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Development of Superior Durum Wheat Germplasm—Altar 84

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The CIMMYT durum wheat improvement program has traditionally responded to the needs of national breeding programs and ultimately to farmers in cooperating countries by providing high yielding, stable, and widely adapted germplasm. Advances made in durum wheat improvement in Mexico demonstrate not only steady improvement in yield potential, good agronomic type, and disease resistance, but also steady improvement in yield stability and good industrial quality.

The pasta industry in Mexico basically uses bread wheats to make semolina-type products. However, in the early 1980s, the industry became interested in using durum wheats to improve the quality of its pasta products. At the same time, farmers were asking for higher yielding durum wheat cultivars. The cultivar Altar 84 was released in 1984 by the National Institute of Forestry, Agriculture and Animal Science Research (INIFAP) to meet the demands of industry and farmers.

Development and Attributes of Altar 84

Altar 84 was derived from the pedigree shown in Figure 4. The name "Altar" comes from a desert area in Sonora, Mexico, near Cd. Obregon where CIMMYT grows its spring nurseries during the winter-spring season.

The cultivar Altar 84, formerly known as the breeding line Gallareta"S", was derived from the cross RUFF"S"/FG"S"//MEXICALI 75 and SHEARWATER"S" made in 1976 (The "S" refers to a sister selection of a given breeding line such as Ruff). Between 1977 and 1980, plants from this cross were selected in segregating generations at Toluca station in the State of Mexico and Cd. Obregon, based on their disease resistance, plant type, high tillering capacity, spike fertility, good seed quality, and high semolina quality.

In preliminary yield tests at the CIANO station at Cd. Obregon in 1981, Gallareta"S" was found to be one of the highest yielding lines. This superior yield potential combined with other desirable traits, such as rust resistance and industrial quality, resulted in its inclusion in the International Durum Screening Nursery (IDSN), and ultimately in elite yield nurseries. This cultivar gave outstanding performance in the 16th International Durum Wheat Yield Nursery (IDYN) and 14th Elite Durum Yield Trial (EDYT), sent to more than 50 locations in 30 countries in 1983-84. In 1984, Gallareta"S" was released as Altar 84 in Mexico. It is currently being yield tested in Spain and Turkey.

Yield potential and adaptation—As shown in Figure 5, the yield potential of Altar 84 under the well watered conditions of CIMMYT's research site at Cd. Obregon is approximately 8.2 t/ha. Other locations where Altar 84 has had high yield, approaching 10 t/ha,

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include Guanajuato, Mexico; Cordoba, Spain; and La Platina, Chile. Under high-input experimental conditions, Altar 84 yielded up to 11 t/ha at Cd. Obregon.

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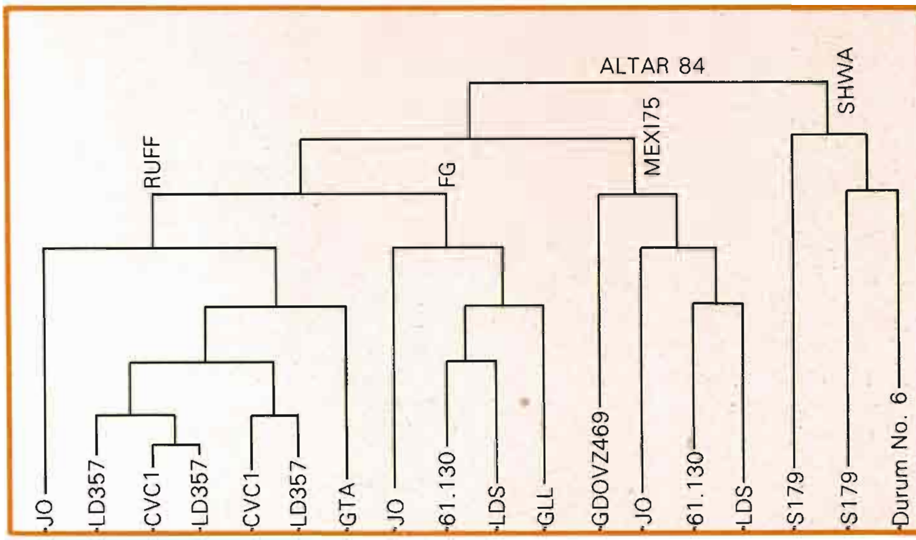

Figure 4. Altar 84 Pedigree.

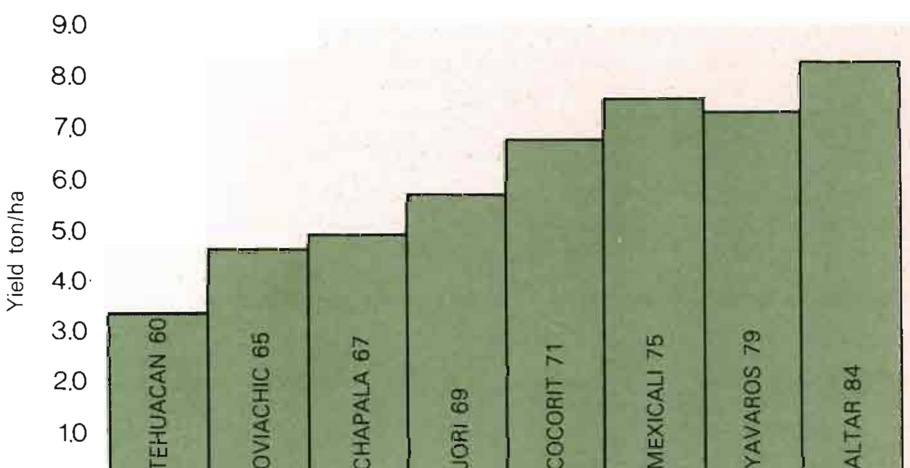

Figure 5. Yield potential of the durum wheat varieties released in Mexico from 1960 to 1984. Three-year means obtained from the Agronomy program in trials conducted at the CIANO station during the 1983-84, 1984-85, and 1985-86 crop cycles.

History of Durum Wheat Improvement at CIMMYT in Mexico

Twenty years ago when CIMMYT's durum wheat improvement program was established, major goals were to incorporate dwarfing genes, photoperiod insensitivity, enhanced spike fertility, and better disease resistance. These goals have all been accomplished. Today's breeding strategy requires developing high-yielding, management-responsive, and input-efficient germplasm that is broadly adapted, stable with good quality traits, and resistant to biotic and abiotic stresses.

In the late 1950s, the first crosses were made between tall durum wheats and wheats bread carrying the Rht1 and Rht2 dwarfing genes. Through intensive backcrossing of progenies to the tall durum wheats, it was possible to select semidwarf durum wheats.

To date, 10 improved durum wheat cultivars have been released in Mexico. The first of these, Tehuacan 60, was named and released by the National Agricultural Research Institute (INIA) in Mexico in 1960. It is a tall cultivar with a yield potential of about 3.3 t/ha (Figure 5). Oviachic 65 was the first semidwarf cultivar released in Mexico. As shown in Figure 5, it has a yield potential of about 4.6 t/ha, almost 40% higher than the yield of tall Tehuacan 60, released 5 years earlier.

By the late 1960s, many outstanding durum wheat advanced lines had been identified with yield potentials superior to that of Oviachic 65. In 1967, the year after CIMMYT was officially established, Mexico released three durum wheat cultivars: Chapala 67, Tehuacan 67, and Pabellon 67. These cultivars further raised the yield potential to about 4.9 t/ha.

1st IDYN

In 1969 an important event in the history of durum wheat improvement in Mexico and worldwide occurred. The International Durum Yield Nursery (IDYN) was assembled and distributed for the first time. The first IDYN consisted of 12 entries, from five countries, including four advanced semidwarf lines from CIMMYT. Inia 66, a semidwarf bread wheat cultivar known to be high yielding and widely adapted, was included as a check. The nursery was grown at 32 locations, most of which were in the durum wheat producing areas of North Africa and the Middle East.

Results of the 1st IDYN provided convincing evidence that the new semidwarf, daylength-insensitive durum wheats were quite widely adapted and demonstrated increased yield potential versus the tall, daylength-sensitive durum wheats grown by farmers at that time.

Another important event in 1969 was the release by Mexico of the cultivar Jori 69. The new semidwarf durum wheats were now showing that they could challenge and, at times, exceed the yields of the semidwarf bread wheats. For example, Jori 69 yielded 10% more than the bread wheat cultivar, Inia 66, in the 1st IDYN.

Advances during the 1970s

In 1971, a CIMMYT-developed durum wheat advanced line was named and released by Mexico as Cocorit 71. This was the first durum wheat cultivar released in which the linkage between sterility and the dwarfing genes was broken. This higher spike fertility increased the yield potential of the durum wheats to 6.7 t/ha (Figure 5), 1.0 t/ha higher than the yield of Jori 69. Both cultivars tended to be somewhat late in maturity and did not have an acceptable level of quality, but they had high yield potential and wide adaptation.

The maturity and quality problems of Jori 69 and Cocorit 71 were solved with the release of Mexicali 75 by Mexico in 1975 Its yield potential is 7.5 t/ha, an increase of 12.0% over Cocorit 71 (Figure 5). Mexicali 75 also matures 7 days earlier than Cocorit 71 and it has good quality for semolina products.

There was a need in some areas for a medium-maturing, high-yielding, semidwarf durum wheat cultivar, so the national program of Mexico named and released Yavaros 79 in 1979. This cultivar is similar to Mexicali 75 in yield potential and with acceptable quality, but slightly later in maturity (similar to Cocorit 71). Yavaros 79 has proven to be widely adapted and highly stable in terms of yield potential across environments and years. Thus Yavaros 79 is currently used as the long-term durum check in CIMMYT's international nurseries.

By the time Yavaros 79 was released, the development of Altar 84 was already in process.

Farmer's field of Altar 84 in the Yaqui Valley in northwestern Mexico.

More important to local breeders, and ultimately farmers, is the relative performance of a given line vs. other lines tested at a particular location. To evaluate the relative yield potential of Altar 84, we graphed the mean yield of Altar 84 vs. the mean yield of each other entry of the 14th EDYT, 16th IDYN, and the 1st National Durum Wheat Yield Trial, Mexico (ENTDUR).

For example, Figure 6 shows the yields of Altar 84 plotted against the yields of Yavaros 79 for each location of the 16th IDYN. Each point on the graph represents the yield of Altar 84 vs. the yield of Yavaros 79 at a specific site. The yield equality line shows where the points would fall if the yield of Altar 84 exactly equaled the yield of Yavaros 79 at each site. Thus, points lying above the equality line indicate Altar 84 to be higher yielding, and points below the line indicate Yavaros 79 superiority

The number of sites where Altar 84 was clearly superior (as shown in the example of Figure 6) to the compared entry (i.e., Altar 84 against entry 1, 2, 3,...30) is tabulated in Table 2. Points falling on the line were assessed in favor of the compared entry such as Yavaros 79. When analyzed over all locations, 67% of the 1st ENTDUR, 71% of the 16th IDYN, and 56% of the 14th EDYT favored Altar 84. In other words, breeders evaluating these nurseries would have selected Altar 84 as superior yielding in 64% of the comparisons against competing entries. These competing entries included the best CIMMYT advanced lines and durum wheat entries from cooperating breeders as well as a local durum wheat

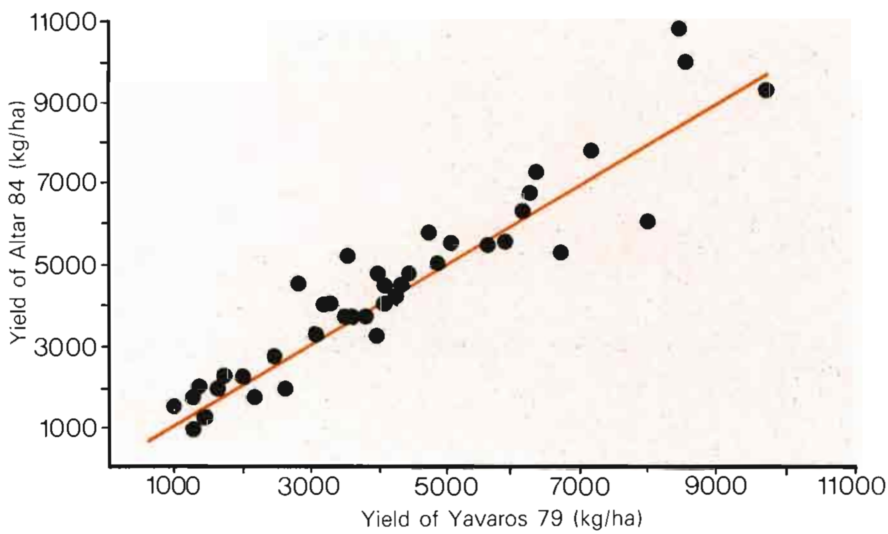

Figure 6. Relative yield of Altar 84 vs. Yavaros 79 across all locations of the 16th IDYN.

check and bread wheat and triticale checks (Seri 82 and Alamos 84, respectively). Thus, the yield potential of Altar 84 is clearly high in many environments, and compares well with many newer CIMMYT advanced lines as well as cultivars entered from cooperating breeders and check cultivars.

An alternative means of assessing yield potential and adaptability of genotypes across environments is the "stability analysis" model developed by Eberhart and Russell (1). Fifty-two locations of the 16th IDYN and the 14th EDYT were classified as stress or nonstress environments according to 4-year

Table 2. Number of sites where Altar 84 was clearly superior to the compared entry in 1st ENTDUR, 16th IDYN, and the 14th EDYT

Entry	14 sites 1st ENTDUR	40 sites 16th IDYN	39 sites 14th EDYT
1	14	25	23
2	12	28	19
3	11	33	26
4	9	23	19
5	13	29	16
6	10	31	19
7	11	31	17
8	10	26	17
9	6	33	17
10	6	39	24
11	12	38	21
12	8	32	26
13	11	36	23
14	11	33	20
15	5	34	21
16	8	28	27
17	8	33	24
18	7	28	29
19	8	32	23
20	9	28	22
21	9	25	24
22	8	18	30
23	9	20	20
24	11	23	21
25	9	30	28
26	5	26	27
27	—	—	—
28	11	16	14
29	12	26	18
30	10	21	18
Total	273/406 = 67.2%	825/1160 = 71.1%	633/1131 = 56.0%

mean rainfall averages recorded in CIMMYT international nursery reports. The 34 stress environments received less than 400 mm of rainfall during the growing season and the 18 nonstress locations received 400 mm or more of precipitation during the growing season or were under irrigation.

The results of performing Eberhart and Russell's stability analysis on Altar 84 across all environments, across the nonstress environments, and across the stress environments are summarized in Table 3. The symbols $\hat{b}$ and S_d^2 denote the slope of the regression line and the sum of the square deviations from the regression line, respectively. $\hat{b}$ is the slope of the regression line of Altar 84 mean yields over the site mean yields (Fig. 7). S_d^2 is a measure of the dispersion of the actual data points around the estimated regression line. The mean yield of Altar 84 at a given site is the average yield from three replicated plots. The site mean yield is the overall average of all cultivars entered in the trial at that site (excluding the local check variety which changes among sites). For example, in Figure 7 the upper line ($\hat{b}$ = 1.25) is the regression of Altar 84 yield vs. the site mean yield of all entries. This slope represents the yield response performance of Altar 84 across all environments. The line through the origin with a slope equal to 1.00 is a hypothetical line of equality between Altar 84 and the site mean.

In the analysis of Figure 7, the slope is equal to 1.25, which is significantly greater than 1 (unit slope). If the scatter of points about the regression line is small enough to be considered stable, such as for the 14th EDYT nonstress analysis in Table 3, it is denoted by "S". The S_d^2 value in Figure 7, however, is 0.53 which is statistically greater than zero, indicating "instability" of yield according to Eberhart and Russell. However, a common criticism of the linear regression methods of studying yield stability is the fact that a few extreme data points may greatly affect stability parameters (2). For example, by removing the four data points in Figure 7 which lie well above the regression line, the subsequent

Table 3. Performance of Altar 84 across all environments in the 14th EDYT and the 16th IDYN. Graph of overall site analysis shown in Figure 7

	Over all sites				
	$\bar{X}$	$\bar{X}_A$	$\hat{b}$	S_d^2	Stability
14th EDYT	4526	4811	1.01	0.35**	H
16th IDYN	4077	4840	1.25*	0.53**	H

X Environment mean yield (kg/ha).
X_A Mean yield of Altar 84 (kg/ha).
* Statistically significant at the 0.05 level of probability.

analysis showed a slope statistically equal to 1.00 and was classified as stable in the overall analysis, nonstress analysis, and stress analysis. Inspecting the position of deviations from regression in Figure 7, it becomes apparent that the large deviations (in the areas of 3000 and 7500 kg/ha site mean yield) are toward higher yield of Altar 84. We have designated this type of deviation "H" in Table 3, for deviations on the high yield side of 1 (unit slope), to differentiate deviations in favor of high yield (which is desirable and an indication of good adaptation) from deviations toward low yield (which is undesirable and an indication of poor adaptation). If Altar 84 had been eliminated as an "unstable" line, ignoring the fact that four high-yield points heavily influenced the deviation from regression

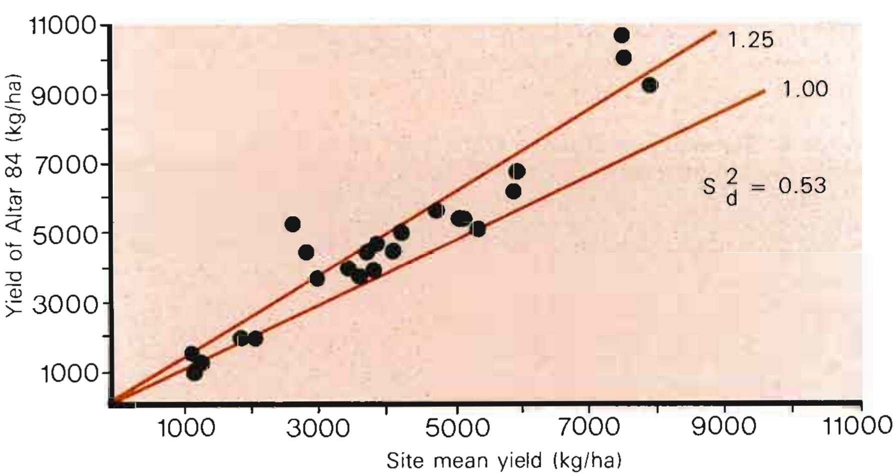

Figure 7. Regression of Altar 84 mean yields over site mean yields for all locations of the 16th IDYN.

Nonstress					Stress				
$\bar{X}$	$\bar{X}_A$	$\hat{b}$	S^2_d	Stability	$\bar{X}$	$\bar{X}_A$	$\hat{b}$	S^2_d	Stability
6112	6319	1.06	0.09	S	3200	3620	1.10	0.73**	H
5388	6424	1.38*	0.44**	H	2866	3382	1.14	0.73**	H

** Statistically significant at the 0.01 level of probability.
Note: For explanation of $\hat{b}$, S^2_d, S, and H, see text.

parameter, we would have eliminated a cultivar which showed 4- to 5-t yield potential in a 2.5-t mean yield environment and 10-t yield potential in a 7.5-t mean yield environment. Furthermore, stability analysis by the Westcott Method (2) showed Altar 84 to be stable in all environments. Thus, broad adaptation, in terms of high yield potential and ability to respond to improved management for Altar 84, is evident in both stress and nonstress environments as shown in Table 3.

Disease resistance—Compared to its predecessors in Mexico, such as Mexicali 75 and Yavaros 79, Altar 84 has excellent resistance to the major rust diseases. As shown in Table 4, the level of resistance in Altar 84, as measured by the average coefficient of infection and the average foliar index, is usually equal to or better than that of Yavaros 79 and Mexicali 75 for the three rusts as well as for head scab, septoria tritici blotch and septoria nodorum blotch, leaf spot, bacterial leaf stripe, and barley yellow dwarf. These data represent

Table 4. Summary of Disease Data from 16th IDYN

Variety	Stripe Rust Leaf[a]	Stripe Rust Head[a]	Leaf Rust[a]	Stem Rust[a]
Altar 84	2.0	8.0	2.0	18.0
Yavaros 79	6.0	23.0	15.0	22.0
Mexicali 75	8.0	3.0	40.0	15.0
Nursery Mean	7.2	12.3	23.1	24.3
No. of observations for each variable	15	5	7	13

a ACI (Average Coefficient of Infection).
b AFI (Average Foliar Index).

Table 5. Industrial quality of durum wheat cultivars Altar 84, Yavaros 79 and Mexicali 75

Variety	Test weight (kg/hl)	1000-grain weight (g)	Yellow Berry (%)	Semolina yield (%)	Semolina protein (%)
Altar 84	84.4	50.07	3.0	57.5	10.3
Yavaros 79	82.4	54.87	2.9	57.5	9.9
Mexicali 75	81.1	56.84	2.8	57.5	10.1

a Residual, solids in water used to cook spaghetti (% based on uncooked spaghetti).
b R = regular; G = good.
c A scale of 1-10, where 1 is the lowest quality and 10 is the highest.

a wide range of environments and pathogen virulence and support the information available from artificially inoculated experiments conducted in Mexico prior to release by the national program.

Quality—One of the primary reasons for the release of Altar 84 in Mexico, and its consideration for release in other countries, is its excellent industrial quality. Grain samples of Mexicali 75, Yavaros 79, and Altar 84 grown in Sonora, Mexico, in 1985-86 were compared for quality characteristics. Overall, Altar 84 was found to combine better quality attributes than the other two cultivars. The results are shown in Table 5.

Altar 84 has a higher test weight and lower 1000-grain weight than Mexicali 75 and Yavaros 79. The higher test weight of Altar 84 is due to its smaller grains. The presence of yellow berry in durum wheat, which increases the percentage of grains with starchy areas and subsequently decreases semolina yield, can lower milling quality. However, this appears to be a

Scab %	Powdery Mildew[b]	*Septoria tritici* [b]	*Septoria nodorum*[b]	*Helm.* spp.[b]	Bacterial Stripe[b]	BYDV[b]
40.0	2.0	5.0	4.0	2.0	5.0	2.0
70.0	4.0	3.0	3.0	2.0	4.0	4.0
70.0	2.0	6.0	4.0	4.0	6.0	3.0
62.7	3.3	4.1	2.9	3.5	4.8	3.8
1	10	10	3	3	3	8

Pigments (ppm)			Sedimentation SDS(cc)		Cooking quality		
Grain	Semo-lina	Pasta	Grain	Semo-lina	Solids[a] (%)	Consistency[b]	Grade[c]
5.9	6.0	4.8	9.5	8.0	6.8	G	8
5.6	5.4	4.1	8.0	7.5	6.8	G	8
5.9	6.6	5.6	9.0	7.0	6.5	R	6

minor problem for these three cultivars as their yellow berry percentage (Table 5) is quite low. The three cultivars showed similar semolina milling potential, under the experimental milling conditions used. However, it is likely that in commercial milling, Altar 84 could be slightly better since it has more rounded grains which make it easier to separate the bran from the endosperm resulting in a greater semolina yield. Spaghetti from Mexicali 75 showed some surface stickiness and therefore its quality was estimated as only fair. Altar 84 and Yavaros 79 have good spaghetti cooking characteristics.

Future of Durum Wheat in Mexico

Land area devoted to the production of durum wheat is increasing in Mexico, and the production of Altar 84 in such areas as the Yaqui Valley of northwestern Mexico is growing at a tremendous rate. Part of the increased planting in this region is due to durum wheat's inherent resistance to the disease Karnal bunt which is a problem with local bread wheat cultivars. While this increase is a sign of success for the Mexican and CIMMYT cooperative durum research programs, the breeders are aware that large-scale planting of a single genotype can result in genetic vulnerability caused by pathogens. In response, the CIMMYT durum wheat program is producing many advanced lines with even better quality than Altar 84, and with different genetic backgrounds.

Figure 8. Aix''S'' is an example of a promising advanced line under consideration for release in Mexico that, like Altar 84, has superior yield potential, wide adaptation, good disease resistance, and acceptable industrial quality.

Four promising advanced lines under consideration for release in Mexico are Aix''S'' (Figure 8), CARC''S''/AUK''S'', CHEN''S''/ALTAR 84, and FG''S''/ATO''S''//HUI''S''/3/ROK ''S''. Like Altar 84, these advanced lines have superior yield potential, wide adaptation, good disease resistance, and acceptable industrial quality.

Soon farmers in Mexico and other countries will have a number of durum wheat cultivars to choose from that will enable them to supply a high quality product that will meet the standards of their countries' pasta industries.

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