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Yield Comparisons and Unique Characteristics of the Dwarf Wheat Cultivar 'USU-Apogee'

Bruce Bugbee
Utah State University, bruce.bugbee@usu.edu

G. Koerner

- **Yield Comparisons and Unique Characteristics of the Dwarf Wheat Cultivar 'USU-Apogee'**
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ABSTRACT **Extremely short, yet high yielding cultivars of all crop plants are needed to optimize the food production of bioregenerative life support systems in space. In the early 1980's, we examined over a thousand wheat genotypes from the world germplasm collection in search of genotypes with appropriate characteristics for food production in space. Here we report the results of 12 years of hybridization and selection for the perfect wheat cultivar. 'USU-Apogee' is a full-dwarf hard red spring wheat (*Triticum aestivum* L.) cultivar developed for high yields in controlled environments. USU-Apogee was developed by the Utah Agricultural Experiment Station in cooperation with the National Aeronautics and Space Administration and released in April 1996. USU-Apogee is a shorter, higher yielding alternative to 'Yecora Rojo' and Veery-10, the short field genotypes previously selected for use in controlled environments. The yield advantage of USU-Apogee is 10 to 30% depending on environmental conditions. USU-Apogee (45-50 cm tall, depending on temperature) is 10 to 15 cm shorter than Yecora Rojo and 1 to 4 cm shorter than Veery-10. USU-Apogee was also selected for resistance to the calcium-induced leaf tip chlorosis that occurs in controlled-environments. Breeder seed of USU-Apogee will be maintained by the Crop Physiology Laboratory in the Plants, Soils, and Biometeorology Dept. at Utah State University and seed is available for testing on request.**

INTRODUCTION AND PEDIGREE **USU-Apogee was named after the point in an orbit that is the farthest from the Earth. USU-Apogee (Reg. no. CV-840; PI 592742) originated from the cross 'Parula'/'Super Dwarf', both of which were obtained from the International Center for Wheat and Maize Improvement (CIMMYT; Obregon, Mexico) germplasm collection in 1984. Parula has the pedigree: FKN/3/2*FCR//'KenyaAD'/'Gabo 54'/4/Bluebird/'Chanate'; where FKN = 'Frontana'/'Kenya58'//'Newthatch'. Parula was selected for its small leaf size. Super Dwarf has the CIMMYT germplasm number CMH79.481-1Y-8B-2Y-2B-0Y; and the pedigree: T. sphaerococcum /2*H-567.71/3/'Era'/'Sonora64'/ /2*Era. Super Dwarf was selected for its short stature (25 cm tall).**

SELECTION CRITERIA AND PROCEDURES **Single head selections were made in the F_2 to F_4 generations for short height (less than 50 cm tall), erect tillering habit, reduced tillering, and small leaves. These traits are desirable in high yield conditions (Donald, 1968; 1979). Small leaves are often more photosynthetically more efficient than large leaves and two small leaves may be better than one large leaf (Morgan et al., 1990; LeCain et al., 1989; Bhagsari and Brown, 1986) Mass selections for short height and yield were made in the F_5 to F_8 generations (1988 to 1989). All selections were made in a CO_2-enriched temperature-controlled greenhouse that had a photosynthetic photon flux (PPF) of 400 μmol m^{-2} s^{-1} (35 mol m^{-2} d^{-1}) of supplemental lighting from high pressure sodium lamps. The photoperiod was 24-h (continuous light). The root-zone was a hydroponic soilless medium, watered twice daily with nutrient solution. Continuous cultivation made it possible to evaluate 3 to 4 generations per year. Yields in this environment (about 16 Mg ha^{-1}; 240 bushels per acre) are typically double that of the best irrigated field yields (Bugbee**

and Salisbury, 1988).

Preliminary yield evaluations, in the near-optimal conditions of the CO_2-enriched greenhouse, were begun in the $_{F.}$ generation. Mice got into the greenhouse prior to harvest in the F8 generation and damaged all six replicate plots of USU-Apogee. No other plots were damaged. USU-Apogee had the least leaf tip necrosis, but had considerable variability for plant height, so 67 single heads selected from the $_{F.}$generation were grown as head rows. Additional selections were made in the next six generations (F_{10} to F_{15}) for yield. In the F_{16} generation, 100 heads were selected and grown as head rows. After roguing off-type and nonuniform rows, the remaining 90 F_{16} lines were harvested and bulked as breeders seed.

RESISTANCE TO CALCIUM-INDUCED "TIP BURN" USU-Apogee is resistant to the leaf tip chlorosis that occurs in wheat under rapid growth conditions, particularly in continuous light. This chlorosis (caused by a calcium deficiency) can kill the top 30% of the flag leaf. The chlorosis is severe in Veery-10 and also occurs in Yecora Rojo. Calcium deficiencies, such as tip burn in Lettuce and blossom end rot in tomatoes are common in controlled-environment crop production because Ca has low phloem mobility and is thus not sufficiently translocated to growing meristems. Foliar Ca applications and increased root-zone Ca are not effective because they do not reach the meristematic tissue. USU-Apogee has significant rates of guttation during dark periods and guttation occurs even during the light period when the stomates are partly closed by elevated CO_2 . Significant amounts of Ca can be translocated by guttation. The segregating lines with the smallest leaves had the least chlorosis. Tissue analysis by inductively coupled plasma emission spectrophotometry indicated adequate calcium in the top 30% of small leaves (0.4% Ca), but inadequate amounts (0.05% Ca) in large leaves. USU-Apogee has smaller flag leaves (11 to 20 cm long, depending on temperature) than Yecora Rojo and Veery-10 (20 to 30 cm long). Calcium deficiencies, such as tip burn in lettuce (*Lactuca sativa)* and blossom end rot in tomatoes (*Lycopersicun esculentum)*, are common in controlled-environment crop production because Ca has low phloem mobility and is thus not sufficiently translocated to rapidly growing meristems. Foliar Ca applications and increased root-zone Ca are not effective because they do not reach the meristematic leaf tissue (Marschner, 1995).

DEVELOPMENTAL CHARACTERISTICS USU-Apogee has an extremely rapid development rate. Heads emerge 23 days after seedling emergence in continuous light with a constant 25^{o}C temperature. Heads of Yecora Rojo and Veery-10 emerge about 6 days later under these conditions. In field conditions, USU-Apogee heads about 3 days earlier than Yecora Rojo and 6 days earlier than Veery-10.

YIELD STUDIES IN GREENHOUSE, GROWTH CHAMBER, AND FIELD ENVIRONMENTS We have examined the yield advantage of USU-Apogee in 5 greenhouse studies, 2 field studies, and 2 sets of growth chamber studies (Table 1). Most studies compared USU-Apogee to Veery-10 because these cultivars are similar in height. USU-Apogee out-yielded Veery-10 by an average of 29 ±1% in two greenhouse studies at 23^{o}C (60 day life cycle), but by an average of 16 ±9% in 3 greenhouse studies at 23 decreasing to 17^{o}C (95-day life cycle). USU-Apogee out yielded Veery-10 by 8% in a replicated study in a growth chamber under high light

(PPF=1500 µmol m^{-2} s^{-1}; 20-h photoperiod; 108 mol m^{-2} d^{-1}). Grotenhuis and Bugbee (1997) examined the effects of elevated and super-elevated CO_2 on USU-Apogee and Veery-10. USU-Apogee out yielded Veery-10 by an average of 11% in 12 hydroponic growth chamber trials under fluorescent lamps, and both cultivars responded similarly to elevated CO_2 . The average yield in all growth chamber and greenhouse trails was 0.33 ±0.04 grams of edible seed yield per mole of photosynthetic photons. Side lighting was minimized by guard rows or Mylar screens at the edges of the plot in all trials.

USU-Apogee out yielded Veery-10 by 15±3% in replicated field trials in 1994 and 1995, and out yielded Yecora Rojo by 14% in 1995 (Table 1). The yield of USU-Apogee was 160% of Super Dwarf and 100.1% of Fremont (an adapted semi-dwarf Utah wheat cultivar) in the 1995 field trial. Neither Veery-10 nor Yecora Rojo are specifically adapted to Utah field conditions.

TABLE 1 Results of yield studies in 3 environments. Data are normalized to Veery-10 to facilitate comparisons. USU lines 1, 10, and 56 are from the same hybrid cross that produced USU-Apogee. The 12 growth chamber studies at PPF=700 are described in detail by Grotenhuis and Bugbee (1997). The greenhouse studies included 4 to 6 replicate plots per genotype. A dashed line indicates that the genotype was not included in the study.

	---- Hydroponic, CO_2 Enriched ----							Utah Field Studies	
	-------- Greenhouse --------					Growth Chamber			
Cultivar Name	Feb. - May '94	Mar. - June '95	July - Sept. '95	Nov. 95 - Feb.'96	Aug. - Dec. '96	12 studies PPF=700 '92 -'96	1 study PPF=1500 '94	4 Reps. '94	6 Reps. '95
USU-Apogee	129	101	130	130	116	111	108	118	112
USU-Line 56	128	99	127	--	--	--	98	114	111
USU-Line 1	111	106	115	--	--	--	108	104	96
USU-Line 10	108	104	112	--	--	--	--	98	107
Veery 10	100	100	100	100	100	100	100	100	100
Yecora Rojo	--	--	--	141	101	--	--	--	97
Statistical Significance	0.05	n.s.	0.01	0.01	0.05	--	0.08	0.05	0.05

HARVEST INDEX AND YIELD COMPONENTS The primary cause of the increased yield of USU-Apogee is increased harvest index, which is 5 to 15% higher than that of Veery-10. Using USU-Apogee, we achieved harvest indexes of 56 and 60% in two greenhouse studies with phasic environmental control (23°C decreasing to 15°C after anthesis). Assuming that the root mass was 6% of the total biomass at harvest, the harvest index including roots in these trials would be 50 and 54%. The harvest index of Veery-10 (without roots) was 48 and 49% in these same trials. The increased harvest index of USU-Apogee is primarily caused by a reduced number of late forming tillers, which are often sterile.

In warm environments (constant 23°C; 60 days from emergence to harvest), heads per m^2 and seeds per head are about 25% higher in USU-Apogee than in Veery-10, and mass per seed is about 25% less. In two studies in a cool environment (23°C, decreasing to 17°C after anthesis; 100 days to harvest), heads per m^2 averaged 20% greater, seeds per head was 5% greater, and mass per seed was 5% less than Veery-10.

BREADMAKING QUALITY **Breadmaking quality was evaluated by the USDA-ARS Western Quality Wheat Laboratory at Pullman, Washington, USA. Milling and baking tests indicated that USU-Apogee has similar quality to Veery-10 and slightly poorer quality than Yecora Rojo.**

FUTURE BREEDING EFFORTS **We recognize the need for even shorter wheat cultivars and are continuing our breeding efforts. We are now conducting a yield trial of an advanced breeding line that is 10 cm shorter than USU-Apogee. This line was a re-selection from the same F_3 plant as USU-Apogee and has the same resistance to leaf tip chlorosis. In March 1996 we planted seed from the F_1 generation from the Parula X Super Dwarf cross and re-selected for genotypes less than 40 cm tall. We are now evaluating selections from the F_4 generation among these genotypes. These lines look exceptionally promising. It appears that we will be able to obtain homozygous lines with heights of 30 to 40 cm. We are selecting for green leaf tip color and high yield. These lines will probably have lower yields than USU-Apogee, but they appear to have higher yields than Super Dwarf.**

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