Effects of Corn Hybrid and Growth Environment on Corn Curl and Pet Food Extrudates[1]

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ABSTRACT

Cereal Chem. 76(5):625–628

The effects of corn growth environment and hybrid on properties of corn curl and pet food extrudates were studied. Extrusion runs were conducted using a twin-screw extruder. Both corn curl and pet food extrudates were affected significantly by the corn growth environment (location) and corn hybrid. Corn hybrids grown at Creston, IA, produced extrudates with significantly higher expansion (indicated by lower bulk density and higher volumetric expansion index) followed by corn hybrids grown at Johnston, IA, and Nevada, IA, showing that growth environment affects extrusion properties. Hybrid 3348 produced extrudates with significantly higher expansion than that of extrudates from Pioneer Hi-Bred 3394. A decrease in protein, and the subsequent increase in starch, appears to be related to the increase in extrudate expansion. This suggests that the amount of starch in the sample may be responsible for the effects of environment and hybrids on expansion. Significant (P < 0.05) correlations existed between corn curl bulk density and pet food extrudate properties, indicating that corn curl extrusion can be used to predict the performance of different corn hybrids in production of extruded pet food.

The importance of high-temperature short-time (HTST) extrusion cooking as a means of processing cereal grains into a wide variety of products is well documented (Mercier et al 1989). It is well known that a number of process variables can affect the quality of extrudates (Meuser et al 1987, van Lengerich 1990). A recent study (Mathew et al 1999) showed that the type of mill used to grind the corn and the particle size of the meal also can have large effects on extrudate quality, even when the other process conditions were held constant. That study also showed that commercial corn samples obtained from different parts of the country affected extrudate quality but did not indicate whether this was due to the corn hybrid or the growth environment or a combination of both. The objective of this study was to determine the effect of corn growth environment (location) and corn hybrid on properties of extruded corn curls and pet foods.

MATERIALS AND METHODS

Materials

Pure corn hybrids grown at three locations in Iowa in 1994 were obtained from Pioneer Hi-Bred Intl., Inc. (Table I). The corn curls used ground corn and water in their formulation. A generic pet food formula was used as described previously (Mathew et al 1999).

To prepare meal for corn curls, the corn was first hammer-milled using a Jacobson tear drop hammer mill through a 4/64-in. (1.500-mm) screen and then reground through the same mill but with a 3/64-in. (1.125-mm) screen. The ground corn was stored in drums until used. All extrusion runs were conducted using a Wenger TX-52 twin-screw extruder (Wenger Manufacturing, Inc., Sabetha, KS) at Kansas State University. Extruder operating conditions for corn curl extrusion, screw configurations, and procedures were as described by Mathew et al (1999).

To prepare meal for pet food extrusion, the corn was first hammer-milled using a Jacobson tear drop hammer mill, through a 4/64-in. (1.500-mm) screen and then reground with the same mill but through a 3/64-in. (1.125-mm) screen. The ground corn was mixed with the base mix (1:1) and blended using a Wenger ribbon batch mixer (capacity: 250 lb, 113.5 kg) for 15 min per batch. The mixed corn plus base mix then was stored in cardboard drums until used. The TX-52 configuration, die specification, and process conditions for pet food extrusion were as described by Mathew et al (1999). For the initial run, the steam rate to the preconditioner was adjusted to achieve a meal temperature of 87–93°C at the exit of the preconditioner barrel. Then the steam rate to the extruder barrel was adjusted to achieve a target bulk density of 304–384 g/L (19–24 lb/ft^3) for the wet extrudate. These steam rates were maintained constant for subsequent runs.

Proximate Analyses

Approved Methods (AACC 1995) were used for the proximate analyses of corn and extrudates. Moisture content, fat, protein, and ash were determined using Approved Methods 14-15A, 30-10, 46-13, and 08-12, respectively. Moisture content was expressed as percentage wet basis. Fat, protein, and ash contents were expressed as percentages on a 14% moisture basis. The hundred kernel weight (HKW, g) of whole corn was measured. The test weight of whole corn (lb/bu) was measured using a Dickeyjohn test weight apparatus. The absolute density of whole corn (g/cm^3) was determined using an air pycnometer. Whole corn kernel size was calculated by sieving a known amount of corn through screens with diameters of 24/64 in. (9.525 mm), 19/64 in. (7.540 mm), and 16/64 in. (6.350 mm). Overs on each screen were expressed as percentages of the total sample. Ten kernel width was measured as the width (in cm) of 10 whole corn kernels placed side by side.

Methods

The starch content (% dwb) of whole corn was determined using near-infrared transmittance (NIR-T) spectroscopy. Starch content data was obtained from an enzymatic assay procedure. The respective scan data obtained from NIR-T spectroscopy were used to generate a regression equation for predicting the starch content from known scan data (average of 10 readings). The method has a prediction accuracy of ±1% starch content. The particle size of ground corn was also analyzed (Mathew et al 1999).

Corn curls and pet food extrudates were analyzed for bulk density, volumetric expansion index, breaking strength, and degree of cook as in Mathew et al (1999). The specific mechanical energy (SME) utilized during the extrusion process also was calculated.

Experimental Design

Five different Pioneer Hi-Bred corn hybrids grown in 1994 (3489, 3394, 3335, 3348, and 3375) were obtained from three different locations (Johnston, Creston, and Nevada IA). Two separate samples of the same hybrid were collected from each location and dried separately to a constant (±0.3%) moisture content. Hence, these two samples were considered to be replicates. A total of 30

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Publication no. C-1999-0726-06R.

samples was used. Each sample was prepared and extruded separately. There were 30 extrusion runs each for corn curls and pet food. Thus, a randomized complete block design with two blocks (replicates) and 15 whole plots (corn hybrids) was used. The statistical analyses including mean, contrast, estimate, regression, and correlation were performed using SAS software (SAS Institute, Cary, NC).

RESULTS AND DISCUSSION

Analyses of Corn

Corn samples (n = 30) were analyzed for chemical and physical properties. The averages for each pair of samples are given in Tables I and II. Significant differences occurred in moisture content, fat, protein, starch, test weight, absolute density, HKW, 10 kernel width, and kernel size (% of overs retained on 24/64 in [9.53 mm], 19/64 in [7.54 mm], and 16/64 in [6.35 mm] diameter screens). Corn moisture content varied only between 10.7 and 11.3% (11.0 ± 0.3%).

Effect of Growth Environment on Corn Curl Extrudates

Mean values of extrudate properties of corn curls produced using corn hybrids from different locations are shown in Table III. The same corn hybrid grown at different locations produced extrudates with significantly different properties. Corn hybrids grown at Johnston produced corn curl extrudates with significantly higher bulk density (BD) (P < 0.0050) and lower volumetric expansion index of extrudate (VEI) (P < 0.0021) and lower SME (P < 0.0035) during extrusion when compared with extrudates from the same hybrids grown at Creston. Extrudates produced from corn grown at Johnston had significantly lower BD (P < 0.0038), higher VEI (P < 0.0004), lower breaking strength (BS), and higher degree of cook when compared with that produced from corn grown at Nevada. Corn grown at Creston produced extrudates with significantly lower BD (P < 0.0001) and higher VEI (P < 0.0001) and significantly higher SME (P < 0.0004) than extrudates from corn grown at Nevada.

The ranking of corn growth locations based on VEI is Creston > Johnston > Nevada. Thus, environment does affect the extrusion properties.

Effect of Hybrid on Corn Curl Extrudates

Effect of hybrid grown at the same location on corn curl properties is shown in Table IV. No significant differences occurred in the degree of cook and the SME values between the different treatments. The BS of corn curl extrudates produced using 3394 was significantly higher than that of extrudates produced using 3348 or 3375. No significant differences occurred between the properties of corn curl extrudates produced using 3394 and 3375 or 3335 and 3375. Hybrid 3489 produced corn curl extrudate with significantly higher BD (P < 0.0004) and lower VEI (P < 0.0406) when compared with those from 3394. Hybrid 3348 produced extrudates with the lowest BD and highest VEI (indicating highest expansion), whereas 3489 produced extrudate with the highest BD and lowest VEI (indicating lowest expansion).

TABLE I
Proximate Analyses, Test Weight, and Density for Corn Hybrid Samples from Three Growth Locations

Hybrid	Location	Moisture (%)	Fat (%)	Protein(%)	Starch (%)	Test Wt. (lbs/bu)	Absolute Density (g/cm^3)
3489	Johnston	10.8bc[a]	3.74a–c	7.5c	70.21de	61.13cd	1.28bc
3489	Creston	11.0a–c	3.58b–e	6.9	70.86a–d	59.55gh	1.27c
3489	Nevada	11.3a	3.51c–e	8.2a	69.72e	63.38a	1.33a
3394	Johnston	11.1a–c	3.20f	7.1de	70.56cd	61.80bc	1.32a
3394	Creston	11.1a–c	3.42ef	6.9 e	71.38ab	59.73f–h	1.28bc
3394	Nevada	11.0a–c	3.87a	8.0a	70.48c–e	59.80e–h	1.28bc
3335	Johnston	11.0a–c	3.53b–e	6.8e	71.60a	62.05b	1.29b
3335	Creston	11.1a–c	3.37ef	7.4cd	71.38ab	59.58gh	1.29b
3335	Nevada	11.3ab	3.77ab	7.2de	70.06de	60.33e–g	1.28bc
3348	Johnston	11.0a–c	3.73a–c	7.1de	70.75b–d	60.38ef	1.27c
3348	Creston	11.0a–c	3.69a–d	7.4cd	70.79b–d	59.18h	1.27c
3348	Nevada	10.9bc	3.41ef	7.9ab	70.18de	60.20e–g	1.28bc
3375	Johnston	11.3a	3.53b–e	7.4cd	70.77b–d	61.35bc	1.27c
3375	Creston	10.7c	3.39ef	7.6c	71.26a–c	59.33h	1.26c
3375	Nevada	10.8bc	3.49de	7.7bc	70.11de	60.55de	1.29b

[a] Values followed by the same letter in the same column are not significantly different (P < 0.05).

TABLE II
Corn Hybrid, Growth Locations, and Kernel Characteristics

Hybrid	Location	HKW[a] (g)	Kernel Width (cm)	Sieve Sizes (% of overs) S24 (24/64 in.)	S19 (19/64 in.)	S16 (16/64 in.)	Particle Size (GMD)[b]
3489	Johnston	29.9b[c]	8.3a	2.4bc	88.2a	8.7gh	388a
3489	Creston	26.2de	8.1b–d	2.1bc	88.3a	8.0gh	407a
3489	Nevada	27.0cd	7.8f	0.0e	68.1e	29.6b	382a
3394	Johnston	31.0ab	8.4a	5.3a	84.4a–c	9.6f–h	383a
3394	Creston	25.6e	8.1cd	1.5cd	82.5b–d	14.0ef	398a
3394	Nevada	31.0ab	8.0de	2.1bc	87.3ab	9.3gh	398a
3335	Johnston	31.6a	8.4a	5.6a	88.9a	5.4h	410a
3335	Creston	25.7 e	8.3a–c	2.1bc	81.9b–d	12.2fg	390a
3335	Nevada	27.6c	8.0d–f	0.4de	80.1cd	18.0de	404a
3348	Johnston	30.8ab	8.5a	4.8a	85.2a–c	8.2gh	387a
3348	Creston	26.3de	8.3ab	3.0b	80.6cd	14.0ef	382a
3348	Nevada	26.1de	7.8ef	0.4de	72.0e	25.4c	410a
3375	Johnston	27.9c	8.0d–f	0.8de	78.0d	20.2d	386a
3375	Creston	23.5f	7.8f	0.6de	60.5f	36.5a	383a
3375	Nevada	30.5ab	7.8f	0.0 e	78.9d	19.7d	404a

[a] Hundred kernel weight.
[b] Geometric mean diameter.
[c] Values followed by the same letter in the same column are not significantly different (P < 0.05).

Effect of Growth Environment on Pet Food Extrudates

Mean values of extrudate properties for pet food produced using corn from different locations are shown in Table V. The same corn hybrid grown at different locations produced extrudates with significantly different properties. Corn hybrids grown at Johnston produced extrudates with significantly higher BD and higher degree of cook with significantly lower SME than the same hybrids from Creston. Corn hybrids grown at Johnston produced extrudates with significantly higher VEI and higher degree of cook with lower SME than extrudates produced from corn grown at Nevada. Corn hybrids grown at Creston produced pet food extrudates with significantly lower BD ($P < 0.0006$) and higher VEI ($P < 0.0300$) when compared with extrudates produced using corn grown at Nevada. Growth location ranked was Creston (highest expansion) > Johnston > Nevada (lowest expansion). No significant differences occurred in BS of extrudates made with corn from the three locations. Corn hybrids from Johnston produced extrudates with a significantly higher degree of cook than extrudates from the same hybrids grown at Creston or Nevada.

The results obtained for pet foods (Table V) generally agreed with those obtained for corn curls (Table III). Processing corn to produce corn curls or pet food extrudates revealed that the extrudates produced using corn hybrids grown at Creston had a significantly higher expansion (low BD and high VEI), followed by that produced using corn hybrids grown at Johnston and Nevada.

TABLE III
Effects of Growth Location on Properties of Corn Curl Extrudates[a]

Location	BD (g/L)	BS (kJ/kg)	VEI (kg)	SME (%)	Cook
Johnston	109.52b[b]	1.95a	7.41b	499.1a	99.85a
Creston	96.06a	2.24a,b	8.20c	522.9b	99.70a
Nevada	123.57c	2.48b	6.44a	491.6a	99.15a

[a] BD = bulk density of wet extrudate; BS = breaking strength; VEI = volumetric expansion index; SME = specific mechanical energy; Cook = degree of cook of extrudate.
[b] Values followed by the same letter in the same column are not significantly different ($P < 0.05$).

TABLE IV
Effects of Hybrid on Properties of Corn Curl Extrudates[a]

Hybrid	BD (g/L)	BS (kJ/kg)	VEI (kg)	SME (%)	Cook
3489	124.80b[b]	2.24a	6.63a	496.4a	99.25a
3394	100.35a	2.57a	7.24a,b	512.6a	99.58a
3335	115.33b	2.27a	7.52b	499.4a	99.67a
3348	96.64a	2.09a	7.98b	513.4a	99.92a
3375	111.45a,b	1.96a	7.35a,b	500.9a	99.42a

[a] BD = bulk density of wet extrudate; BS = breaking strength; VEI = volumetric expansion index; SME = specific mechanical energy; Cook = degree of cook of extrudate.
[b] Values followed by the same letter in the same column are not significantly different ($P < 0.05$).

TABLE V
Effects of Growth Location on Properties of Pet Food Extrudates[a]

Location	BD (g/L)	BS (kJ/kg)	VEI (kg)	SME (%)	Cook
Johnston	341.84b[b]	5.37a	2.64a	247.5a	90.05a
Creston	336.39a	5.65a	2.63a	262.0b	88.15a
Nevada	343.38b	5.21a	2.54a	257.7a,b	88.35a

[a] BD = bulk density of wet extrudate; BS = breaking strength; VEI = volumetric expansion index; SME = specific mechanical energy; Cook = degree of cook of extrudate.
[b] Values followed by the same letter in the same column are not significantly different ($P < 0.05$).

TABLE VI
Effects of Hybrid on Properties of Pet Food Extrudates[a]

Hybrid	BD (g/L)	BS (kJ/kg)	VEI (kg)	SME (%)	Cook
3489	344.84b[b]	5.04a,b	2.55a	259.5b	86.67a
3394	336.42a	6.39b	2.63a	262.7b	89.50a,b
3335	336.45a	4.75a	2.60a	256.6a,b	90.33b
3348	340.11a,b	5.72a,b	2.67a	255.5a,b	90.17b
3375	344.88b	5.16a,b	2.58a	244.4a	87.58a,b

[a] BD = bulk density of wet extrudate; BS = breaking strength; VEI = volumetric expansion index; SME = specific mechanical energy; Cook = degree of cook of extrudate.
[b] Values followed by the same letter in the same column are not significantly different ($P < 0.05$).

TABLE VII
Correlation Coefficients and Probabilities of the Dependence of Pet Food Extrudate Properties on Corn Characteristics[a]

Characteristics[b]	BD (g/L)	BS (kJ/kg)	VEI (kg)	SME (%)	Cook
Moisture					
r	0.26	–0.17	–0.15	–0.29	–0.04
SL	0.3538	0.5350	0.6034	0.2983	0.8931
Fat					
r	–0.06	–0.22	0.16	–0.03	0.29
SL	0.8208	0.4218	0.5642	0.9101	0.2927
Protein					
r	0.44	–0.32	–0.56	0.11	–0.45
SL	0.0976	0.2443	0.0302	0.6882	0.0884
Starch					
r	–0.68	0.03	0.43	0.17	0.32
SL	0.0057	0.9092	0.1127	0.5567	0.2451
Test weight					
r	0.63	–0.38	–0.52	–0.2	–0.17
SL	0.0112	0.0652	0.0466	0.4687	0.5332
Abs. density					
r	0.29	–0.15	–0.54	0.24	–0.38
SL	0.3008	0.5914	0.0360	0.3930	0.1627
S24[c]					
r	–0.44	0.22	0.54	0.05	0.55
SL	0.0971	0.4305	0.0363	0.8612	0.0330

[a] BD = bulk density of wet extrudate; BS = breaking strength; VEI = volumetric expansion index; SME = specific mechanical energy; Cook = degree of cook of extrudate.
[b] *r* = Correlation coefficient; SL = significance level.
[c] S24 = % whole corn retained over 24/64-in. screen.

TABLE VIII
Correlation Coefficients and Probabilities on the Dependence of Corn Curl Extrudate Properties on Corn Characteristics[a]

Characteristics[b]	BD (g/L)	BS (kJ/kg)	VEI (kg)	SME (%)	Cook
Moisture					
r	0.72	0.26	–0.40	–0.54	–0.54
SL	0.0027	0.3414	0.1443	0.0357	0.0379
Fat					
r	0.03	0.08	–0.33	0.01	0.13
SL	0.9244	0.6725	0.2308	0.9596	0.6482
Protein					
r	0.36	0.35	–0.54	–0.33	–0.54
SL	0.1613	0.2035	0.0392	0.2268	0.0398
Starch					
r	–0.66	–0.26	0.62	0.60	0.60
SL	0.0065	0.3261	0.0026	0.0160	0.0161
Test weight					
r	0.64	–0.04	–0.33	–0.69	–0.46
SL	0.0108	0.2985	0.2290	0.0046	0.0849
Abs. density					
r	0.51	0.43	–0.32	–0.51	–0.64
SL	0.0535	0.1123	0.2450	0.0496	0.0108
S24[c]					
r	–0.5	–0.29	0.39	0.24	0.56
SL	0.0588	0.2899	0.1470	0.3849	0.0291

[a] BD = bulk density of wet extrudate; BS = breaking strength; VEI = volumetric expansion index; SME = specific mechanical energy; Cook = degree of cook of extrudate.
[b] *r* = Correlation coefficient; SL = significance level.
[c] S24 = % whole corn retained over 24/64-in. screen.

Effect of Hybrid on Pet Food Extrudates

The effect of corn hybrids grown at the same location on the extrudate properties of pet food are shown in Table VI. Hybrid 3394 produced extrudates with a significantly lower BD ($P < 0.0011$), higher VEI ($P < 0.0975$), higher BS ($P < 0.0174$), and higher degree of cook ($P < 0.0107$) when compared with extrudates from 3489. Hybrid 3489 produced pet food extrudates with a significantly higher BD and lower VEI when compared with extrudates produced using 3394, 3335, or 3348. No significant differences (at $\alpha = 0.05$) occurred between the extrudate properties (BD and VEI) of pet food produced using 3489 and 3375, 3394 and 3335, 3394 and 3348, or 3335 and 3348.

Hybrid 3375 produced an extrudate with a significantly higher BD and lower degree of cook with lower SME when compared with that produced using 3394, 3335, and 3348. In conclusion, hybrid 3348 produced extrudates with the highest expansion (lowest BD and highest VEI) followed by 3394, 3335, 3375, and 3489. Results obtained with corn curls (Table IV) are in general agreement with these results. However, extrusion of corn curls showed that 3375 produced extrudates with a significantly higher expansion (lower BD and higher VEI) when compared with that produced using 3489, whereas no significant differences were observed between pet food extrudates produced using those hybrids.

Corn Properties and Pet Food Extrudates

Correlation coefficients (*r*) and the significance levels (SL) for the effects of corn moisture content, fat, protein, starch, test weight (TW), absolute density, and kernel size (S24, % whole corn retained over 24/64 in. screen) on the BD, BS, VEI, SME, and degree of cook of extruded pet food were analyzed (Table VII). Corn moisture and fat content did not have any significant correlation with extrudate properties.

Corn protein content was correlated significantly ($r = -0.56$, $P < 0.0302$) with VEI. An increase in protein content caused a decrease in extrudate expansion. Starch content ($r = -0.68$, $P < 0.0057$) and test weight (TW) ($r = 0.63$, $P < 0.0112$) also were correlated significantly with BD of pet food extrudates. Thus, increased starch and decreased protein contents appear to result in increased expansion. The results obtained with corn curls on the correlation between protein content and VEI, starch content and BD, TW and BD, and kernel size (S24) and degree of cook (Table VIII) agree with the results obtained for pet food.

TABLE IX
Correlation Coefficients and Probabilities of the Dependence of Pet Food Extrudate Properties on Corn Curl Properties[a]

	Pet Food				
Corn Curls[b]	BD (g/L)	BS (kJ/kg)	VEI (kg)	SME (%)	Cook
BD					
r	0.67	–0.38	–0.54	–0.23	–0.41
SL	0.0059	0.1640	0.0369	0.4200	0.1272
BS					
r	–0.24	0.15	–0.11	0.53	–0.28
SL	0.3904	0.5987	0.6866	0.0436	0.3151
VEI					
r	–0.41	0.15	0.18	0.15	0.30
SL	0.1310	0.5855	0.5167	0.5925	0.2701
SME					
r	–0.63	0.37	0.37	0.26	0.26
SL	0.0115	0.1783	0.1692	0.3479	0.3486
Cook					
r	–0.58	0.17	0.74	–0.18	0.72
SL	0.0222	0.5391	0.0015	0.5116	0.0027

[a] BD = bulk density of wet extrudate; BS = breaking strength; VEI = volumetric expansion index; SME = specific mechanical energy; Cook = degree of cook of extrudate.
[b] *r* = Correlation coefficient; SL = significance level.

Table IX summarizes the correlations between properties of corn curl and pet food extrudates. BD of corn curls was correlated significantly with BD ($r = 0.67$, $P < 0.0059$) and VEI ($r = -0.54$, $P < 0.0369$) of pet food extrudates. Hence, corn curl extrusion can be used as a first approximation to predict the performance of different corn hybrids in extruded pet food.

Model to Predict Pet Food BD

Conducting pet food extrusion runs to determine of the effects of corn hybrid and growth environment on pet food extrudate properties were more time-consuming and expensive than conducting corn curl runs. Hence, an attempt was made to predict pet food extrudate (PET) properties using corn curl (CC) properties. A regression model was created using the backward elimination procedure of SAS:

$$\text{PET BD} = 916.66 + 0.16 \times \text{CC BD} - 9.68 \times \text{CC BS} - 5.75 \times \text{CC COOK}$$
$$(r^2 = 0.81)$$

The model predicts that an increase in BD of corn curl extrudates will cause an increase in BD of pet food extrudate.

CONCLUSIONS

Properties of both corn curl and pet food extrudates were affected significantly by different corn growth environments (locations) and corn hybrids. Hybrid 3489 produced corn curl extrudate with significantly higher BD ($P < 0.0004$) and lower VEI ($P < 0.0406$) when compared with extrudate from 3394. Hybrid 3348 (largest expansion) produced corn curl extrudate with the highest VEI, followed in order by 3335, 3375, 3394, and 3489.

Corn hybrids grown at Creston produced pet food extrudate with a significantly larger expansion (lower BD and higher VEI) than those produced using hybrids grown at Johnston and Nevada. Hybrids 3348, 3335, and 3394 produced pet food extrudates with the largest expansion (smallest BD), followed by those produced using 3375, and 3489. The results are in general agreement with those obtained with for corn curls. A decrease in protein and the subsequent increase in starch appears to be related to the increase in extrudate expansion. This suggests that the amount of starch in the sample may be responsible for the effects of environment and hybrids on expansion. A significant correlation was found between the BD of corn curl and pet food extrudates, indicating that corn curl extrusion can be used to predict the performance of different corn hybrids for production of extruded pet food.

ACKNOWLEDGMENTS

We thank Friskies R&D for their assistance and Pioneer Hi-bred International for furnishing the corn samples and the starch analysis.

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[Received October 26, 1998. Accepted May 7, 1999.]