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Search for High Yielding, Lodging Resistant Barley Cultivars with Satisfactory Straw Yields for a Fertile Production Area of Turkey

N. Kandemir
Gaziosmanpaşa Üniversitesi, Ziraat Fakültesi, Tarla Bitkileri Bölümü, 60250 Tokat, Turkey

Abstract: In the present study, four Turkish cultivars along with four foreign cultivars with known lodging resistance features and 10 advanced ICARDA lines were studied in a fertile environment in three years with quite different precipitations. Turkish cultivars had relatively long stems and lodged almost completely in the first and second years in which the precipitations were similar or higher than the long term average of the region. In the absence of lodging, seed yields of these cultivars were only 5% lower than the best four foreign genotypes. In years when lodging occurred, however, their yields were about 20% less. IC-15, IC-20, IC-22 and Baronesse were the highest yielding foreign genotypes. Of these, IC-15 was the most prominent one since it combined high grain yield, good lodging resistance and very good levels of straw yield, a trait valued by Turkish farmers who use barley straw as feed. IC-15 is a promising cultivar candidate for our environment until better cultivars are developed through breeding programs.

Key words: Lodging, semidwarf, straw yield

INTRODUCTION

Barley crop suffers from considerable yield losses due to lodging in high yielding environments. Although environmental factors such as the amount of available water and nutrients affect lodging, prevention of lodging is possible to some degree using genetic resistance. Most of the lodging resistance genes are related to shorter plant stature. In countries like Turkey where barley straw is a valuable fodder for livestock, barley cultivars with short stems are not preferred by farmers. Besides, some of the lodging resistance genes are sometimes negatively correlated with grain yield and cause losses from yield potential[1,2], These factors make barley breeding for lodging resistance a challenge for plant breeders.

There are many genes known to decrease lodging in barley such as *denso*[2,3], *Ea* locus (later proposed to be *Ppd-H1*)[4-6] a quantitative trait locus (QTL) on barley chromosome 3 centromeric region[7] and some dwarfing genes that cause extremely short plants such as *gai* and *gal*[8]. Semidwarf genes such as *sdw1*, also known as *denso*[8] and *uzu*[9] rather than dwarfing genes, are commonly used in barley breeding. Semidwarf genes normally results in 10-30 cm shorter plants, don't cause losses from potential yields and allow combine-harvesting. Nevertheless, in areas where barley straw is used as animal feed, semidwarf cultivars are not favoured by farmers. Most of the barley cultivars developed in Turkey have been selected for low yielding arid regions where lodging is not a problem. Farmers prefer cultivars with long stems such as Tokak 157/37. However, when these cultivars are grown in high yielding environments such as Yesilirmak basin of Turkey, lodging becomes a major problem and about 15-20% yield losses and serious deteriorations in grain quality occur[10]. Thus, development of barley cultivars that combine satisfactory grain and straw yields is a necessity.

The goal in this study was to compare local varieties with some known foreign genotypes and advanced ICARDA lines and, thus, to determine genotypes with enough lodging resistance, high seed yield and an acceptable level of straw yield to be grown in Yesilirmak Basin of Central Anatolia Plateau, a region with fertile plains around Yesilirmak River. The new genotypes will serve for a short term and will be replaced by the new cultivars to be developed specifically for the region. They may also be used in the breeding programs for the improvement of already established, lodging susceptible local cultivars such as Tokak 157/37.

MATERIALS AND METHODS

This investigation was conducted in 1999-2000, 2001-02 and 2002-03 growing periods in the experimental areas of Rural Services Agricultural Research Station in Tokat province of Turkey. This station is located

Corresponding Author: N. Kandemir, Gaziosmanpaşa Üniversitesi, Ziraat Fakültesi, Tarla Bitkileri Bölümü, 60250 Tokat, Turkey
Tel.: 90 : 356 : 252 14 79 (ext.2128) Fax: 90 : 356 : 252 14 88 E-mail: Kandemir@gop.edu.tr

Table 1: Physical and chemical properties of experimental soils

Experiment	Texture	pH	Organic matter (%)	Total salt (%)	Lime (%)	P_2O_5 Kg da^{-1}	K_2O Kg da^{-1}
1999-2000	Clayed loam	7.84	2.28	0.03	7.9	2.98	74.3
2001-2002	Clayed loam	7.90	1.81	0.02	10.9	3.44	37.6
2002-2003	Clayed loam	7.93	1.35	0.03	8.7	2.75	127.9

Table 2: Precipitation and air temperature in the region during the growth period in long term and experimental years

		Months								
Climatic factor	Period	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May.	June	Total average
Total	1999-00	24.5	37.6	58.8	73.6	41.8	93.4	82.8	12.8	425.3
precipitation	2001-02	73.4	50.5	45.1	20.4	29.2	68.4	16.8	57.6	361.4
(mm)	2002-03	33.8	25.0	27.8	21.8	16.4	75.6	11.8	11.4	223.6
	1965-03	46.7	45.9	39.5	34.7	38.2	62.4	59.5	38.6	365.5
Average	1999-00	5.6	3.6	-1.2	-0.1	4.6	14.7	14.2	17.6	7.9
temperature	2001-02	7.4	5.1	-4.5	4.1	9.3	11.1	15.6	18.8	8.9
(°C)	2002-03	6.9	-2.0	5.5	2.0	3.0	11.0	17.0	18.2	7.7
	1965-03	7.0	3.2	1.3	2.8	6.9	12.5	16.2	19.5	8.7

in Kazova plain within Yesilirmak Basin of Central Anatolia Plateau. Experimental soils had a clayed-loam texture, slightly alkaline soil reaction, low or moderate organic matter content, low salt content, moderate lime, low P_2O_5 and enough or high K_2O (Table 1).

Long term (38 years) average temperature in the growing period (November-June) of the experimental area is 8.7°C (Table 2). Average temperatures of growing period are 7.9, 8.9 and 7.7, in the first, second and third years. Long term November-June total precipitation is 365.5 mm. The second experimental year had a similar value (361.4 mm) to long term average. However, total precipitation was somehow high in the first experimental year (425.3 mm) but was considerably low in the third (223.6 mm).

Eighteen cultivars were studied. Tokak 157/37 is traditional Turkish cultivar dominantly grown in Turkey and in the region. TARM-92, Yesevi-93 and Bülbül-89 are modern Turkish cultivars with some acreage in the region. Harrington is very high quality, semidwarf Canadian malting barley[11]. Steptoe is a high-yielding American feed barley. Steptoe has been reported to have a quantitative trait locus (QTL) on chromosome 3 that lowers plant height and lodging percentage without affecting flowering time[7]. Baronesse is a high yielding, lodging resistant German cultivar and has been reported to have higher straw strengths than Steptoe[12]. Golden Promise is a well known short stature American cultivar with an *erectoides* short stature gene *GP-ert*[13]. IC-2, IC-5, IC-13, IC-14, IC-15, IC-17, IC-19, IC-20, IC-22 and IC-23 are advanced experimental lines from International Barley Yield Trial-Continental Highlands-Cold Winter 1999-2000 program of ICARDA. Steptoe, IC-22 and IC-23 are six row cultivars while the others are two-row.

Each plot consisted of six 1.5 m long rows. After six rows, one row of a wheat line with a good lodging resistance was planted in order to prevent the intervention of lodged plants in one plot with the plants in another plot. Row spacing was 30 cm. Thus each plot was 2.7 square-meter. Seeding rate was 200 kg ha^{-1}. Plots were hand-planted. Planting dates were November 3rd, 14th and 6th in the first, second and third years, respectively.

In trials, 75 kg P_2O_5 and 150 kg N ha^{-1} were applied in the form of triple super phosphate and ammonium nitrate, respectively. All of the phosphorus and half of the nitrogen were applied in sowing while the remaining nitrogen was applied in spring.

Lodging percentage was visually determined as the percentage of lodged plants in a plot at harvest. Plant height was measured from the ground to the tip of the spike excluding the awns in 20 randomly chosen tillers in each plot. Head weights were determined in the same 20 tillers. Straw yields were determined on cut and air dried stems before threshing. Seed yield was calculated from the weight of threshed, air-dried grains of a plot.

Experimental design was a randomized blocks with three replications. Due to large variations in total precipitation, years were analyzed separately rather than combined. Comparisons among cultivar means were conducted using Duncan's multiple range test. MSTAT statistical analysis software was used for all statistical analyses[14].

RESULTS

Because of the large variation in precipitations among years in growing period (November-June), results of the experiments conducted in three years were not combined in statistical analysis. This variation made itself felt in quite different yield and lodging in some years, making the combined analysis impossible due to heterogeneous variances.

Average plant heights of 18 cultivars were 88.6, 104.6 and 78.4 cm in the first, second and the third experimental years, respectively (Table 3). Six-rowed IC-22 genotype was always the tallest. Tokak 157/37, Steptoe and IC-5 were consistently tall in three years. Golden Promise, on

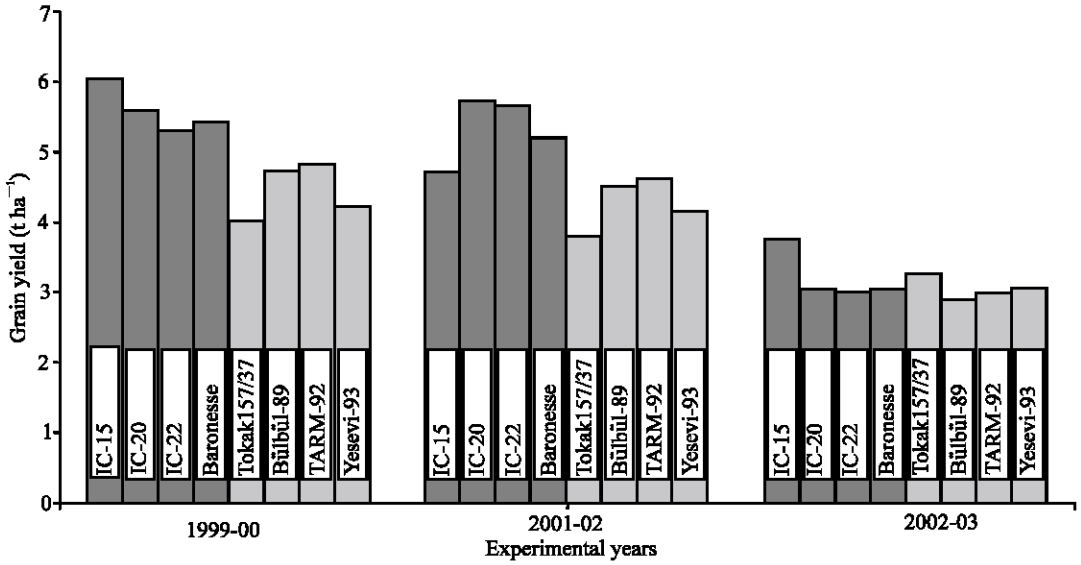

Fig. 1: Yield comparisons of four Turkish barley cultivars (Tokak 157/37, Bülbül-89, TARM-92 and Yesevi-93) and four highest yielding foreign genotypes grown in three years under high yielding Yesilirmak Basin conditions of Turkey. In the first two years, all Turkish cultivars and IC-22 lodged heavily while in the third year no lodging occurred in any genotype

the other hand, was the shortest of all. Baronesse, IC-13 and IC-14 had short stems compared to others in all trials.

Spike weight was studied as a possible lodging-related trait. As expected, six-rowed genotypes Steptoe (2.10, 2.57 and 2.00 g), IC-22 (1.65, 1.89 and 2.12 g) and IC-23 (1.89, 2.49 and 1.83 g) had highest spike weights in the first, second and third years, respectively (Table 3). Of the two-rowed cultivars, Yesevi-93 (1.20 and 1.58 g), IC-5 (1.16 and 1.57 g), IC-15 (1.12 and 1.49 g) and IC-19 (1.16 and 1.57 g) had heavier spikes in the first two years. In the third year, however, all Turkish varieties, i.e. TARM-92 (1.31 g), Tokak 157/37 (1.44 g), Yesevi-93 (1.35 g) and Bülbül-89 (1.20 g) had heavier spikes. Spike weight of Golden Promise was lowest in all trials.

Average straw yields of 18 cultivars were 4.68, 4.23 and 2.88 ha^{-1} in the first, second and third years, respectively (Table 3). In the first year, the highest straw yield was obtained from IC-15 (6.38 t ha^{-1}) which was followed by TARM-92 (6.06 t ha^{-1}). Other three Turkish cultivars Tokak 157/37, Yesevi-93 and Bülbül-89 had high straw yields that varied between about 5.0-5.5 t ha^{-1}. Straw yields of Golden Promise, IC-14, IC-20, IC-22 and IC-23 were quite low, being less than 4.0 t ha^{-1}. In the second year, TARM-92 had the highest straw yield as 5.03 t ha^{-1} followed by Bülbül-89, Yesevi-93, IC-20 and IC-5 as about 4.75-4.80 t ha^{-1}. The lowest straw yield was obtained from IC-23 (2.98 t ha^{-1}). In the third year, IC-15 had the highest straw yield (4.45 t ha^{-1}) followed by IC-5 (3.81 t ha^{-1}). Four Turkish varieties had about 3.0-3.5 t ha^{-1} straw yields and were at the highest statistical group for straw yield. IC-22 and IC-23 had straw yields less than 2.0 t ha^{-1} and were the lowest.

As the average of all cultivars, 39.1 and 39.9% of barley plants lodged in the first and second years. However, no lodging occurred in any plot in the third year. All Turkish varieties had at least 93.3% lodging throughout the experiments. IC-22 had 93.3 and 96.7% lodging in the first and second years. Harrington (33.3 and 53.3%), Golden Promise (20.0 and 50.0%) and Steptoe (46.7 and 83.3%) had considerable amount of lodging in these years. Baronesse, IC-2, IC-5, IC-14, IC-15, IC-19 and IC-20 had 10% or lower lodgings in both years.

Grain yield averages of 18 cultivars were 4.88, 4.71 and 2.93 ha^{-1} in the first, second and third years, respectively (Table 3). In the first year, IC-15 (6.06 t ha^{-1}) had the highest yield followed by IC-20 (5.59 t ha^{-1}), IC-19 (5.46 t ha^{-1}), Baronesse (5.41 t ha^{-1}), IC-22 (5.28 t ha^{-1}) and IC-17 (5.26 t ha^{-1}). Golden Promise had the lowest yield (4.02 t ha^{-1}). Four Turkish cultivars were listed between 10th and 17th. In the second experimental year, IC-20 (5.74 t ha^{-1}), IC-22 (5.67 t ha^{-1}) and Baronesse (5.19 t ha^{-1}) had the highest grain yields. Four Turkish varieties were within the six lowest yielding genotypes. In the third year, IC-15 again had the highest grain yield as 3.74 t ha^{-1} followed by Tokak 157/37 (3.23 t ha^{-1}) and Steptoe (3.10 t ha^{-1}). All four Turkish varieties were within the highest grain yield group based on Duncan test ($P<0.01$). IC-23 (1.99 t ha^{-1}) and Golden Promise (2.20 t ha^{-1}) had the lowest grain yields. As the average of the three years, IC-15, IC-20, IC-22 and Baronesse had

Table 3: Various agronomic features of barley cultivars

Cultivar	Plant height (cm)	Head weight (g)	Straw yield (t ha^{-1})	Lodging (%)	Yield (t ha^{-1})
1999-00					
TARM-92	90.0ABC**	1.00C**	6.06AB**	96.7A**	4.81BCD*
Tokak157/37	94.0A	1.02C	5.21A-D	100.0A	4.03D
Yesevi-93	90.0ABC	1.20C	5.41A-D	100.0A	4.22CD
Bülbül-89	82.0CDE	1.08C	5.09A-D	93.3AB	4.70BCD
Baronesse	84.0BCD	1.16C	4.45A-D	1.7CD	5.41ABC
Harrington	90.0ABC	1.20C	4.39A-D	33.3CD	4.50BCD
Golden Promise.	75.0E	0.92C	3.59CD	20.0CD	4.02D
Steptoe	90.0ABC	2.10A	4.46A-D	46.7BC	4.85A-D
IC-2	92.0AB	1.02C	4.21BCD	10.0CD	4.49BCD
IC-5	92.3AB	1.16C	5.65ABC	20.0CD	4.81A-D
IC-13	78.3DE	0.92C	4.15BCD	40.0CD	4.61BCD
IC-14	87.0ABC	1.10C	3.50D	11.7CD	5.04A-D
IC-15	88.0ABC	1.12C	6.38A	0.0D	6.06A
IC-17	93.3A	1.00C	5.55A-D	16.7CD	5.26A-D
IC-19	91.7AB	1.16C	5.18A-D	6.7CD	5.46ABC
IC-20	93.0A	1.27C	3.65CD	0.0D	5.59AB
IC-22	94.7A	1.65B	3.57D	93.3A	5.28A-D
IC-23	89.7ABC	1.89AB	3.67CD	13.3CD	4.76BCD
Average	88.6	1.22	4.68	39.1	4.88
2001-02					
TARM-92	105.3A-D**	1.38CD**	5.03A**	93.3A**	4.60A-D**
Tokak157/37	113.7A	1.36CD	4.28ABC	100.0A	3.78D
Yesevi-93	105.7A-D	1.58BC	4.74AB	100.0A	4.14CD
Bülbül-89	101.3A-D	1.32CD	4.79AB	93.3A	4.48BCD
Baronesse	93.3DE	1.41CD	4.18ABC	0.0C	5.19ABC
Harrington	105.0A-D	1.46CD	4.03ABC	53.3B	4.28CD
GoldenPrm.	86.0E	1.12D	3.60ABC	50.0B	4.05CD
Steptoe	112.7A	2.57A	4.14ABC	83.3AB	4.69A-D
IC-2	108.3ABC	1.28CD	4.35ABC	3.3C	5.00A-D
IC-5	109.7AB	1.57BCD	4.73AB	10.0C	4.63A-D
IC-13	95.0CDE	1.17CD	4.03ABC	3.3C	4.87A-D
IC-14	96.7B-E	1.14CD	3.78ABC	3.3C	4.78A-D
IC-15	107.7ABC	1.49BCD	4.38ABC	10.0C	4.72A-D
IC-17	107.0ABC	1.17CD	4.50AB	3.3C	4.61A-D
IC-19	108.3ABC	1.57BC	4.29ABC	0.0C	5.18ABC
IC-20	107.7ABC	1.22CD	4.74AB	5.0C	5.74A
IC-22	114.0A	1.89B	3.58BC	96.7A	5.67AB
IC-23	108.0ABC	2.49A	2.98C	10.0C	4.36CD
Average	104.6	1.51	4.23	39.9	4.71
2002-03					
TARM-92	75.0C-F**	1.31BC**	2.99A-D**	0.0^{NS}	3.00ABC**
Tokak157/37	78.0B-E	1.44B	3.04A-D	0.0	3.23AB
Yesevi-93	75.0C-F	1.35BC	3.55ABC	0.0	3.05ABC
Bülbül-89	72.3DEF	1.20BCD	3.21A-D	0.0	2.89ABC
Baronesse	70.3EF	1.15BCD	2.73BCD	0.0	3.09ABC
Harrington	72.7DEF	1.19BCD	3.10A-D	0.0	2.99ABC
GoldenPrm.	68.0F	0.90D	2.28BCD	0.0	2.20CD
Steptoe	87.0AB	2.00A	3.57ABC	0.0	3.10AB
IC-2	77.3B-F	1.24BCD	2.46BCD	0.0	2.98ABC
IC-5	86.0AB	1.25BCD	3.81AB	0.0	2.96ABC
IC-13	74.3C-F	1.08BCD	2.76BCD	0.0	2.98ABC
IC-14	80.0B-E	1.02CD	2.19CD	0.0	2.52BCD
IC-15	84.0ABC	1.17BCD	4.45A	0.0	3.74A
IC-17	85.7AB	1.16BCD	3.16A-D	0.0	3.07ABC
IC-19	75.0C-F	1.21BCD	2.66BCD	0.0	2.80BCD
IC-20	79.0B-E	1.38BC	2.11CD	0.0	3.07ABC
IC-22	90.3A	2.12A	1.92D	0.0	2.99ABC
IC-23	82.0A-D	1.83A	1.80D	0.0	1.99D
Average	78.4	1.33	2.88	0.0	2.93

*, ** Means with the same letter(s) are not significantly different at 5 and 1% level of probability. NS, non-significant

the highest yields. Averages of four Turkish varieties (TARM-92, Tokak 157/37, Yesevi-93 and Bülbül-89) for the first, second and third experimental years were 4.44, 4.25 and 3.04 t ha^{-1} and the averages of four overall highest yielding cultivar (IC-15, IC-20, IC-22 and Baronesse) were 5.59, 5.33 and 3.22 t ha^{-1}, respectively. Thus, while Turkish cultivars had about 5% lower seed yields than the average of best foreign cultivars in the

absence of lodging, their yields were about 20% less in the presence of lodging (Fig. 1).

DISCUSSION

In Turkey, barley cultivars are developed by national institutes for all production areas, most of which have low rainfall and, hence, are low yielding areas. In high yielding areas such as Yeşilirmak basin, these cultivars are not suitable especially because of their high lodging. Four of the most common barley cultivars in Turkey were evaluated together with some known barley cultivars of the world and some ICARDA lines developed for highlands with cold winters.

Barley plants given 150 kg ha^{-1} N and 75 kg $ha^{-1}P_2O_5$ lodged when the rainfall in growth period is 360 mm or over as in the first and second experimental years. Seed yields were higher in those years because lodging occurred in most cultivars around the harvest and plots were hand-harvested. This is the reason why a cultivar with quite high lodging such as IC-22 had high grain yields in the first two years when it lodged over 90%. No cultivars lodged in the third year in which the precipitation during the growth period was only 223.6 mm. Despite the lack of lodging, low amount of precipitation also resulted in low grain yields in that year.

Comparison of the performance of four Turkish varieties with the four highest yielding foreign genotypes showed that Turkish cultivars had about 5% less yield in the absence of lodging and 20% less in the presence of lodging. Thus, assuming that the cultivar responses to different years are the same, lodging caused about 15% yield losses in Turkish cultivars, which is similar to 15-20% losses due to lodging reported by Akar *et al.*[10]

Four Turkish barley cultivars, i.e. Tokak 157/37, TARM-92, Yesevi-93 and Bülbül-89 had relatively tall plants. In the first two years in which precipitations during the barley growth period were 425 and 361 mm, these four cultivars had about 82-94 and 101-114 cm heights, respectively. Over 90% of the plants lodged in these two years, causing statistically lower yields compared to highest yielding genotypes. Unlike other cultivars that lodged late in the grain filling period, four Turkish cultivars lodged around or before the flowering time which might indicate that they had no semidwarf or other lodging-decreasing genes. In the third year which had 223 mm of precipitation in growth period, plants had 72-78 cm height and no lodging occurred. As a result, grain yields of these four cultivars were at the highest group. These four cultivars, all of which are two-rowed, had relatively high spike weights compared to other two-rowed cultivars, especially in the third year in which no lodging occurred. Straw yield of these four cultivars were always among the highest group in all trials. High straw yields of these cultivars are one of the reasons why Turkish farmers prefer them.

Four foreign cultivars, (Steptoe, Harrington, Golden Promise and Baronesse), all of which had certain degree of lodging resistance and 10 ICARDA lines developed for highlands with cold winters were studied to determine a non-lodging, high yielding variety suitable for fertile Yesilirmak Basin conditions. Canadian malting barley quality standard cultivar Harrington, a semidwarf variety[11] had 33.3 and 53.3% lodging in the first and second years, respectively. Plant height of Harrington was similar to Turkish cultivars in all years. Grain yield of Harrington was not statistically different from Turkish cultivars throughout the experiment. Golden Promise, cultivar with *Gp-ert erectoides* gene[15] had the shortest stems and very low straw yields in all years. Nevertheless, its short stature was not able to provide him resistance against lodging. Fifty and twenty percent of Golden Promise plants lodged in the first and second years, respectively. Yields of Golden Promise were generally the lowest. This was not surprising since *Gp-ert* locus was reported to be associated with reduction in grain weight and single plant yield[15]. Steptoe is a six-rowed feed barley with known lodging resistance[7]. It had one of the tallest stems of all cultivars. Despite its known lodging resistance, Steptoe had 46.7 and 83.3% lodgings in the first and second years. Thus, Steptoe does not have sufficient lodging resistance in our environment. Baronesse had relatively short stems and had almost no lodging in all trials. Its grain yields were always among the highest but straw yields were moderate or low. Baronesse was reported to have high grain yields across a range of environments and to be lodging resistant[16]. Although Baronesse is a good candidate as a parent for crossing programs, its low straw yields may lower its chance as a candidate cultivar for the region since low straw yielding cultivars are not be preferred by Turkish farmers who value barley straw.

Of the 20 advanced barley lines from 1999-2000 International Barley Yield Trial package, 10 lines (IC-2, IC-5, IC-13, IC-14, IC-15, IC-17, IC-19, IC-20, IC-22 and IC-23) were selected based on their first year performance (data not shown) and used in the second and third year experiments. Most of these lines were superb for lodging resistance. IC-15 and IC-20 showed good levels of lodging resistance and had superior yields in three years. Plant heights of these two cultivars were similar to those of four Turkish cultivars. Straw yields of IC-20 were rather low compared to Turkish cultivars. IC-15, on the other hand, had very good levels of straw

yields and was sometimes superior to Turkish varieties for this trait. Thus, IC-15 has the potential to be grown in the region.

In conclusion, Turkish cultivars developed centrally for all production areas of Turkey have serious lodging problems in high yielding environments. These cultivars had relatively tall stems and high straw yields and lodged almost completely in years with usual precipitation. Unlike lodging of others, Turkish cultivars started lodging before flowering. In the absence of lodging, seed yields of these cultivars were comparable to those of foreign cultivars. IC-15, IC-20, IC-22 and Baronesse were the highest yielding foreign cultivars. Except IC-22, these cultivars had satisfactory levels of lodging resistance. Unlike IC-20 and Baronesse that had relatively low straw yields, IC-15 had straw yields equal or even superior to those of Turkish cultivars. Turkish farmers attach great importance to straw yields since straw is used as a feed for cattle. Thus, IC-15 is a good candidate as a non-lodging, high-yielding feed barley cultivar to be grown in our environment, in which irrigated barley is also a possibility, until better cultivars are developed through breeding programs.

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