means of Barley and Malt Parameters

Parameter	1971 Aberdeen	1971 Ft. Ellis	1973 Aberdeen	1973 Ft. Ellis
Kernel weight (mg)	39.51	31.21	39.20	40.70
Plumpness (%)	76.82	34.61	74.06	81.30
Agtron color	50.49	76.40	38.71	47.02
Fine grind extract (%)	77.36	74.89	75.42	75.96
Fine-coarse grind extract (%)	7.48	3.29	3.59	3.10
Wort color (srm)[a]	1.28	1.44	1.60	1.49
Barley protein (%)	15.28	15.07	16.09	14.93
Wort protein (%)	0.66	0.70	0.68	0.65
$\frac{\text{Wort protein}}{\text{Malt protein}} \times 100$	27.52	29.51	26.92	28.50
Diastatic power[b]	163.38	209.76	167.84	159.69
α-Amylase[c]	24.13	34.65	24.30	23.22

[a]Standard reference method, Lovibond Tintometer.
[b]Degrees, arbitrary units.
[c]20° units.

TABLE III

Variety Means of Barley and Malt Parameters

	Hiproly				CI 4362			
	1971		1973		1971		1973	
Parameter	**Aberdeen**	**Ft. Ellis**	**Aberdeen**	**Ft. Ellis**	**Aberdeen**	**Ft. Ellis**	**Aberdeen**	**Ft. Ellis**
Kernel weight (mg)	38.0	32.2	36.1	38.4	50.9	40.3	48.8	50.5
Plumpness (%)	22.9	3.6	12.1	32.2	91.4	51.7	89.7	94.5
Agtron color	10.7	42.9	0.9	18.7	17.3	50.9	2.9	20.0
Fine grind extract (%)	74.6	73.3	71.8	72.4	77.0	73.3	74.8	74.8
Fine-coarse grind extract (%)	10.2	2.3	5.0	4.1	14.6	7.3	7.9	6.9
Wort color (srm)[a]	1.32	1.38	1.84	1.58	1.12	1.20	1.46	1.26
Barley protein (%)	18.1	18.3	20.1	19.9	16.5	16.7	18.4	17.5
Wort protein (%)	0.699	0.751	0.761	0.767	0.567	0.613	0.601	0.604
$\frac{\text{Wort protein}}{\text{Malt protein}} \times 100$	23.8	25.9	23.2	23.6	21.6	22.5	20.4	22.5
Diastatic power[b]	154	247	171	190	107	204	123	111
α-Amylase[c]	12.3	13.2	13.9	12.1	10.9	14.5	11.3	11.3

[a]Standard reference method, Lovibond Tintometer.
[b]Degrees, arbitrary units.
[c]20° units.

Table III continued on p. 578.

TABLE III, *Continued*
Variety Means of Barley and Malt Parameters

Parameter	Larker				Firlbecks III				Conquest			
	1971		1973		1971		1973		1971		1973	
	Aberdeen	Ft. Ellis	Aberdeen	Ft. Ellis	Aberdeen	Ft. Ellis	Aberdeen	Ft. Ellis	Aberdeen	Ft. Ellis	Aberdeen	Ft. Ellis
Kernel weight (mg)	36.4	28.1	36.9	38.5	37.9	28.3	39.7	40.6	34.5	27.1	34.6	35.5
Plumpness (%)	90.2	45.4	90.4	94.6	94.5	45.4	95.8	96.1	85.0	27.0	82.3	89.2
Agtron color	73.3	97.6	58.4	63.8	62.4	91.8	54.2	50.2	88.7	98.9	77.1	82.4
Fine grind extract (%)	78.0	75.8	76.5	76.9	78.5	75.4	77.2	78.1	78.7	76.6	76.9	77.6
Fine-coarse grind extract (%)	3.1	1.0	1.2	1.0	6.2	4.0	2.5	2.3	3.4	1.9	1.3	1.2
Wort color (srm)[a]	1.31	1.52	1.52	1.44	1.34	1.51	1.61	1.62	1.31	1.58	1.56	1.53
Barley protein (%)	14.1	12.9	13.8	12.5	13.9	14.3	13.9	12.5	13.7	13.1	14.2	12.2
Wort protein (%)	0.695	0.713	0.675	0.626	0.610	0.658	0.594	0.591	0.715	0.745	0.748	0.653
$\frac{\text{Wort protein}}{\text{Malt protein}} \times 100$	31.3	34.1	30.5	31.8	27.8	29.6	27.3	30.2	33.2	35.6	33.3	34.5
Diastatic power[b]	211	211	204	192	163	191	157	144	182	195	183	161
α-Amylase[c]	28.5	44.2	29.3	30.6	27.5	42.0	27.7	24.2	41.5	59.4	39.3	38.0

[a]Standard reference method, Lovibond Tintometer.
[b]Degrees, arbitrary units.
[c]20° units.

the optimum amount. The levels of N as NH_4NO_3 were 0, 50, and 101 kg/ha at Aberdeen and 0, 67, and 135 kg/ha at Ft. Ellis. There were three replications for each treatment combination. The experimental factors and the levels studied are summarized in Table I.

Malting

The barley samples were cleaned on a Hart-Carter Dockage Tester. Lots of 170 g cleaned barley were malted as described by Pomeranz *et al.* (5). The steeping time was varied to attain a moisture content of 45% at the end of steep. The steeped samples were germinated in malting chambers at 16° ± 0.5° C for 5 days. The malted samples were kilned in a programmed procedure that employs higher temperatures after most of the moisture has been removed at lower temperatures. Final kiln temperature was 65° C.

Analytical Methods

The grains and malts were analyzed according to methods of the American Society of Brewing Chemists (6) except that coarse grind extract was determined on material obtained by grinding 25-g samples in the Casella mill with sieve holes of 0.125 in. in diameter. Protein content (on a dry matter basis) was calculated by multiplying Kjeldahl-N by the factor 6.25.

RESULTS AND DISCUSSION

Means of the barley and malt parameters are given in Table II for each combination of year and location. Examination of this table reveals a consistency among the means of practically all parameters, with the exception of Ft. Ellis, Montana, in 1971. This departure from the other year-location combinations resulted in lower overall means for kernel weight and plumpness, and higher means for Agtron color, diastatic power, and α-amylase. From Table III, we see that kernels from CI 4362 were larger than kernels from the other cultivars. Also, there were only small differences in plumpness, except that the plumpness of the hull-less, shrunken Hiproly kernels was low for all year-location combinations and the plumpness of all cultivars, and particularly of Conquest kernels, was low in Ft. Ellis, Montana, in 1971. The Agtron color values of the hull-less Hiproly and CI 4362 were lower than the values of the three hulled cultivars. Fine grind extracts of the two hull-less cultivars were slightly lower than extracts of the hulled cultivars, and in all year-location combinations except Montana 1971, CI 4362 was higher than Hiproly. The low extract of the hull-less cultivars despite the absence of hulls can be attributed to their high protein content and, presumably associated with it, poor modification during malting. The latter is confirmed by the high fine-coarse grind extract of the hull-less barleys for all year-location combinations except Montana 1971. Large varietal differences in barley protein were not reflected in protein levels in the wort, because of the reduced solubilization of the malt proteins in the wort (low wort protein/malt protein ratios in the hull-less barleys). For all year-location combinations except Montana 1971, CI 4362 was the lowest, and Larker the highest, in diastatic power. In Montana 1971, hull-less Hiproly had the highest diastatic power, with the other four varieties essentially equal. Both hull-less

TABLE IV
Treatment Means of Barley and Malt Parameters

Parameter	No Fertilizer				Optimum Fertilizer Level				Twice Optimum Fertilizer Level			
	1971		1973		1971		1973		1971		1973	
	Idaho[a]	Mont.[b]	Idaho[a]	Mont.[b]	Idaho[a]	Mont.[b]	Idaho[a]	Mont.[b]	Idaho[a]	Mont.[b]	Idaho[a]	Mont.[b]
Kernel weight (mg)	40.0	33.7	39.0	40.1	39.4	30.6	39.4	41.3	39.2	29.3	39.2	40.6
Plumpness (%)	79.6	59.1	74.1	81.1	75.7	27.2	74.7	82.6	75.2	17.6	73.4	80.2
Agtron color	56.0	77.1	40.3	56.0	49.5	77.0	39.2	46.1	46.0	75.1	36.7	38.9
Fine grind extract (%)	78.1	76.4	76.1	76.7	77.3	74.7	75.4	76.1	76.7	73.6	74.8	75.1
Fine-coarse grind extract (%)	6.19	3.15	3.51	3.05	8.22	3.16	3.52	3.26	8.04	3.56	3.73	2.98
Wort color (srm)[c]	1.20	1.45	1.62	1.52	1.27	1.41	1.55	1.46	1.37	1.45	1.63	1.48
Barley protein (%)	14.4	13.5	15.6	14.0	15.4	15.1	16.0	14.7	16.0	16.5	16.7	16.0
Wort protein (%)	0.630	0.654	0.672	0.629	0.666	0.684	0.673	0.648	0.676	0.750	0.683	0.669
$\frac{\text{Wort protein}}{\text{Malt protein}} \times 100$	28.5	31.4	27.9	29.4	27.6	28.5	26.8	28.5	26.4	28.6	26.1	27.6
Diastatic power[d]	149	177	165	138	156	218	166	156	185	234	173	186
α-Amylase[e]	24.2	29.8	23.6	23.1	23.3	35.7	24.4	23.2	24.9	38.5	24.8	23.3

[a]Aberdeen.
[b]Ft. Ellis.
[c]Standard reference method, Lovibond Tintometer.
[d]Degrees, arbitrary units.
[e]20° units.

TABLE V
Results of Analyses of Variance for Barleys

Mean Squares and Results of Tests of Significance[a]

Sources of variation	Location[b]	Year	Kernel weight	Plumpness	Agtron color	Fine grind extract	Fine-coarse grind extract	Wort color	Barley protein	Wort protein	Wort protein/ malt protein	Diastatic power	α-Amylase
Variety	ID	71	**	**	**	**	**	**	**	**	**	**	**
	MT	71	**	**	**	**	**	**	**	**	**	**	**
	ID	73	**	**	**	**	**	**	**	**	**	**	**
	MT	73	**	**	**	**	**	**	**	**	**	**	**
Check	ID	71	*	**	**	**	**	**	**	**	**	**	...
vs.	MT	71	**	**	...	**	...	...	**	**	**	**	**
fertilizer	ID	73	Δ	...	Δ	**	...	...	**	...	**	...	...
	MT	73	Δ	...	**	**	...	*	**	**	Δ	**	...
Optimum	ID	71	...	...	**	*	...	**	**	...	*	**	*
fertilizer	MT	71	*	**	...	**	...	Δ	**	**	...	**	**
vs. twice	ID	73	...	**	...	**	...	*	**	...	Δ	Δ	...
optimum	MT	73	...	...	**	**	...	...	**	Δ	...	**	...
Variety	ID	71	...	**	...	...	**	Δ	...	...	Δ	*	...
×	MT	71	*	**	...	**	...	**	**	**	**	**	**
fertilizer	ID	73	**	*	...	*	...	...	...	Δ	*	Δ	...
	MT	73	...	...	*	*	...	...	**	**	...	...	...

[a]** = Significant at P ≤ 0.01, * = significant at 0.01 < P ≤ 0.05, Δ = significant at 0.05 < P ≤ 0.10, and ... = not significant at P > 0.10.
[b]ID = Aberdeen; MT = Ft. Ellis.

barleys produced malts with low α-amylase, and malt from Conquest was highest in α-amylase.

From Table IV we see that increasing N-fertilizer levels increased barley protein. The increase in barley protein was accompanied by a decrease in fine grind extract and an increase in diastatic power. There were only small increases in wort protein, accompanying large increases in barley protein, as the latter resulted in substantial decreases in the ratio of wort protein to malt protein. Other parameters were also found to change with increases in fertilizer levels, but these changes were not consistent for all year-location combinations.

Questions 1 and 2: Fertilizer Effects and Varietal Differences

Separate analyses of variance were performed on the data from each year-location combination. The results of these analyses are not the same for all four location-year combinations (Table V). Nevertheless, if we carefully examine the means in Tables II and IV, we see that generalizations made in the last section are justified.

Question 3: Fertilizer Effects for Individual Varieties

Interactions between variety and fertilizer level were found with several of the malt and barley parameters studied (Table V). The presence of such interactions indicates that the effects of applying different fertilizer levels were not the same for all varieties. The parameters for which a significant interaction was found in most location-year combinations were: plumpness, fine grind extract, wort protein, the ratio between wort and malt proteins, and diastatic power.

Fertilizer treatment comparisons were made for each variety (data not shown here). Application of fertilizer did not affect plumpness of Hiproly but was accompanied by a reduction in plumpness with the other cultivars. In the two hull-less cultivars, the effect of fertilizer on fine grind extract and the ratio of wort

TABLE VI
Slopes of Linear Regressions of Various Parameters on Barley Protein

Parameters	1971		1973		All Data	Significantly Different
	Aberdeen	Ft. Ellis	Aberdeen	Ft. Ellis	Combined	Slopes
Kernel weight (mg)	1.17**[a]	0.66*[b]	0.58*	0.59**	0.75**	...
Plumpness (%)	−10.0**	− 6.2**	− 8.4**	−5.4**	−7.5**	*
Agtron color	−14.0**	− 7.6**	−10.4**	−6.9**	−9.7**	**
Fine grind extract (%)	− 0.823**	− 0.717**	− 0.721**	−0.651**	−0.728**	...
Fine-coarse grind extract (%)	1.72**	0.36**	0.75**	0.48**	0.83**	**
Wort color (srm)	− 0.0053	− 0.0324**	0.0249**	−0.0091	−0.0055	**
Wort protein (%)	0.0021	0.0081*	0.0064	0.0141**	0.0077**	...
$\frac{\text{Wort protein}}{\text{Malt protein}} \times 100$	− 1.89**	− 1.68**	− 1.44**	−1.28**	−1.57**	...
Diastatic power	− 5.96*	10.05**	− 4.10**	1.07	0.26	**
α-Amylase	− 4.35**	− 4.20**	− 3.11**	−2.58**	−3.56**	...

[a] **indicates slope is significantly different from zero ($P < 0.01$).
[b] *indicates slope is significantly different from zero ($P < 0.05$).

TABLE VII
Simple and Partial (Protein Constant) Correlation Coefficients for Barley and Malt Parameters[a]

Partial Correlation Coefficients

Parameter	Kernel weight	Plumpness	Agtron color	Fine grind extract	Fine-coarse grind extract	Wort color	Barley protein	Wort protein	Wort prot./malt prot.	Diastatic power	α-Amylase
Kernel weight	1.000	0.578**	−0.105	0.136	−0.014	−0.165Δ	...	0.188*	0.146	−0.020	−0.149Δ
Plumpness	0.526**	1.000	−0.092	0.242**	0.057	−0.052	...	0.045	−0.026	−0.063	−0.167Δ
Agtron color	−0.690**	0.138Δ	1.000	−0.123	0.026	−0.005	...	−0.126	−0.042	−0.099	−0.026
Fine grind extract	0.007	0.697**	0.539**	1.000	0.380**	−0.005	...	0.106	0.105	−0.011	0.037
Fine-coarse grind extract	0.619**	−0.016	−0.626**	−0.189*	1.000	0.031	...	−0.069	0.041	−0.213*	−0.004
Wort color	−0.382**	−0.218**	0.052	−0.151*	−0.477**	1.000	...	0.144	0.083	0.090	0.081
Barley protein	0.299**	−0.537**	−0.793**	−0.834**	0.509**	−0.025	1.000	...	...	...	...
Wort protein	−0.590**	−0.639**	0.107	−0.422**	−0.317**	0.347**	0.338**	1.000	0.784	0.282**	−0.015
Wort protein / Malt protein	−0.627**	0.178*	0.848**	0.603**	−0.705**	0.231**	−0.809**	0.235**	1.000	0.053	−0.070
Diastatic power	−0.686**	−0.486**	0.373**	−0.277**	−0.495**	0.149*	0.045	0.620**	0.269**	1.000	0.265**
α-Amylase	−0.711**	0.028	0.871**	0.412**	−0.582**	0.241**	−0.644**	0.273**	0.793**	0.362**	1.000

Simple correlation coefficients

[a] ** = significant at $P < 0.01$, * = significant at $0.01 < P < 0.05$, Δ = significant at $0.05 < P < 0.10$; all other correlation coefficients were insignificant.

protein to malt protein was negligible. On the other hand, in the hulled cultivars, an increase in fertilizer was accompanied by a decrease in both fine grind extract and protein ratio. With the three hulled cultivars, wort protein increased with fertilizer. This was not the case with the hull-less varieties, although the double quantity of fertilizer caused some increase in wort protein when applied to CI 4362. For diastatic power, the interactions were not consistent for the different location-year combinations, but tended to have a self-cancelling effect which did not produce overall interactions. Barley protein, however, displayed significant interactions at Ft. Ellis for both years. Apparently, an increase in fertilizer application was accompanied by a corresponding increase in barley protein with the three hulled varieties (and to a lesser extent with CI 4362), but not with Hiproly.

Question 4: Regression Lines of Barley and Malt Parameters on Protein

The effects of protein on barley and malt parameters were considered as regression of the form:

$$\text{PARAMETER} = \alpha + \beta\ (\text{BARLEY PROTEIN}),$$

where β is the slope of the regression line. Estimates of the slopes are given in Table VI, for each location-year combination as well as for the combined data from all four combinations.

Increases in protein were accompanied by increases in kernel weight and fine-coarse grind extract and by decreases in kernel plumpness, Agtron color, fine grind extract, the ratio of wort protein to malt protein, and α-amylase. No consistent relationship was found between barley protein and either wort protein or diastatic power. Increasing protein content of barley by 1% was accompanied by a decrease in fine grind extract of about 0.7% and an increase in fine-coarse grind extract of about 0.8%.

Question 5: Correlation among Parameters if Protein Held Constant

The partial correlations in Table VII have been adjusted to constant protein. Barley protein was highly correlated with all barley and malt parameters, except wort color and diastatic power. There were 43 highly significant simple correlations, eight of which were with barley protein. Of the remaining 35 correlation coefficients, only six continued to be highly significant if the protein content were held constant. They were: kernel weight and plumpness, plumpness and fine grind extract, fine grind extract and fine-coarse grind extract, wort protein and ratio between wort protein and malt protein, wort protein and diastatic power, and α-amylase and diastatic power.

CONCLUSIONS

From a study of five widely varying barley cultivars—two hull-less and three hulled—grown for 2 years, at two locations, and treated with three N-fertilizer levels, the following conclusions have been drawn:

1) Means of barley and malt parameters over five cultivars were relatively consistent for three of four year-location combinations studied. Not

unexpectedly, the departure from consistent performance occurred at the nonirrigated location (Ft. Ellis) in 1971, when drought was a factor.

2) Cultivar means varied widely for most barley and malt parameters and, as expected, the malting cultivars were superior in malting quality.

3) Increasing N-fertilizer levels increased barley protein, which was accompanied by decreased fine grind extract and increased diastatic power. Variety × fertilizer level interactions were significant for several barley and malt parameters, particularly plumpness %, fine grind extract, wort protein, wort/malt protein ratio, and diastatic power.

4) Barley protein was highly correlated with practically all malt parameters.

5) Eight, out of 43 highly significant correlations among barley and malt parameters, were with barley protein. Of the remaining 35 simple correlations, only six continued to be highly significant if the barley protein were held constant.

Results of our study confirm that protein content is one of the most important parameters of malting barley. The relation between protein content and malt characteristics was modified, however, by the test material (crop year, location, variety, and N-fertilization). Varietal effects reported here were highly significant, as cultivars differing widely in genetic background, grain morphology, and kernel composition were studied.

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