Relationship Between Nutritional Quality Characters and Grain Yield in Pearl Millet[1]

K. A. Kumar, S. C. Gupta, and D. J. Andrews[2]

ABSTRACT

Before selecting genotypes for such quality characteristics as protein or amino acid contents, it is important to know how such selection is likely to affect yield. Using a diverse range of germplasm grown over seasons, locations and years, the relationships that exist between protein content, dye binding capacity (DBC) per unit protein (an estimate of the basic amino acids in protein), grain yield and grain size in pearl millet [*P. americanum* (L.) Leeke] were investigated. Protein content was estimated as total N × 6.25, total N being measured with an automatic analyzer. Basic amino acid content was estimated using the Udy DBC technique. Grain yield and protein content were not significantly correlated and the relationship between grain yield and DBC/protein was nonsignificant and negative. The relationship between protein and DBC/protein was strongly negative. These results suggest that in pearl millet it should be possible to select for increased protein content or basic amino acid content (of which lysine is the most important) by monitoring levels of lysine and protein, respectively, without detrimental effect on grain yield or grain weight.

***Additional index words: Pennisetum americanum* (L.) Leeke, Protein content.**

PEARL millet [*Pennisetum americanum* (L.) Leeke] is among the six leading cereals in the world in providing calories and proteins for human consumption (9). This crop is principally grown on 26 million hectares in the hot, drought-prone arid and semi-arid regions of Africa and the Indian sub-continent. Though pearl millet is the staple cereal supplying 80 to 90% of the calories for many millions of the poorer people in these regions (3), the nutritive value of this crop has not received extensive attention and as a result the data available are limited (12).

At the International Crops Research Institute for Semi-Arid Tropics (ICRISAT) grain quality of pearl millet is divided into two categories: the evident quality characters based on appearance and cooking quality and the cryptic quality characters based on nutritional value (7). In the millet breeding program a strong emphasis is placed on selection for evident quality characters such as grain color, size and hardness. For the cryptic quality characters, the research effort is focused on improving protein and lysine content.

Before placing a strong emphasis on breeding for cryptic quality characters, the relationships that exist among protein content, estimated basic amino acid content, grain yield and grain size were investigated on a diverse range of germplasm grown over locations and seasons.

MATERIALS AND METHODS

The seed stocks used for this study included two different types of material: (a) eleven yield trials containing hybrids, experimental varieties, synthetics, inbreds, composite bulks and selected progenies of individual composites termed unrelated material grown over four locations and 2 years, 1976 and 1977 (Table 1), and (b) 280 full sib progenies of the World Composite (modified at ICRISAT from a Nigerian source) termed related material grown over four locations in 1977. All trials were grown in randomised block designs and for (a) the net plot sizes varied from 7.5 to 22.5 m^2 and for (b) were 3.4 m^2. Plots were overplanted and thinned between 15 to 20 days later to 10 cm between plants in rows 50 or 75 cm apart. At harvest grain yield/net plot was recorded on (a) group material and head yield/ plot for (b) group material and converted to kilogram per hectare. The mean of two 1000 grain weights measured on a FMC Syntron EBOOC seed counter was recorded for each plot. Grain protein content was estimated (N × 6.25) using a Technicon Auto analyser (16). Basic amino acid content was estimated using the Udy dye-binding capacity (DBC) technique with an amount of flour that contained 80 mg of protein, values being expressed as DBC/protein (14). Analyses of variance were computed by the method described in Cochran and Cox (4) and correlations by the method given in Snedecor and Cochran (17).

RESULTS AND DISCUSSION

Unrelated Material

The means and ranges for protein content, DBC/protein, thousand-grain weight and grain yield are presented in Table 2 for the 10 trials (total of 30 tests) in 1976 and the 1977 trial (3 tests). Protein content over trials and locations ranged from 6.3 to 16.0%. The range for protein content was at the maximum for the Best Population Progeny Trial (BPPT) (8.7 to 16.0% over two locations). DBC/protein over seven tests ranged from 2.9 to 3.8 and thousand grain weight over twelve tests ranged from 3.9 to 13.2 g. Grain yield averaged over locations and trials ranged from 443 to 4,511 kg/ha.

The range and distributions of correlations among grain yield and weight, protein content and DBC/protein are presented in Table 3. Correlations between grain yield and protein content ranged from −0.50 to 0.16 in 33 tests, most being distributed between −0.40 and −0.01. Generally the relationship between these traits was nonsignificant and the R^2 values were low. The relationship between grain yield and DBC/protein though negative was nonsignificant.

Correlations between thousand-grain weight and protein content were positive but generally nonsignificant. The relationship between thousand-grain weight and DBC/protein was generally negative but nonsignificant.

Related Material

Means and ranges for head yield, protein content, DBC/protein and thousand-grain weight for 280 full sib progenies of the World Composite are given in Table 4. Protein content ranged from 8.3 to 12.3% with a mean of 9.9%, and DBC/protein ranged from 2.9 to 3.8. Thousand grain weight ranged from 5.1 to 10.0 g and head yield exhibited a range from 2,159 to 6,168 kg/ha with a mean of 4,379 kg/ha.

The relationship between head yield and protein content was generally nonsignificant and negative (Table 5). They were significant in two cases but the R^2 values were too low for any application. The relationship between head

---

[1] Journal Series Article No. 193 of the Int. Crops Res. Inst. for the Semi-Arid Tropics. Received 11 Dec. 1981.

[2] Pearl millet breeder, ICRISAT Sahelian Ctr., P.O.12404, Niamey, Niger; pearl millet breeder ICRISAT Co-operative Program, CNRA, Bambey, BP 51, Senegal, and program leader, Pearl Millet Improvement Program, ICRISAT, Patancheru P.O., Andhra Pradesh 502 324, India, respectively.

yield and DBC/protein was negative and nonsignificant. Correlations between thousand grain weight and protein content were positive and significant. The relationship between thousand grain weight and DBC/protein was not significant. Correlations between head yield and thousand grain weight were positive and significant.

The means for protein content and thousand grain weight in our materials are similar to those reported by other researchers (1, 6, 10, 11). In many of those reports however protein contents and grain weight were not identified with specified genotypes or were not related to environment or management.

The relationship between grain yield and protein content for both groups of material was nonsignficant, a relationship which indicates that pearl millet may be different from other cereals where strong negative relationships between yield

Table 1. Title, entries, replications, locations, and types of seed stocks in trials containing unrelated material studied in 1976 and 1977.†

Year	Trial	Acronym	Entries	Replications	Locations‡	Type of seed stock
1976	International pearl millet adaptation trial-2	IPMAT-2	21	4	1,2,3,4	Hybrids, experimental varieties, synthetics
	Hybrid trial-1	PMHT-1	25	4	1,2,3,4	Hybrids
	Hybrid trial-2	PMHT-2	25	4	1,3,4	Hybrids
	Hybrid trial-3	PMHT-3	23	4	1,2,3,4	Hybrids
	Hybrid trial-4	PMHT-4	10	3	1,3,4	Hybrids
	Inbred trial-1	PMIT-1	46	2	1,2	Inbreds
	Inbred trial-2	PMIT-2	49	2	1,2	Inbreds
	Experimental varieties trial	EVT	22	4	1,2,3	Experimental varieties
	Composite bulks trial	CBT	28	4	1,2,3	Composite bulks
	Best population progenies trial	BPPT	81	2	1,3	Population (composite) progenies
1977	International pearl millet adaptation trial-3	IPMAT-3	21	3	1,2,4	Hybrids, experimental varieties, synthetics

† Rainfall during the crop season in 1976 and 1977 was respectively at ICRISAT 678 and 543 mm; at Bhavanisagar 525 and 587 mm; and at Hissar 714 and 439 mm.

‡ 1 = ICRISAT Center (17°N) high fertility management (40N:40P_2O_5 kg/ha preplant, 40 kg/ha N at 3 weeks after planting). 2 = ICRISAT Center, low fertility management (20N:20P_2O_5 kg/ha preplant). 3 = Bhavanisagar (11°N) (40N:40P_2O_5 kg/ha preplant, 30 kg/ha N at 3 weeks after planting. 4 = Hissar (29°N), (40N:40P_2O_5 preplant, 40 kg/ha N at 3 weeks after planting).

Table 2. Means, least significant differences (LSD) and ranges for protein content, DBC/g protein, thousand-grain weight and grain yield in some multilocation trials containing the unrelated material in 1976 and 1977.

Trial	Location†	Protein (%)			DBC/g Protein			1000-grain weight (g)			Grain yield (kg/ha)		
		Mean	LSD*	Range	Mean	LSD*	Range	Mean	LSD*	Range	Mean	LSD*	Range
IPMAT-2 (1976)	1	10.3	NS	8.3 to 11.9	3.2	NS	3.0 to 3.3	7.2	1.42	3.9 to 10.6	2,334	682	721 to 3,646
	2	10.2	NS	9.3 to 11.2	3.2	NS	3.0 to 3.4	6.1	0.95	4.7 to 7.9	1,424	788	714 to 2,795
	3	10.8	1.42	9.9 to 12.6	--	--	--	9.0	0.99	6.4 to 13.2	3,048	255	1,161 to 4,183
	4	12.1	1.38	10.7 to 14.2	3.0	0.17	2.9 to 3.3	8.5	1.33	6.3 to 11.1	2,590	949	1,061 to 3,908
PMHT-1	1	9.6	1.06	8.2 to 11.8	--	--	--	--	--	--	2,789	771	1,669 to 3,803
	2	10.5	1.18	9.0 to 12.0	--	--	--	--	--	--	1,258	765	779 to 2,450
	3	10.7	1.45	9.2 to 13.7	--	--	--	8.1	0.94	5.9 to 11.4	2,912	721	1,993 to 3,813
	4	12.4	1.36	11.0 to 15.0	--	--	--	8.6	0.89	6.9 to 12.6	3,306	670	2,045 to 4,437
PMHT-2	1	8.6	0.82	7.7 to 9.9	--	--	--	--	--	--	2,984	738	1,497 to 3,761
	3	10.1	NS	7.4 to 11.9	--	--	--	8.0	0.97	6.3 to 9.7	2,822	979	1,073 to 3,511
	4	11.9	1.15	10.9 to 12.7	--	--	--	8.5	1.02	6.8 to 9.6	3,205	856	1,885 to 4,022
PMHT-3	1	9.0	0.98	6.9 to 10.0	--	--	--	--	--	--	3,642	683	2,470 to 4,149
	2	11.4	1.09	9.4 to 13.3	--	--	--	--	--	--	780	427	392 to 1,159
	3	11.4	NS	9.6 to 13.1	--	--	--	7.7	1.39	5.4 to 10.5	2,197	NS	1,151 to 3,076
	4	11.5	0.91	9.8 to 13.5	--	--	--	8.3	0.61	6.5 to 11.8	3,585	812	2,182 to 4,392
PMHT-4	1	8.7	1.50	7.5 to 10.2	--	--	--	--	--	--	2,170	997	1,645 to 2,701
	3	12.7	NS	11.8 to 14.1	--	--	--	7.6	NS	6.2 to 8.9	2,651	936	1,714 to 4,400
	4	12.1	1.62	10.5 to 14.1	--	--	--	8.4	1.08	6.9 to 10.5	3,096	287	2,273 to 3,753
PMIT-1	1	10.2	1.55	8.2 to 12.1	--	--	--	--	--	--	2,413	1,110	814 to 3,675
	2	11.6	1.65	8.9 to 13.2	--	--	--	--	--	--	980	811	152 to 2,017
PMIT-2	1	10.3	1.50	8.4 to 13.1	--	--	--	--	--	--	2,314	1,097	809 to 3,521
	2	11.6	1.50	9.5 to 13.8	--	--	--	--	--	--	443	308	170 to 733
EVT	1	7.9	1.19	7.1 to 9.6	3.4	0.21	3.1 to 3.5	--	--	--	2,117	630	1,316 to 2,831
	2	6.8	0.54	6.3 to 7.5	3.7	0.18	3.5 to 3.8	--	--	--	797	NS	616 to 1,051
	3	10.0	NS‡	8.8 to 11.5	--	--	--	--	--	--	1,904	NS	1,320 to 2,426
CBT	1	8.2	NS	7.2 to 9.6	3.3	NS	3.1 to 3.7	--	--	--	2,877	759	1,807 to 3,819
	2	7.2	0.79	6.4 to 8.3	3.4	NS	3.3 to 3.6	--	--	--	928	325	393 to 1,307
	3	11.2	NS	9.5 to 12.4	--	--	--	--	--	--	4,511	1,677	2,768 to 6,596
BPPT	1	10.9	NS	8.7 to 13.8	--	--	--	--	--	--	808	NS	303 to 1,670
	3	11.8	NS	9.8 to 16.0	--	--	--	--	--	--	1,076	NS	251 to 1,776
IPMAT-3 (1977)	1	11.3	1.17	9.5 to 15.0	--	--	--	--	--	--	2,615	701	1,149 to 3,551
	2	12.1	1.14	10.7 to 13.4	--	--	--	--	--	--	1,504	679	975 to 2,103
	4	12.3	1.20	11.0 to 13.3	--	--	--	--	--	--	2,800	857	1,914 to 3,852

* LSD value at the 5% probability level.

† As in Table 1.

‡ NS = Nonsignificant.

Table 3. Range and distribution of correlation coefficients (r) between grain yield, thousand-grain weight, protein content and DBC/g protein among the unrelated material.

Correlation between	No. of tests†	Range of r	Distribution of r −0.80 to −0.61	−0.60 to −0.41	−0.40 to −0.21	−0.20 to −0.01	0.00 to 0.20	0.21 to 0.40	0.41 to 0.60
Yield vs. protein	33(3)	−0.50 to 0.16	--	2	13	13	5	--	--
Yield vs. DBC/protein	7(0)	−0.25 to 0.13	--	--	1	5	1	--	--
Grain weight vs. protein	12(2)	−0.41 to 0.46	--	1	--	2	4	3	2
Grain weight vs. DBC/protein	3(1)	−0.46 to −0.01	--	1	1	1	--	--	--
Protein vs. DBC/protein	7(6)**	−0.79 to −0.21	3	3	1	--	--	--	--
Yield vs. grain weight	11(1)	−0.32 to 0.44	--	--	1	2	1	6	1

** All six significant at the 1% level of probability.
† Figures in parentheses show number of tests significant at the 5% level of probability.

Table 4. Means, least significant differences (LSD) and ranges for head yield, protein content, DBC/g protein and thousand-grain weight in 280 full sib progenies of the World Composite grown over 4 locations† in 1977.

Character	Mean	LSD (0.05)	Range
Head yield (kg/ha)	4379	1034	2159 to 6168
Protein content (%)	9.9	1.04	8.3 to 12.3
DBC/g protein	3.2	0.24	2.9 to 3.8
Thousand-grain weight (g)‡	7.7	1.10	5.1 to 10.0

† Same locations as shown in Table 1.
‡ Not recorded at Bhavanisagar.

Table 5. Linear correlation coefficients between head yield protein content, DBC/g protein and thousand-grain weight among 280 full sib progenies of the World Composite in 1977.

Character	Location†	Protein	DBC/ protein	Thousand-grain weight
Head yield	1	−0.33**	−0.12	0.14*
	2	−0.08	−0.04	0.34**
	3	0.08	−0.12	--
	4	−0.31*	0.07	0.16**
Protein	1	--	−0.74**	0.20**
	2	--	−0.82**	0.16
	3	--	−0.86**	--
	4	--	−0.60**	0.10
DBC/protein	1	--	--	−0.19**
	2	--	--	−0.21**
	3	--	--	--
	4	--	--	−0.22**

*,** Correlation coefficients significant at the 5 and 1% levels of probability, respectively.
† Same locations as shown in Table 1.

and protein content have been demonstrated (5, 8, 15). Deosthale et al. (6) found that grain yield and protein content were not significantly correlated among 15 pearl millet hybrids grown under limited moisture or among 14 hybrids grown with adequate moisture. Perhaps therefore selection for increased grain protein content without concomitant reductions in grain yield will be possible for pearl millet.

Deosthale et al. (6) also found that the relationship between grain yield and lysine content in pearl millet was negative but nonsignificant. Similar coefficients were found in our study. Thus, selection for grain yield and basic amino acid content (i.e. primarily lysine) in protein independent of protein content should be possible. The relationship between protein and DBC/protein was strongly negative indicating that selection for increased protein content may lead to a reduced level of basic amino acids. The relationship between grain yield and grain weight was generally nonsignificant. This is in agreement with other yield component studies at ICRISAT (13) where grain number has been found to be the major determinant of grain yield. In this respect pearl millet is similar to wheat, (*Triticum aestivum* L.), rice (*Oryza sativa* L.) and barley (*Hordeum vulgare* L.) (2).

Our study indicates that increased protein or basic amino acid content in pearl millet could be selected without detrimental effect on grain yield and weight. At ICRISAT a breeding project is underway in pearl millet to select simultaneously for protein content and grain yield with constant monitoring of lysine levels, using both recurrent and pedigree selection.

ACKNOWLEDGMENTS

The assistance of Dr. R. Jambunathan, Principal Biochemist and Head and Dr. V. Subramaniam, Biochemist of ICRISAT's Biochemistry and Nutrition Laboratory is gratefully acknowledged.

REFERENCES

1. Adrian, J., and C. Sayerse. 1957. Composition of Senegal millets and sorghums. Br. J. Nutr. 11:99–105.
2. Biscoe, P.V., and J.N. Gallagher. 1977. Weather, dry matter production and yield. p. 75–100. *In* J.J. Landsberg and C.G. Cutting, (ed.) Environmental effects on crop physiology. Academic Press, London and New York.
3. Burton, G.W., A.T. Wallace, and K.O. Rachie. 1972. Chemical composition and nutritive value of pearl millet [*Pennisetum typhoides* (Burm) Stapf and E.C. Hubbard] grain. Crop Sci. 12:187–188.
4. Cochran, W.G., and G.M. Cox. 1964. Experimental Designs 2nd ed. John Wiley & Sons, Inc., New York.
5. Crook, W.J., and A.J. Casady. 1974. Heritability and interrelationships of grain protein content with other agronomic traits of sorghum. Crop Sci. 14:622–624.
6. Deosthale, Y.G., K.V. Rao, V. Nagarajan, and K.C. Pant. 1971. Varietal differences in protein and amino acids of grain Bajra (*Pennisetum typhoides*). Indian J. Nutr. Diet. 8:301–308.
7. Doggett, H. 1977. Quality improvement in sorghum and millets. p. 7–9. *In* D.A.V. Dendy (ed.) Proc. Symp. on Sorghum and Millets for Hum. Food. Vienna. 11–12 May 1976. Tropical Products Inst., London.
8. Dudley, J.W., R.J. Lambert, and D.E. Alexander. 1971. Variability and relationships among characters in *Zea mays* L. synthetics with improved protein quality. Crop Sci. 11:512–514.
9. Evans, L.T. 1975. Crops and World Food Supply, Crop evolution and the origins of crop physiology, p. 1–22. *In* Evans, L.T. (ed.) Crop physiology, Cambridge Univ. Press, Cambridge.
10. Goswami, A.K., K.L. Sehgal, and K.P. Sharma. 1969. Chemical composition of Bajra grains. I. African entries. Indian J. Nutr. Diet. 6:287–290.
11. ----, K.P. Sharma, and K.L. Sehgal. 1970. Chemical composition of Bajra grains. 4. Indian varieties. Indian J. Nutr. Diet. 7:67–70.
12. Hulse, J.H., E.M. Laing, and O.E. Pearson. 1980. Sorghum and the Millets: Their composition and nutritive value. p. 152–177. Academic Press, London.
13. ICRISAT (International Crops Research Institute for the Semi-Arid Tropics). 1980. Annual Report 1978/79. p. 68–69. Patancheru, A.P. 502 324, India.
14. Jambunathan, R. 1980. Improvement of the nutritional quality of sorghum and pearl millet. Food and Nutr. Bull. (The U.N. Univ.). 2:11–15.

15. Mattern, P.J., A. Salem, V.A. Johnson, and J.W. Schmidt. 1968. Amino acid composition of selected high protein wheats. Cereal Chem. 45:437–444.
16. Singh, U., and R. Jambunathan. 1980. Evaluation of rapid methods for the estimation of protein in Chickpea (*Cicer arietinum* L.). J. Sci. Food Agric. 31:247–254.
17. Snedecor, G.W., and W.G. Cochran. 1967. Statistical Methods. 6th ed. Oxford and IBH. New Delhi.

Inheritance of Ozone Resistance in Tall Fescue[1]

W. J. Johnston, R. L. Haaland, and R. Dickens[2]

ABSTRACT

Ozone is considered the most important air pollutant affecting vegetation. With progessive urbanization, ozone levels have steadily escalated. Reports suggest that ozone tolerance is a highly heritable characteristic and that the selection of resistant plants and breeding for ozone resistance should be possible. This study was undertaken to gain information on the inheritance of ozone resistance in tall fescue (*Festuca arundinacea* Schreb.). Progenies from a diallel among six tall fescue genotypes of diverse origin were evaluated for ozone resistance in a fumigation-chamber. Sixteen-day-old seedlings were exposed to 0.5 ppm ozone for 3 hours and scored for injury after 3 days. General combining ability (GCA) and reciprocal effects were both highly significant; however, GCA constituted a major portion of the genotypic variation. Specific combining ability was not significant. The predominance of additive genetic variance observed indicates that breeding for ozone resistance in this tall fescue population should be possible.

Additional index words: **Air pollution, Diallel analysis, *Festuca arundinacea* Schreb.**

OZONE is the most ubiquitous air pollutant in the United States and is considered to be the most important air pollutant affecting vegetation (7). With progressive urbanization ozone levels have steadily escalated and presently exceed the federal standard with increasing frequency.

The influence of genetic variability on plant response to ozone has been documented in several reviews (12). Improved ozone resistance has been achieved through plant breeding in several species (1, 3, 12); however, except for the selection of a smog resistant turf-type bermudagrass, 'Santa Ana' (13), and the ranking of grass species for ozone resistance (2, 11), little work has been done in breeding for ozone resistance in turf or forage grass species.

Aycock (1) evaluated ozone resistance in progeny of a 7 × 7 diallel in tobacco (*Nicotiana tabacum* L.) and found the major part of the genetic variance to be additive. Heritability based on parent progeny regression was 0.95. Campbell et al. (3) found that general combining ability (GCA) constituted most of the genotypic variation for ozone resistance in alfalfa (*Medicago sativa* L.); however, specific combining ability (SCA) was large enough to indicate that progress might also be made by a hybrid variety development program. Although maternal and reciprocal effects were significant, they were relatively unimportant. Hanson et al. (6) obtained narrow and broad sense heritability estimates of 0.80 and 0.93, respectively, for ozone resistance in petunia (*Petunia hybrida* Vilm). These reports suggest that ozone tolerance is a highly heritable characteristic and that selection of resistant plants and breeding for ozone resistance should be possible. This study was undertaken to gain information on the inheritance of ozone resistance in tall fescue.

Table 1. Parents used in diallel cross.

Clone	Source	Origin
32	'Kentucky 31'	United States
145	PI297303	Sweden†
220	PI231778	The Netherlands
227	PI302993	France
239	PI231562	Morocco
264	PI208680	Algeria

† Origin previously reported by the authors to be Australia (9).

MATERIALS AND METHODS

Six tall fescue clones were selected for diversity of origin (Table 1). Four replications of each clone were brought into the greenhouse, subdivided, and planted in screened, methyl bromide-fumigated, Cahaba fine sandy loam (fine-loam, siliceous, thermic Typic Hapludult).

To simulate winter field conditions, plants were transferred outdoors from 15 Nov. 1977 through 31 Jan. 1978. If subfreezing temperatures were anticipated, plants were moved to a greenhouse (4 to 27 C). In February 1978, plants were transferred to an environmental chamber with a 28 C day, 15 C night, and a 16-hour photoperiod of 320 ± 20 μmol m^{-2}sec^{-1}. Due to differential heading of the clones, to delay flowering, early heading clones were transferred to a cold room maintained at a constant 9 C and an 8-hour photoperiod of 85 ± 10 μmol m^{-2}sec^{-1}.

During May and June 1978, crosses were made by placing panicles of the desired clones together in a glassine bag prior to anthesis. Individual panicles of clones were placed in bags for selfing. Bags were agitated several times daily to ensure pollination. Day temperature in the environmental chamber was lowered to 20 C to mitigate heat buildup in the glassine bags.

Because several crosses yielded few seed, a second diallel was begun October 1978. Material was handled as previously, except that beginning 31 Jan. 1979, and every 7 days thereafter, five plants per clone were transferred to environmental chambers as previously described. This measure was taken to ensure better nicking among early and late flowering clones. Crosses were made during April and May 1979.

In September 1979, 4 × 22 cm Cone-Tainers were filled with potting soil and planted with five F_1 seeds per cone and subsequently thinned to four plants per cone. Plants were grown in an environmental chamber with a 25 C day, 15 C night, and a 12-hour photoperiod of 300 ± 30 μmol m^{-2}sec^{-1}. Sixteen days after emergence seedlings were exposed to 0.5 ppm ozone for 3 hours in a fumigation chamber. The ozone fumigation chamber (Sherer CEI 38-15. Warren/Sherer, Marshall, Mich.) was modified by adding a blower unit with a capacity of 2.7 m^3 min^{-1} to the intake vent and exhaust tubing from the exit vent to the outside atmosphere. The entire volume of the chamber could be exchanged approximately every 5 min. A supplemental forced-air, cool-mist

---

[1] Contribution from the Dep. of Agronomy and Soils, Auburn Univ. Agric. Exp. Stn., 36849. Received 1 Feb. 1982.

[2] Former research associate (now assistant professor, Dep. of Agronomy and Soils, Washington State Univ., Pullman, WA 99164), former associate professor (now president, Sun Rise, Inc., Auburn, AL 36830), and professor, Dep. of Agronomy and Soils, Auburn Univ., Al 36849.