E C O N O M I C S

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Adoption and Impact of High Yielding Wheat Varieties in Northern Tunisia

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CIMMYT

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Abstract

This study assesses the extent to which durum and bread wheat high yielding varieties (HYVs) have been adopted by farmers in northern Tunisia, a region which accounts for more than 80% of the nation's durum wheat production and close to 90% of its bread wheat production. Estimates are presented of the areas grown to various HYVs by agroclimatic zone and farm size. The adoption history of each wheat HYV is outlined, including its date of release, its peak adoption, an (if applicable) its disadoption. The impact of HYVs is discussed; particular attention is devoted to genetic yield gains, impact on farmers' income, and impact at the national level.

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Introduction

Wheat is the most important crop in Tunisia: it covers about 1 million ha, accounting for an average of 23% of the nation's total arable land (République Tunisienne, various years). More than 60% of the wheat area is located in northern Tunisia, where average annual rainfall ranges from 350 to 800 mm. Because of favorable rainfall and soil conditions, the North accounts for more than 80% of Tunisia's durum wheat production and close to 90% of its bread wheat production. Tunisian wheat production exhibits highly variable yields due to severe fluctuations in rainfall. Since 1985, the nation has had three of the worst crop seasons on record (1986, 1988, and 1989) and three of the best (1985, 1987, and 1991); average national yields were as low as 3 quintals per hectare (qx/ha) in 1988 and as high as 17 qx/ha in 1991 (République Tunisienne, various years).

Between the 1950s and the 1980s, average annual wheat production increased from 5.1 to 7.9 million qx, an average growth rate of 1.5% per year. However, domestic wheat consumption increased at a much faster rate than production as a result of three factors: rapid population growth (an average of 2.7% per year during the 1960s), urbanization, and increasing incomes. Tunisia was an occasional exporter of durum wheat in the 1960s and early 1970s; by the early 1990s, however, it was importing an average of 2.7 million qx of durum wheat per year, about 45% of its consumption (computed from Newman et al. 1989).

Urbanization was particularly important to the rapid growth in bread wheat consumption, leading to a substantial increase in imports, which amounted to an average of 5.2 million qx by the early 1990s, or about 71% of consumption (République Tunisienne, various years). Increased wheat imports have placed a drain on Tunisia's foreign exchange budget: total wheat imports amounted to 172 million Tunisian dinars (TD)[1] in 1988, or about 36% of the value of total food imports (République Tunisienne 1991). Even during the exceptionally good production season of 1990/91, when Tunisia produced a record wheat crop of 18 million qx, wheat imports amounted to 61 million TD and accounted for 19% of total food imports.

Faced with rapidly increasing wheat imports, the Tunisian government has invested heavily in increasing wheat production. In the early 1960s, public investments focused primarily on mechanization as the means of increasing wheat yields (Gafsi 1976). In the mid-1960s, efforts shifted toward the widespread diffusion of high yielding varieties (HYVs) coupled with increased fertilizer use and improved cultural practices. In 1966, a major program (the Wheat Project) was initiated by the Tunisian Ministry of Agriculture with technical assistance from the International Center for Maize and Wheat Improvement (CIMMYT).

1 The average official exchange rate during 1993 was US$ 1 = 0.95 TD.

The Wheat Project's aim was to introduce semidwarf Mexican bread wheat HYVs developed by CIMMYT (Purvis 1972). Moreover, the Project had the ambitious goal of making Tunisia self-sufficient in bread wheat production. To that end, a target of 520,000 ha were to be planted to Mexican varieties by 1973/74. The Project was based at l'Institut National de la Recherche Agronomique de Tunisie (INRAT), which had a long-standing program in wheat breeding research, particularly for durum wheat. By the late 1960s, the Wheat Project had released to farmers several Mexican bread wheat varieties, as well as two new durum wheat varieties (INRAT 69 and Badri) developed by INRAT.

The potential for success of Mexican wheats in Tunisia was first assessed by Purvis (1972), who surveyed 27 state farms during the 1969/70 crop year. The findings were rather negative: Mexican varieties were found to outyield ordinary varieties (OVs) by only 34%; earlier forecasts had called for yield increases of up to 300%. Furthermore, under low input use and unfavorable soil and rainfall conditions, the Mexican varieties were likely to be outyielded by the OVs.

Similar negative conclusions were reached by Gafsi (1976), who made the first systematic attempt to measure the extent of adoption of wheat HYVs based on a survey of 375 private farmers in northern Tunisia during the 1972/73 crop year (see also Gafsi and Roe 1979). Gafsi found that wheat HYVs accounted for less than 5% of wheat area on small farms (<15 ha) and about 25% on large farms (>40 ha). Durum wheat HYVs were found to be technically neutral in input productivity, leading to an average 16% yield increase over the OVs at the same level of input use. In contrast, bread wheat HYVs had lower yields than OVs at the existing low level of input use, but significantly outyielded the OVs at higher input levels, particularly for fertilizer.

Roe and Nygaard (1980) did a follow-up study based on a survey (during the 1976/77 season) of 125 farmers covered by Gafsi's study. Contrary to Gafsi's conclusions, Roe and Nygaard found that durum wheat HYVs only outyielded the OVs at high levels of input use and under high rainfall conditions. Since the majority of farmers were found to be risk-averse, Roe and Nygaard concluded that production and price risks were important reasons for low input use and limited adoption of wheat HYVs, particularly among small farmers.

Based on these findings, Tunisia's experience has often been cited as an example of the Green Revolution's negative impact and, more specifically, of how semidwarf wheat HYVs fail under rainfed conditions (Pearse 1980). But the introduction, during the 1970s, of new wheat lines better adapted to rainfed conditions resulted in the release of several highly productive durum and bread wheat varieties starting in 1980. Although the adoption of wheat HYVs in central and southern Tunisia continues to be insignificant, there are clear indications that adoption of these new varieties in the North has been increasing at a fast rate since the late 1970s. In fact, data from the annual farm survey collected by the Ministry of Agriculture (Enquete Agricole de Base) indicate that the area sown to durum HYVs in the North increased from 54% of durum wheat area in 1980/81 to 75% in 1985/86 and that the area sown to bread wheat HYVs increased from 75% to 92% over the same period (République Tunisienne, various years).

Although such data provide clear proof of the widespread adoption of HYVs in northern Tunisia, they do not provide information on adoption by farm size or by agroclimatic zone. Furthermore, the data do not differentiate between the different varieties under the category HYV; this failure is particularly problematic given that some earlier HYVs have been recently reclassified as OVs. To evaluate the success or failure of specific varieties, researchers need estimates of areas grown to each wheat variety, as well as information on the history of adoption or disadoption of these varieties. Moreover, the previous aggregate information on HYV adoption has been inadequate to assess impact given that varietal impact may differ across agroclimatic zones or among farm-size categories.

The main goal of this study is to estimate the extent of adoption for the various wheat HYVs in northern Tunisia and to assess their impact on farmers and the nation. The specific objectives of the study are as follows:

1. To determine to what extent wheat HYVs have been adopted by farmers in northern Tunisia and to estimate the areas grown to each of these varieties by agroclimatic zone and farm size;

2. To identify the adoption history of each wheat HYV, including its date of release, its peak adoption, and (if applicable) its disadoption;

3. To assess the impact of wheat HYVs on yields, production, farmers' income, and the national economy.

Three main data sources were essential to this study. National agricultural statistics provided information on historical trends in wheat production, area, and yields. Results from on-station varietal trials conducted by INRAT and from on-farm trials conducted by the Office des Céréales provided information on the genetic yield gain of the various wheat varieties. Estimates of areas grown to these varieties and their adoption history were based on data from a survey of 247 farmers in northern Tunisia jointly conducted in 1991 by INRAT, the Ministry of Agriculture's Direction Générale de la Planification du Développement et des Investissements Agricoles (DGPDIA), and the International Center for Agricultural Research in the Dry Areas (ICARDA) (hereafter referred to as the INRAT/ICARDA Survey).

The paper is organized into six sections, including this Introduction. Section II provides general information on trends in Tunisian wheat production based on a time-series analysis of national agricultural statistics. Section III summarizes information on all the wheat varieties released in Tunisia. Section IV estimates areas grown to each of these varieties and their adoption history. Impacts of wheat HYVs on yields, production, farmers' incomes and the nation are discussed in Section V. Section VI presents a summary and conclusions.

Trends in Wheat Production

Wheat accounts for 73% of Tunisia's cereal area and 78% of its total production (Table 1). Unlike barley, the bulk of wheat areas (63%) are located in the sub-humid and semi-arid zones of the North (respectively, 500-600 and 400-500 mm average annual rainfall). Wheat yields in these areas are substantially higher than in the arid zones of central and southern Tunisia. Durum wheat *(Triticum durum)* is by far the dominant wheat species, accounting for 85% of total wheat area. Bread wheat (*T. vulgare)* is particularly important in the North, where it accounts for 18% of total wheat area and 21% of total production.

Wheat production in Tunisia has increased steadily over the past 50 years, particularly durum wheat production, which increased by more than five times between the 1940s and late 1980s (Table 2; Figures 1 and 2). Prior to the 1960s, most of the increase in wheat production resulted from an expansion in cultivated area, which more than doubled between 1910 and 1960. During the 1960s, however, wheat production declined significantly as a result of two factors. First, government efforts to expand the area planted to fruit trees probably occurred, at least in part, at the expense of wheat area, which declined by about 15% compared to the 1950s. Second, following Tunisia's independence in 1956, yields of bread wheat dropped sharply due to disinvestment and neglect by colonial farmers, who controlled the bulk of Tunisia's bread wheat area (Hyslop and Dahl 1970).

Table 1. Area, yield, and production of cereals in Tunisia (average 1981-1993)

	Area		**Yield**	**Production**	
Cereal species	**1000 ha**	%	**qx/ha**	**1000 qx**	%
North					
Durum wheat	485	59.2	13.1	6,401	61.3
Bread wheat	108	13.2	15.7	1,706	16.3
Total wheat	593	72.5	13.7	8,107	77.6
Barley	225	27.5	10.3	2,342	22.4
Total North	818	100.0	12.7	10,449	100.0
Center and South					
Durum wheat	319	44.7	4.8	1,630	47.5
Bread wheat	34	4.8	6.1	238	6.9
Total wheat	353	49.5	5.3	1,868	54.5
Barley	360	50.5	4.2	1,561	45.5
Total Center and South	713	100.0	4.6	3,429	100.0
Tunisia					
Durum wheat	804	52.5	10.0	8,031	57.9
Bread wheat	142	9.3	13.7	1,944	14.0
Total wheat	946	61.8	10.5	9,975	71.9
Barley	585	38.2	6.7	3,903	28.1
Total Tunisia	1,531	100.0	9.1	13,878	100.0

Source: République Tunisienne, Ministere de l'Agriculture (various years).

Government policies favoring wheat production during the mid-1960s resulted in a spectacular increase in national wheat output during the early 1970s, with average annual growth rates of 7% and 4.6% for bread and durum wheats, respectively. Significant improvements in productivity were responsible for a large share of the production increase, with average wheat yields more than 50% higher than in the 1960s. Given the limited use of durum HYVs, improvement in durum wheat productivity was essentially a result of better management, including increased use of fertilizers and mechanization and improved cultural practices. Better management also contributed significantly to improved bread wheat productivity, though the use of HYVs also must have been an important factor.

During the late 1970s, bread wheat production dropped sharply as a result of drastic declines in area; for durum wheat, a significant expansion in area allowed production to continue increasing in spite of a slight drop in yield caused by expansion into drier areas.

Table 2. Trends in wheat area, yield, and production, Tunisia, 1940-1993

Period	1940-49	1950-59	1960-69	1970-74	1975-79	1980-86	1987-93
Durum wheat							
Area (1000 ha)	578	950	825	876	1069	808	804
Yield (qx/ha	3.0	3.8	4.0	6.3	6.1	8.6	11.3
Production (million qx)	1.75	3.58	3.32	5.55	6.47	6.91	9.06
Bread wheat							
Area (1000 ha)	147	189	148	225	121	113	161
Yield (qx/ha)	8.4	8.0	5.1	7.4	9.0	13.8	12.9
Production (million qx)	1.24	1.52	0.76	1.67	1.08	1.56	2.07

Source: République Tunisienne (various years).

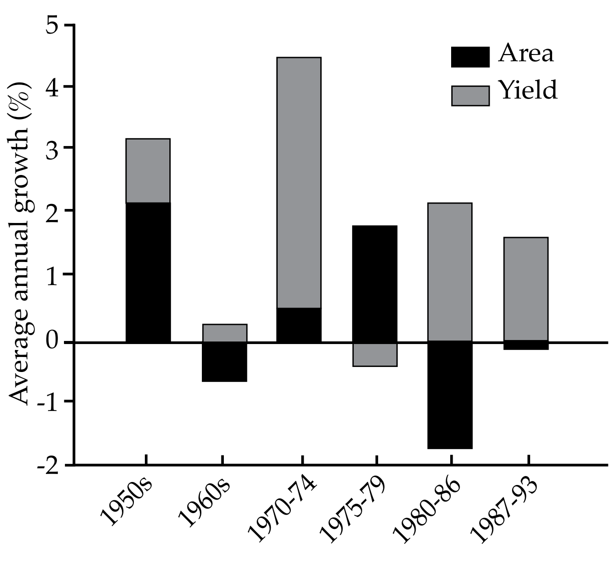


Figure 1. Sources of growth in durum wheat production, Tunisia, 1950s-1980s.
Source: Computed from data in Table 2.

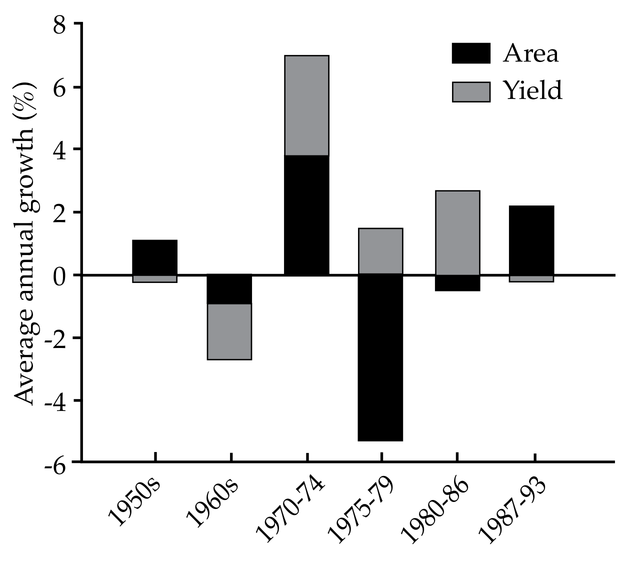


Figure 2. Sources of growth in bread wheat production, Tunisia, 1950s-1980s.
Source: Computed from data in Table 2.

Why durum wheat area should have expanded at the apparent expense of bread wheat area is not clear. One explanation is that durum wheat was less affected by the low official prices during this period because producers had the option of selling their output in the parallel market, where prices were much higher than official prices.

During the early 1980s, durum wheat area dropped by more than 25% compared to the late 1970s. Despite this drastic decline, durum wheat production grew at a modest average annual rate of 0.41% as a result of significant improvements in yields, which were more than 40% higher than yields during the late 1970s. The widespread diffusion of durum HYVs starting in 1980 was probably the key to this improvement. Similarly, in the early 1980s, wider HYV use enabled production to increase at an average annual rate of 2.3% despite a slight decline in area.

During the late 1980s and early 1990s, the most noticeable development was the substantial expansion in bread wheat area: from an average of 113,000 ha during the 1980-1986 period to 161,000 ha during the 1987-1993 period. Widespread adoption of the drought-tolerant variety Salambo may account for this expansion, particularly as it affected farmers in semi-arid areas of the North. Expansion into drier zones could also explain the slight drop in average bread wheat yields in comparison to yield levels during the first half of the 1980s. Although durum wheat area stagnated, production increased steadily at an average annual rate of 1.7%, primarily as a result of increasing yield due to widespread adoption of durum HYVs in the North

In summary, wheat production during the 1987-1993 period averaged more than 11 million qx, an increase of 173% over production levels during the 1960s. Such increases were almost exclusively a result of drastic improvements in yields: 183% for durum wheat and 153% for bread wheat over yield levels during the 1960s. As shown in Figure 3, long-term wheat yields (10-year moving averages) increased steadily after the late 1960s. Durum wheat yields increased at an average rate of 1.9% per year; for bread wheat, the corresponding increase was 1.7%. Higher input use and improved cultural practices were most likely the dominant factors underlying yield increases during the 1970s. Widespread adoption of wheat HYVs in the North was the most likely reason for the yield gains during the 1980s.

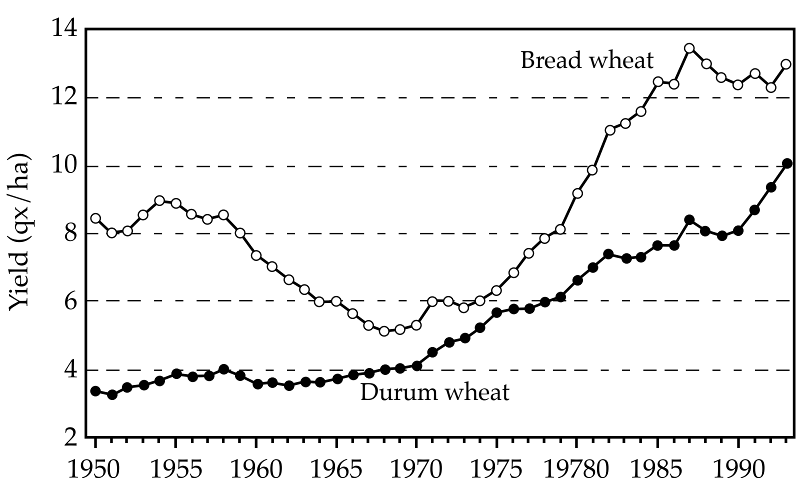


Figure 3. Long-term wheat yields (10-year moving averages), Tunisia, 1950-1993.
Source: République Tunisienne (various years).

Wheat Varieties in Tunisia[2]

Durum wheat

Tunisia's long-standing durum wheat breeding program started early in this century. Until the 1930s, the local lines Derbassi, Biskri, Adjimi, and Jenah Khoutifa were dominant, and early breeding efforts were based on selections from these populations. These lines were late-maturing, tall (120-150 cm), and very low in yield potential (Maamouri and Gharbi 1992). The variety Mahmoudi was selected from these local populations and became the dominant durum variety until the 1960s. Early in that decade, the variety Chili was selected from a commercial shipment imported from Chile and was quickly adopted by farmers. Chili is a late-maturing variety adapted specifically to a continental climate with cold winters, as in the high plateaux of Le Kef. Its productivity is relatively low, but it is tolerant to black rust and septoria. It is susceptible to powdery mildew. Chili is relatively tall (>150 cm) and is thus particularly sensitive to lodging when grown in high rainfall areas or under high fertility levels.

By the late 1950s, introduced germplasm used in INRAT's crossing program resulted in earlier maturity, higher spike fertility, and better disease resistance. In 1969, these crosses resulted in the release of two new varieties: INRAT 69 and Badri. INRAT 69 (better known to farmers by its original name D58-25) was derived from a cross between the Cypriot variety Kyperounda and Mahmoudi (see Table 3 for information on pedigrees and origins of varieties). INRAT 69 is more productive than Mahmoudi under favorable conditions and has earlier maturity. Its height (120-150 cm) and good tillering enable it to compete well with weeds but also make it susceptible to lodging under high-fertility conditions.

In 1967, the Wheat Project began introducing semidwarf durum lines developed by CIMMYT, which allowed the selection and release in 1972 of Amel and Maghrebi, the first semidwarf durum varieties released in Tunisia. These varieties have proven very productive, but only under favorable rainfall and high-fertility conditions. Because they are short (70-80 cm), their straw yield is very low and they compete poorly with weeds. In the early 1970s, the introduction of CIMMYT lines more adapted to rainfed conditions allowed INRAT to select and release two highly productive durum varieties, Ben Bachir and Karim. Ben Bachir (derived from CIMMYT's Stork cross), released in 1978, is very productive under high fertility conditions, particularly in the semi-arid zones. It is very early maturing (20 days earlier than INRAT 69), short (90-100 cm) and resistant to lodging. It has average resistance to black and yellow rusts but is relatively susceptible to powdery mildew and septoria.

Derived from CIMMYT's Bittern cross and released in 1980, the variety Karim is highly productive and widely adaptable, making it suitable for most wheat-producing areas in the North. It is early maturing (15 days before INRAT 69) and short (90-100 cm). It has good tillering capacity, good resistance to lodging and powdery mildew, and average resistance to septoria and to black and yellow rusts.

2 This section draws heavily from Maamouri et al. 1988.

In 1987, the variety Razzak was released from a cross (made by INRAT in 1976) between Karim and the line DM x 69-331:AA"S"(LAKE-Ld390). Razzak is very productive and is as adaptable as Karim. High tillering capacity, good spike fertility, high kernel weight and excellent resistance to lodging make Razzak particularly suitable to high rainfall conditions and cultivation under supplementary irrigation. Razzak also has good resistance to yellow rust and septoria. Finally, the durum variety Khiar (derived from the cross Chen/Altar 84 made at INRAT) was released in 1992 and is targeted essentially for the higher rainfall zones, where it is expected to outperform both Razzak and Karim (A. Maamouri, personal communication).

Bread wheat

Bread wheat was introduced into Tunisia by French colonial farmers early this century. The rapid expansion in bread wheat area during the 1930s and 1940s was made possible mainly by the release of the variety Florence Aurore around 1930. This variety was derived from a cross made in France in 1921 and selected at INRAT. Florence Aurore is a tall early-

Table 3. Durum and bread wheat varieties released in Tunisia

Variety	Year of release	Pedigree	Selection history	Semi-dwarf	Origin
Durum wheat					
Mahmoudi	-	Landrace		no	Tunisian landrace
Chili 931	-			no	Commercial shipment from Chile in early 1960s
INRAT 69	1969	Mahmoudi/Kyperounda		no	Cross by INRAT (Kyperounda from Cyprus)
Badri	1969	ZB/MAHON/MRARI		no	
Amel 72	1972	BELLE/TC*2//ZBW/TME/TC*2/ZBW		yes	CIMMYT, selected by INRAT
Maghrebi 72	1972	GIL/3/BR180/LK//GZ/61.130	D26842-21Y-3M-OY	yes	CIMMYT 1969, selected by INRAT
Ben Bachir 78	1978	VZ 469(21563/61130 x 60.115)	CM470	yes	CIMMYT (Stork) 1972, selected by INRAT
Karim 80	1980	21563-AA/FG	CM9799	yes	CIMMYT (Bittern) 1973, selected by INRAT
Razzak 87	1987	21563/AO//FG/3/DM//69/331		yes	Cross by INRAT in 1976, CIMMYT parent
Khiar 92	1992	CHEN/ALTAR 84		yes	Cross by INRAT
Bread wheat					
Florence Aurore	1930s	Florence/Aurore		no	Francel 921, selected by INRAT
Ariana 66	1966	Kenya 338/Etoile de Choisy		no	France 1960, selected by INRAT
Soltane 72	1972	SON64/KLRE	II19975-68-IJ-3Y	yes	CIMMYT (Marco Juarez), selected by INRAT
Dougga 74	1974	KLRE/RAF//2*8156-R	II23997-4Y-lOOM-300Y	yes	CIMMYT, selected by INRAT
Carthage 74	1974	NAPO/TOB//8156-R	II28071-7M-3Y-7M-OY	yes	ClMMYT, selected by INRAT
Salambo 80	1980	PATO//CC/INIA	CM1021-14BJ-4BJ	yes	ClMMYT 1970, selected by INRAT
Tanit 80	1980	TZPP/PL/ /7C	CM5287-J-1Y-2M-2Y-3M-OY	yes	CIMMYT (Bluejay) 1974, selected by INRAT
Byrsa 87	1987	GLL/CUC//KVZ/SX	CM34630	yes	CIMMYT (Sunbird) 1982, selected by INRAT
Vaga 93	1993			yes	CIMMYT (Chilero), selected by INRAT

Source: Maamouri et al. (1988) and CIMMYT data base.

maturing variety with moderate tillering capacity; it is quite resistant to black rust and tolerant to powdery mildew and septoria. Because of its susceptibility to lodging, it is primarily recommended for the semi-arid zones of northern Tunisia. As a result of its adaptability to low rainfall conditions, Florence Aurore quickly spread to several countries in the Mediterranean basin, where it remained the dominant bread wheat variety until the introduction of semidwarf varieties from CIMMYT in the mid-1960s. In fact, Florence Aurore was an important parent stock in CIMMYT's early breeding work (Purvis 1972).

In 1966, INRAT released a new bread wheat variety, Ariana 66 (better known to farmers by its original name T21-23), derived from a French cross (Kenya 338/Etoile de Choisy). Although it is a tall variety, Ariana 66 is more resistant to lodging than Florence Aurore, and it matures about 10 days later. It is more tolerant to powdery mildew, septoria, and brown and black rusts; it has good resistance to yellow rust. It has a rather wide area of adaptation but is most productive under favorable rainfall conditions.

The first semidwarf bread wheats were all Mexican varieties released to farmers by the Wheat Project, starting in 1967. These varieties include Sonora, Inia, Jaral, and Tobari (Purvis 1972). In the early 1970s, selections from CIMMYT germplasm resulted in the official release of three more varieties, Soltane in 1972 and Dougga and Carthage in 1974. However, these semidwarfs were too short, resulting in low straw yield and poor competition with weeds. Furthermore, they were only suitable for high rainfall and good soil fertility conditions, and they were highly susceptible to septoria and yellow rust.

The variety Tanit (derived from CIMMYT's Bluejay cross), released in 1980, is highly productive under favorable conditions. It exhibits good straw productivity because it is taller than earlier semidwarfs. However, as with earlier releases, it is highly susceptible to septoria and yellow rust. In contrast, the variety Salambo (selected by INRAT from CIMMYT material and released in 1980) has good resistance to yellow rust and is moderately resistant to septoria and to brown and black rusts. Although it has a relatively wide adaptation, Salambo's best performance has been in the semi-arid zones of the North.

The variety Byrsa (derived from CIMMYT's Sunbird cross), released in 1987, has good resistance to septoria and yellow rust. Although it is relatively tall (90-100 cm), it is highly resistant to lodging. Such attributes make Byrsa very productive under irrigation and high rainfall conditions. Finally, the variety Vaga (derived from CIMMYT's Chilero cross), released in 1993, has shown substantially better disease resistance than either Tanit or Byrsa, and it is expected to replace these two varieties in the more favorable zones (M. Deghaies, personal communication).

Adoption of Wheat Varieties in Northern Tunisia

The INRAT/ICARDA survey

An INRAT/ICARDA farm survey conducted in northern Tunisia in 1991 covered a random sample of 236 private cereal farmers and 11 state farms (Secteur Organisé) located in 11 districts (délégations) distributed among the six most important wheat-growing governorates of northern Tunisia: Bizerte, Béja, Jendouba, Zaghouan, Siliana, and Le Kef (Figure 4).

These 11 districts are representative of the three agroclimatic zones of the North: Zone 1 (subhumid), delimited by the 500 mm and 600 mm isohyets; Zone 2 (upper semi-arid), delimited by the 400 mm and 500 mm isohyets and characterized by mild winters, good soils, and limited elevation; Zone 3 (middle semi-arid), delimited by the same isohyets as Zone 2 but characterized by colder winters, less favorable soils, and more accentuated topography, which makes it less suitable for wheat production than Zone 2 (République Tunisienne 1987, p.36).

The survey sample was stratified by farm-size categories, with the size of each sub-sample representative of farm-size distribution in northern Tunisia (Table 4). Subsistence farmers with less than 5 ha, who account for 43% of all northern farmers, were excluded from the sample given their insignificant contribution to cereal production. Survey farmers were interviewed in December 1991 using a formal questionnaire, and they were asked to provide detailed data on their production practices during the 1990/91 crop year in addition to information on the history of wheat varietal adoption on their farms.

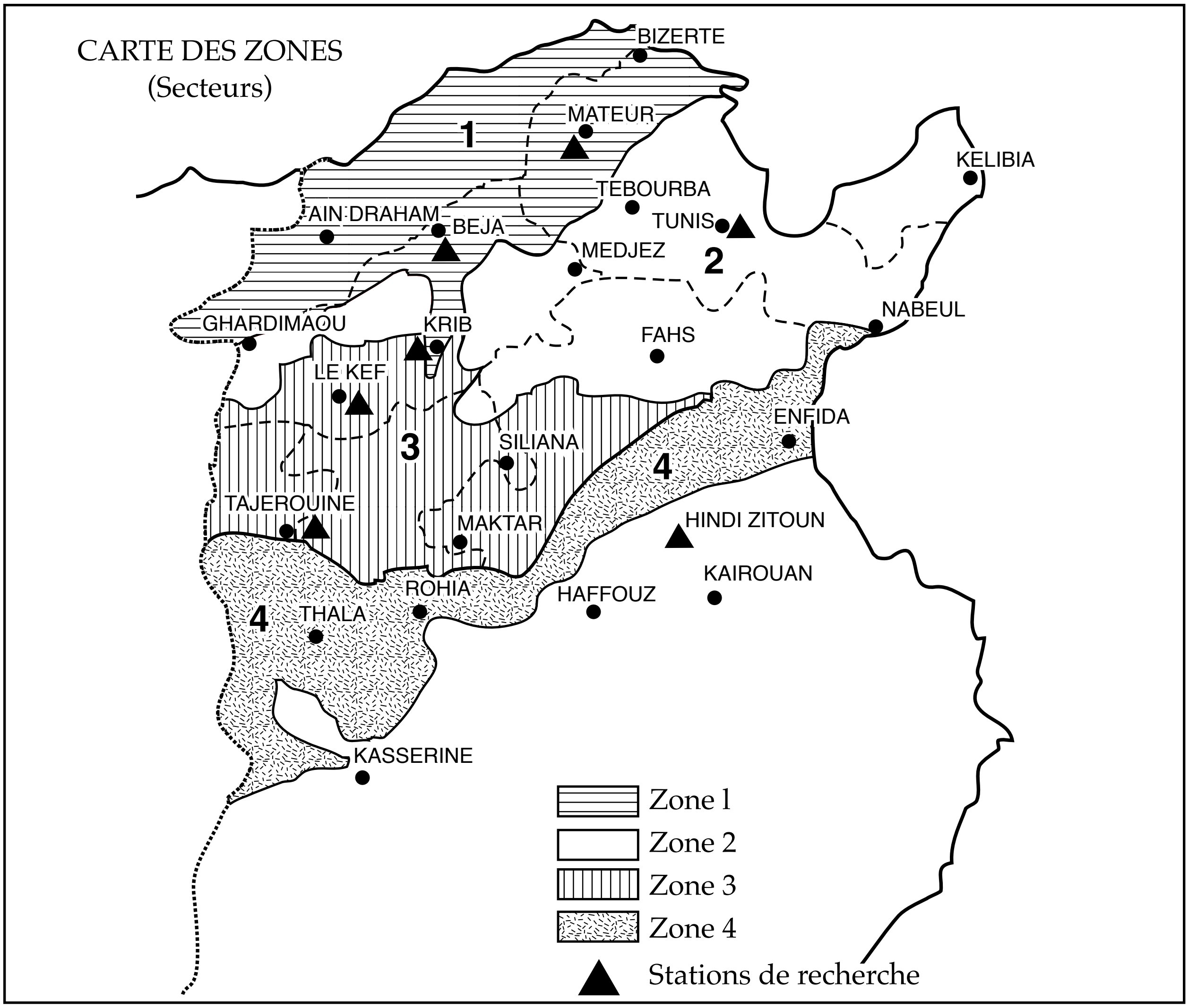


Figure 4. Agroclimatic zones in northern Tunisia
Source: Maamouri et al. (1988).

Distribution of wheat varieties in 1990/91

During the 1990/91 season, survey farmers grew a total of 7,929 ha of wheat, 70% of which was devoted to durum wheat (Tables 5 and 6). Although the distribution of durum wheat area was relatively even across the three agroclimatic zones, bread wheat area was most concentrated in Zone 2 and least concentrated in Zone 3. Furthermore, state farms accounted for more than half of the total bread wheat area and large private farms for another 37%. In contrast, small farmers, who

Table 4. Land distribution by farm size in northern Tunisia

Farm size: total arable land	No. of farmers (%)	Total arable land (%)	Survey sample size
< 5 ha	43.0	7.0	—
5 to 20 ha	42.0	31.0	139
21 to 50 ha	11.0	20.0	39
51 to 100 ha	2.5	14.0	25
> 100 ha	1.5	28.0	33
Total private farms	100.0	100.0	236

Source: République Tunisienne (1987).

Table 5. Adoption of high yielding durum wheat varieties by survey farmers, by zone and by farm size (1990/91)

				Percentage of total durum wheat area by variety							
						High yielding varieties (HYVs)					
		Total area durum wheat		Traditional varieties		Tall	Semidwarf varieties				
	Sample size	Ha	%	Mahmoudi	Chili	INRAT 69 (1969)	Ben Bachir (1978)	Karim (1980)	Razzak (1987)	Total semidwarf	Total HYVs
Agroclimatic zone											
Zone 1 (sub-humid)	88	2080	37.4	0.3	–	0.5	–	65.8	33.5	99.2	99.7
Zone 2 (upper semi-arid)	79	2184	39.3	0.4	0.4	0.5	0.1	58.9	39.7	98.7	99.5
Zone 3 (middle semi-arid)	80	1299	23.3	–	3.9	1.8	–	65.5	28.7	94.2	96.0
Total	247	5563	100.0	0.3	1.1	0.8	0.0	63.0	34.8	97.9	98.6
Farm size											
Small (5-20 ha)	139	544	9.8	2.8	7.5	1.5	0.4	81.1	6.8	88.2	89.7
Medium (21-100 ha)	64	1051	18.9	–	1.8	2.4	–	72.5	23.3	95.8	98.2
Large (>100 ha)	33	2833	50.9	–	–	0.4	–	57 5	42.2	99.6	100.0
State farms	11	1135	20.4	–	–	-	–	59.4	40.6	100.0	100.0
Total	247	5563	100.0	0.3	1.1	0.8	0.0	63.0	34.8	97.9	98.6
Small farms by zone											
Zone 1 (sub-humid)	51	231	4.2	2.6	–	–	–	86.2	11.3	97.4	97.4
Zone 2 (upper semi-arid)	46	173	3.1	4.6	4.1	–	1.2	84.4	6.4	91.3	91.3
Zone 3 (middle semi-arid)	42	141	2.5	0.7	24.1	5.7	–	68.8	0.7	69.5	75.2

Source: INRAT/ICARDA survey data.

represented more than half of the survey sample, cultivated less than 2% of total bread wheat area, as compared to 10% of total durum wheat area.

The limited cultivation of bread wheat by small farmers may be explained in several ways. First, durum wheat tends to be the small farmers' main subsistence and cash crop. For this reason, they prefer the traditional two-course rotation of durum wheat/legumes (or durum wheat/fallow in the drier zones), which allows them to obtain acceptable wheat yields with lower fertilizer (mainly nitrogen) costs. Also, small farmers capitalize on their abundant family labor to grow the more labor-intensive and cash-generating food legumes, such as chickpeas and fava beans, which are also consumed on the farm. For these farmers, increases in bread wheat area would have to occur at the expense of the more profitable (i.e., higher priced) durum wheat.

Table 6. Adoption of high yielding bread wheat varieties by survey farmers, by zone and by farm size (1990/91)

				Percentage of total bread wheat by variety								
					High yielding varieties (HYVs)							
		Total area bread wheat		Traditional varieties	Tall	Semidwarf varieties						
	Sample size	Ha	%	Florence Aurore	Ariana (1966)	Dougga (1974)	Carthage (1974)	Salambo (1980)	Tanit (1980)	Byrsa (1987)	Total semidwarf	Total HYVs
Agroclimatic zone												
Zone 1 (sub-humid)	88	695	29.4	9.4	13.2	0.6	–	35.5	9.9	31.4	77.4	90.6
Zone 2 (upper semi-arid)	79	1354	57.2	3.7	3.6	3.4	0.7	64.5	1.5	25.3	95.7	99.3
Zone 3 (middle semi-arid)	80	317	13.4	1.9	45.3	10.8	–	15.2	5.7	21.2	52.8	98.1
Total	247	2366	100.0	3.4	12.0	3.7	0.4	49.4	4.5	26.5	84.6	96.6
Farm size												
Small (5-20 ha)	139	47	2.0	21.7	34.8	8.7	–	6.5	23.9	19.6	43.5	78.3
Medium (21-100 ha)	64	234	9.9	2.6	23.5	10.3	4.3	33.8	8.5	17.1	73.9	97.4
Large (>100 ha)	33	876	37.0	–	9.6	6.9	–	45.3	8.7	29.6	90.4	100.0
State farms	11	1209	51.1	5.4	11.2	–	–	57.1	-	26.4	83.4	94.6
Total	247	2366	100.0	3.4	12.0	3.7	0.4	49.4	4.5	26.5	84.6	96.6
Small farms by zone												
Zone 1 (sub-humid)	51	17	0.7	–	17.6	23.5	–	–	47.1	11.8	82.4	100.0
Zone 2 (upper semi-arid)	46	19	0.8	21.1	26.3	–	–	15.8	–	36.8	52.6	78.9
Zone 3 (middle semi-arid)	42	11	0.5	54.5	18.2	–	–	–	27.3	–	27.3	45.5

Source: INRAT/ICARDA survey data.

Furthermore, the lack of a private market for bread wheat implies that farmers have to sell all their marketable surplus to the state. Small farmers, however, are usually reluctant to do so for the following reasons: they would be required to sell their entire output immediately after harvest, incur substantial transaction costs, repay whatever they owe the state in debts and tax arrears, and often endure complex procedures and delays before receiving payment for their deliveries. The existence of a parallel market for durum wheat in virtually every town in Tunisia, where prices are only slightly lower than official prices, provides an important incentive for small farmers to produce durum wheat rather than bread wheat.

Larger farmers, on the other hand, tend to practice a three- or four-course rotation in which bread wheat is frequently grown as a secondary cereal, following durum wheat and followed by barley and/or a forage crop such as oats or a vetch/oats mixture. By increasing fertilizer rates, large farmers can minimize their food legume areas—thus reducing labor costs—and use their machinery to produce cereals and forages.

Farm survey results (Tables 5 and 6) reveal the extent of HYV adoption in northern Tunisia: as of 1990/91, HYVs covered 98.6% of total durum wheat area and 96.6% of bread wheat area. Semidwarfs accounted for virtually all of the area grown to durum HYVs; they also accounted for 84.6% of the area grown to bread wheat HYVs. Even small farmers and farmers in the semi-arid zones allocated the bulk of their durum area to semidwarf varieties. In contrast, semidwarf varieties covered slightly more than half the bread wheat area in Zone 3; the tall variety Ariana 66 accounted for more than 45% of the total area. Ariana 66 was also the dominant bread wheat variety grown by small farmers, who allocated significant areas to the production of Florence Aurore as well. In fact, these two tall varieties accounted for more than 70% of the very small bread wheat area grown by small farmers in Zone 3.

Karim was by far the most widely grown durum variety: it was cultivated by 80% of farmers who grew durum wheat and it covered 63% of the total durum area. The only other important durum variety was Razzak, grown by 26% of durum wheat producers and covering 35% of the total durum wheat area. Karim adoption was highest on small farms and lowest on large farms; the opposite was true for Razzak. This may reflect a faster rate of varietal replacement among larger farmers, who appeared to be gradually replacing Karim by the newer variety Razzak. The ordinary varieties Chili and Mahmoudi can only be found on small farms, where they accounted for about 10% of durum wheat area. In Zone 3, however, small farmers were still growing significant amounts of Chili, which covered 24% of their durum area.

Compared with durum wheat, bread wheat varieties appeared more heterogenous across agroclimatic zones and by farm size. While the variety Salambo accounted for close to one half of the total bread wheat area, it was clearly most dominant in Zone 2. In contrast, Ariana 66 was by far the most important variety in Zone 3, followed by Byrsa and Salambo; the latter two varieties were equally important in Zone 1. Therefore, it seems that Ariana 66 is the variety most adapted to the drier conditions of Zone 3, while Salambo's area of adaptation is primarily in Zone 2. Byrsa appears to have relatively wide adaptation, though its adoption declines as we move from favorable to drier zones.

Although small farmers cultivate only a small fraction of the total bread wheat area, they exhibited adoption patterns quite different from larger farmers. They continued to grow significant amounts of Florence Aurore and Ariana 66, most likely because these tall varieties produce more straw and have lower input requirements than semidwarf varieties. Furthermore, the variety Tanit, which accounted for only 4.5% of the total bread wheat area, continued to be extensively grown by small farmers, particularly in Zone 1. Paradoxically, the most widely grown variety, Salambo, seems to be the least popular among small farmers, whereas the most recent variety, Byrsa, had its highest adoption rate among small farmers in Zone 2. The reasons for such peculiar adoption patterns among small farmers are not very clear, and the results should be viewed with caution given the potential for bias as a result of the very small bread wheat area cultivated by such farmers (47 ha out of a total bread wheat area of 2,366 ha grown by survey farmers).

Extrapolating the results of the INRAT/ICARDA survey to total wheat area in northern Tunisia in 1990/91 (620,000 ha) indicates the following: (1) the durum variety Karim covered about 315,000 ha, more than 50% of total wheat area in the North, followed by Razzak (174,000 ha) and the bread wheat varieties Salambo (59,300 ha) and Byrsa (31,800 ha); and (2) HYVs covered about 608,000 ha, the bulk of which were grown to semidwarf varieties, which accounted for more than 95% of total wheat area (Table 7).

Adoption history of wheat HYVs

The INRAT/ICARDA survey collected useful information on the adoption history of each wheat variety by farmers. Such information can provide a clear picture of adoption patterns since the early 1970s. Unfortunately, the survey did not include questions on changes over time in areas allocated to each variety, nor did it ask questions on changes in total areas grown to durum and bread wheat. Nonetheless, it is possible to estimate changes in areas grown to each variety over time by assuming (1) that total durum and bread wheat areas grown by each survey farmer have remained constant over the period in question and (2) that farmers did not grow more than one durum or bread wheat variety at a time. Although such simplifying assumptions may constitute important sources of bias, they are necessary in order to outline a rough picture of adoption trends over time, which is a key pre-condition for estimating the impact of HYVs on wheat yields (see next section).

Results indicate that bread wheat HYVs were adopted by farmers much earlier than durum HYVs (Table 8; Figures 5 and 6).

Table 7. Estimated distribution of wheat varieties in northern Tunisia, 1990/91

Variety	% of area (ha)	Total wheat area
Durum wheat	500,000	80.65
Razzak 87	174,000	28.06
Karim 80	315,000	50.81
Others	11,000	1.77
Bread wheat	120,000	19.35
Byrsa 87	31,800	5.13
Tanit 80	5,400	0.87
Salambo 80	59,300	9.56
Ariana 66	14,400	2.32
Others	g,100	1.47
Total wheat	620,000	100.00
Semidwarfs	590,400	95.23
HYVs [a]	608,800	98.19

Source: Extrapolated from INRAT/ICARDA survey data.
[a] HYVs include all semidwarf varieties in addition to the tall varieties Ariana 66 and INRAT 69.

In 1975, HYVs covered close to one-third of the bread wheat area compared to only 17% of durum wheat area. By 1977, HYVs accounted for more than half of bread wheat area; not until 1984 did the area grown to durum HYVs exceed the area allocated to ordinary varieties.

The slow adoption rate of durum HYVs during the 1970s seems to have resulted from the limited adaptability of earlier HYVs to production conditions in northern Tunisia. In fact, the earlier varieties Badri and Maghrebi were never grown in any significant amounts—peak adoption barely reaching 7% of the total durum area. The only exception was the early tall variety INRAT 69, which increased from about 5% of total durum area in 1970 to a peak of 23% in 1981 and which continued to be the dominant durum HYV until 1983.

Not until the early 1980s did the adoption of durum HYVs increase at a fast rate. This increase coincided with the release of varieties better adapted to rainfed conditions (e.g., Ben Bachir and Karim). Released in 1978, Ben Bachir was a promising variety, but its success was limited since it was soon over-shadowed by the spectacular success of Karim, released in 1980. By 1987, Karim covered close to 50% of the durum wheat area. This rapid expansion

Table 8. Adoption history of wheat HYVs in northern Tunisia

Variety	Year of release	Peak adoption Year	Peak adoption % of area[a]	Year of disposition[b]
Durum wheat				
INRAT 69	1969	1981	22.8	1987
Badri	1969	1982	5.5	1985
Maghrebi	1972	1978	7.3	1983
Ben Bachir	1978	1983	8.1	1986
Karim	1980	1991 [c]	63.0 [c]	na
Razzak	1987	1991 [c]	34.8 [c]	na
Bread wheat				
Ariana 66	1966	1985	28.4	na
Dougga	1974	1979	26.6	na
Carthage	1974	1978	14.2	1988
Salambo	1980	1991 [c]	49.4 [c]	na
Tanit	1980	1986	30.9	na
Byrsa	1987	1991 [c]	26.5 [c]	na

Source: Computed from INRAT/ICARDA survey data.

[a] Percentage of total durum or bread wheat areas grown by survey farms.

[b] Year when the area grown to the variety in question dropped below 2% of total durum or bread wheat area.

[c] Varieties still expanding in area by 1991.

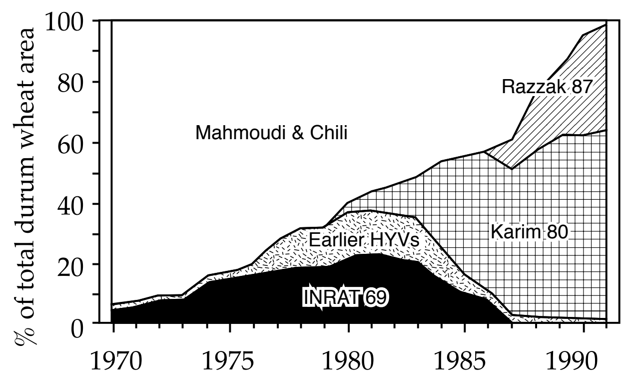


Figure 5. Adoption history of durum wheat varieties, northern Tunisia, 1970-1991.
Note: Earlier HYVs: Badri, Maghrebi and Ben Bachir
Source: INRAT/ICARDA survey data.

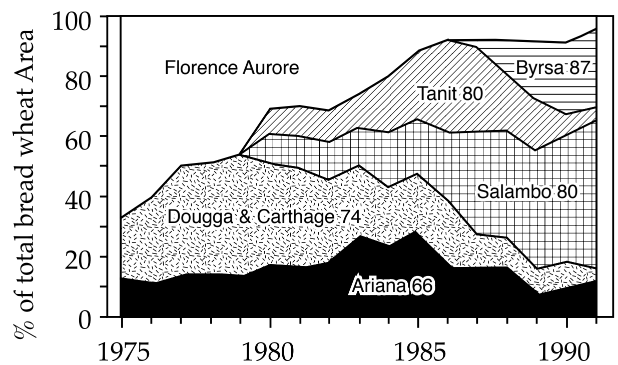


Figure 6. Adoption history of bread wheat varieties, northern Tunisia, 1975-1991.
Source: INRAT/ICARDA survey data.

occurred at the expense of all other varieties, including the OVs Mahmoudi and Chili and the earlier HYVs, which had virtually disappeared by 1987. Even after the release of Razzak in 1987, the area grown to Karim continued to expand (at the expense of OVs), reaching 63% in 1991. Also by 1991, Mahmoudi and Chili had practically disappeared as a result of the rapid expansion of both Karim and Razzak. By 1991, there were clear indications that Karim had reached its peak adoption and that farmers were gradually replacing it with Razzak. In fact, 91% of survey farmers who grew durum wheat in 1990 had planted Karim, compared to only 80% in 1991, though the area grown to Karim had increased slightly from 62% to 63% of the durum wheat area over that same period.

Bread wheat HYVs show a different adoption pattern. The earlier semidwarf varieties Dougga and Carthage were reasonably successful, with their combined areas increasing from about 20% of total bread wheat area in 1975 to a peak of 40% in 1979. With the release of Salambo and Tanit in 1980, the area grown to Dougga and Carthage declined gradually during the 1980s, reaching insignificant levels by 1991. The variety Tanit proved very productive, particularly in the favorable zones, where its cultivation reached a peak of 31% of the total bread wheat area in 1986. But Tanit soon proved highly susceptible to septoria and yellow rust. Most farmers quickly replaced Tanit with Byrsa, a more disease-resistant variety released in 1987. By 1991, the area planted to Tanit had dropped to less than 5% of total bread wheat area.

Salambo was the most widely grown bread wheat variety in 1991. Its success is attributable to its high productivity in the semi-arid zones, where it gradually replaced Florence Aurore. In fact, the widespread diffusion of Salambo in the semi-arid zones must have been an important underlying factor in the North's dramatic increase in bread wheat area, from 75,000 ha in 1982 to 141,000 ha in 1992. However, as noted earlier, Salambo seems more adapted to Zone 2 than to Zone 3, where Ariana 66 continues to be the dominant bread wheat variety (Table 6). The areas grown to Ariana 66 have remained relatively unchanged throughout the 1970s and 1980s, ranging from 10% to 15% of the total bread wheat area.

Impact of High Yielding Wheat Varieties

Estimating the impact of wheat HYVs involves several steps. First, genetic yield gains of the various HYVs above the ordinary varieties are estimated based on data from on-farm and on-station varietal yield trials. The genetic yield gain of each variety is then multiplied by the area grown to that variety based on the results of varietal adoption history computed from the INRAT/ICARDA survey data. This figure helps estimate the contribution of genetic yield gains to the observed increase in total wheat production in northern Tunisia from 1960 through the 1980s. Finally, the impacts of wheat HYVs on farmers' incomes and on the national economy are estimated by multiplying the increase in wheat production attributed to genetic yield gain by the value of durum or bread wheat. For impact on farmers' incomes, producer prices of durum and bread wheats are used in valuing the increase in wheat production; impact on the national economy is based on economic Import Parity Prices (IPPs) derived from wheat international market prices.

Genetic yield gains of wheat HYVs

Maamouri and Gharbi (1992) have estimated the yield gains resulting from durum HYVs, based on data from varietal yield trials at the main INRAT station at Béja between 1972 and 1986. During this period, the yields of the ordinary varieties Mahmoudi and Chili averaged 19.5 qx/ha, compared to 38.1 qx/ha for the tall varieties INRAT 69 and Badri. With the introduction of semidwarf varieties, average durum yields increased as follows: to 48.7 qx/ha with Maghrebi and to 53.1 qx/ha with Ben Bachir and Karim. The variety Razzak brought an additional average yield increase of 6% above Karim (République Tunisienne, Ministère de l'Agriculture 1987). Khiar, a more recent variety, outyielded Razzak by an average of 4.93 % (République Tunisienne, Ministère de l'Agriculture 1989).

However, yield gains observed in research stations may not always be obtained under farmers' conditions given that on-station trials are conducted under optimal input use and cultural practices. This is clearly illustrated by the results of on-farm varietal trials conducted by the Office des Céréales (République Tunisienne, Office des Céréales, various years) between 1982 and 1993 across all the agroclimatic zones of northern Tunisia. These results showed that Karim outyielded the check variety INRAT 69 by an average of 29%, compared to a 39% yield gain reported by Maamouri and Gharbi. Therefore, there is a yield gap of about 26% between on-station yields and yields obtained in farmers' fields.

Based on this yield gap, genetic yield gains for the various durum HYVs over the ordinary variety Mahmoudi are estimated by a downward adjustment of 26% from the yield figures reported by Maamouri and Gharbi (Table 9). As for bread wheat HYVs, the on-farm varietal trials conducted by the Office des Céréales covered all the HYVs released in Tunisia. Given the large number of observations from different sites and during different years, the results of these on-farm trials were considered sufficiently representative of farmers' conditions to provide an accurate basis for estimating genetic yield gains (Table 9).

The results in Table 9 clearly show that genetic yield gains were substantially higher for durum wheat HYVs than for bread wheat HYVs. In fact, the most productive durum variety, Razzak, outyielded the local check Mahmoudi by an average of 137%. In contrast, the average yield of the most productive bread wheat variety, Byrsa (though 20% higher than

Table 9. Average yield gains of wheat HYVs in northern Tunisia

Variety	Average yield (qx/ha)	Yield increase (%)
Durum wheat		
Mahmoudi (*check*)	19.5	100
Badri (1969)	33.0	169
INRAT 69	33.0	169
Maghrebi(1972)	41.0	210
Ben Bachir 78	44.1	226
Karim 80	44.1	226
Razzak87	45.2	237
Bread wheat		
Florence Aurore (*check*)	35.0	100
Ariana 66	41.0	117
Dougga 74	45.1	129
Carthage 74	45.1	129
Salambo 80	48.0	137
Tanit 80	48.7	139
Byrsa 87	54.2	155

Sources: Durum wheat data from on-station varietal yield trials reported by Maamouri and Gharbi (1992), but adjusted downward by 26% to account for yield gaps (refer to text). Bread wheat data from on-farm trials conducted by République Tunisienne, Office des Céréales (various issues).

Razzak's average), was only 55% higher than that of the check Florence Aurore. This difference in yield gains, however, is a result of the relatively good productivity of Florence Aurore, which averaged 35 qx/ha in on-farm yield trials, close to 80% higher than the average yield of Mahmoudi.

When these yield gains are weighted to reflect the total area grown to each variety, the results (see Figure 7) show that, in 1977, the adoption of durum HYVs increased average yields in northern Tunisia by about 22%, compared to yields that would have been obtained if all areas had been grown only to Mahmoudi. With the release and widespread adoption of the more productive semidwarf varieties Karim and Razzak during the 1980s, the contribution of HYVs increased rapidly: by 1991, the increase in average durum yield for northern Tunisia was 128%. In other words, had all the durum wheat areas been planted to Mahmoudi in 1991, the average yield in the North would have been about 8.8 qx/ha compared to the actual average yield of 20.1 qx/ha. Thus genetic yield gains in durum wheat increased at an average rate of 1.82% per year between 1977 and 1991.

For the 1977-1991 period, durum yield in the North averaged 11.4 qx/ha; without the adoption of HYVs, this average would have been 7.2 qx/ha. Genetic yield gains thus amounted to an average of 4.2 qx/ha. These gains were significantly higher during the late 1980s, with an average yield gain of 5.6 qx/ha during the 1986-1991 period compared to 3.3 qx/ha for the 1977-1985 period (Table 10). Given that average durum wheat yield in the North was 5.1 qx/ha during the 1959-1968 period (Hyslop and Dahl 1970), one can conclude that genetic yield gains accounted for two-thirds of the 6.5 qx/ha increase in average yield between the 1958-1969 period and 1977-1991 period; factors such as higher input use and better cultural practices (i.e., the "management" factors) contributed the remaining one-third.

The relative contribution of HYVs was even higher during 1986-1991 period, accounting for more than 90% of the increase in yield, compared to about 50% during the 1977-1985 period. Therefore, the average growth rate in genetic yield gain was 1.19% per year between 1959-1968 and 1977-1991, compared to 1.82% per year between 1977-1991. These rates are comparable to the highest growth rates attained during similar periods in countries such as Mexico, India, and Argentina—where the widespread adoption of wheat HYVs was a crucial element in the Green Revolution (Byerlee and Moya 1993, p. 35).

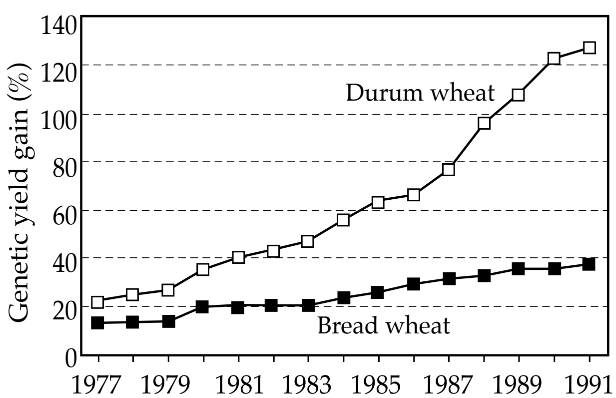


Figure 7. Genetic gain in wheat yields owing to the adoption of HYVs, northern Tunisia, 1977-1991.
Source: Computed from Table 9 and INRAT/ICARDA survey data.

Although bread wheat HYVs were as widely adopted as durum HYVs in northern Tunisia, the increase in bread wheat yields as a result of such adoption was comparatively modest, going from about 13% in 1977 to 38% in 1991 (Figure 7), for an average growth rate of 0.58% per year. As noted earlier, this modest growth in genetic yield gains was essentially a result of the relatively high yield of the OV Florence Aurore. The average yield of bread wheat in the North increased from 6.8 qx/ha during 1959-1968 to an average of 15.3 qx for the 1977-1991 period, an average growth rate of 1.69% per year. Although this rate equals that of durum wheat over the same period, management factors were clearly the main contributors, accounting for about 65% of the increase in yield, compared to 35% from HYV adoption (Table 10).

Impact on farmers' income

The primary beneficiaries of wheat HYVs are those farmers who substantially increase their yields and, by implication, their incomes. For instance, during the exceptionally good crop season of 1990/91, wheat yields in the North reached a record of 20.1 qx/ha for durum wheat and 24.3 qx/ha for bread wheat. Had all the wheat area been planted to Mahmoudi and Florence Aurore, average durum and bread wheat yields would have been 8.8 and 17.7 qx/ha, respectively. Given official producer prices of 24.5 and 20.9 TD/qx for durum and bread wheat in 1990/91, the contribution of HYVs to farmers' gross revenues is estimated at 277 TD/ha grown to durum wheat and 140 TD/ha for bread wheat. When these figures are aggregated for northern Tunisia (500,000 ha durum wheat and 120,000 ha bread wheat in 1990/91), the contribution of HYVs to gross farm income in 1990/91 amounts to 155.3 million TD (138.5 million TD for durum wheat plus 16.8 million TD for bread wheat).

These figures obviously inflate the magnitude of HYV impact due to the exceptionally favorable conditions during the 1990/91 season. If one takes the average for the 1981-1991 period (484,000 ha of durum wheat and 102,000 ha of bread wheat)—when average genetic yield gain amounted to 4.90 and 3.35 qx/ha for durum and bread wheat and when producer prices averaged 17.2 and 15.7 TD/qx, respectively—the average contribution of HYVs to gross farm income would amount to 46.2 million TD per year (40.8 million TD for durum wheat plus 5.4 million TD for bread wheat) (Table 11).

Table 10. Gains in wheat yields owing to the adoption of HYVs and to improved management, northern Tunisia, 1959-1968 to 1977-1991

	Durum wheat	Bread wheat
	qx/ha	
Average yield 1959-1968	5.1	6.8
Average yield 1977-1991	11.4	15.3
Yield increase over 1959-1968	6.3	8.5
Genetic yield increase	4.2	3.0
Increase due to management	2.1	5.5
Average yield 1977-1985	11.6	16.4
Yield increase over 1959-1968	6.5	9.6
Genetic yield increase	3.3	2.6
Increase due to management	3.2	7.0
Average yield 1986-1991	11.2	13.7
Yield increase over 1959-1968	6.1	6.9
Genetice yield increase	5.6	3.5
Increase due to management	0.5	3.4
	%	
Average annual growth in yield 1959-1968 to 1977-1991	1.68	1.69
Average annual growth in genetic yield gains		
1959-1968 to 1977-1991	1.19	0.76
1977 to 1991	1.82	0.58

Sources: Average yields for 1959-1968 from Hyslop and Dahl (1970); average yields for 1977-1991 from République Tunisienne (various years); genetic yield gains computed from Table 9 and INRAT/ICARDA survey data.

However, because the distribution of wheat areas in the North is highly skewed in favor of large farms (>100 ha) and state farms (accounting for 47% and 30% of total wheat area, respectively), the benefits of wheat HYVs were highly concentrated among these two groups: large farmers obtained close to 50% of the total benefits, state farms an additional 24%. Thus, among the estimated 85,500 cereal farmers in the North (excluding state farms and the 64,500 subsistence farmers with less than 5 ha), the average annual contribution of HYVs to gross farm income during the 1981-1991 period was about 412 TD per farmer. But for small farmers (i.e., those with 5 to 20 ha), the average annual contribution was only 65 TD, compared to more than 10,000 TD for large farmers (Table 11). It should be noted that these estimates of impact on gross farm income are likely to over-estimate the impact of HYVs on small farmers given their slightly lower rate of HYV adoption (Tables 5 and 6) and their substantially lower wheat yields as a result of lower input use and poorer soils.

It is important to note that the above estimates refer to HYV impact on gross farm income. That is, they were based on the estimated increase in gross revenues from sales of the additional wheat output made possible by the use of HYVs, without taking into consideration potential increases in costs associated with HYV use. As shown in Table 12, the majority of farmers covered by the INRAT/ICARDA survey reported increasing their input use (e.g., seeding rates, fertilizer and herbicide applications, mechanized land preparation operations) in comparison with input use on OVs. It is not clear whether farmers would have increased their inputs in any case, regardless of the adoption of HYVs. Unfortunately, the data collected by the INRAT/ICARDA survey cannot be used to estimate increases in input use for HYVs as compared with OVs, because the vast majority of survey farmers grew HYVs only. Future researchers must attempt to compare the magnitude of input increases for HYVs and OVs, thus enabling a more accurate estimate of the net impact of wheat HYVs on farmers' incomes.

Table 11. Impact of wheat HYVs on gross farm income, by farm size, northern Tunisia, average for 1981-1991

Farm size	Small (5-20 ha)	Medium (21-l00 ha)	Large (> l00 ha)	State farms	Total
Area (% of total wheat area)					
Durum wheat	6.9	13.3	35.7	14.3	70.2
Bread wheat	0.6	3.0	11.0	15.3	29.8
Total wheat	7.5	16.3	46.7	29.6	100.0
Contribution of HYVs to gross farm income					
Durum wheat (million TD/yr)	4.0	7.7	20.8	8.3	40.8
Bread wheat (million TD/yr)	0.1	0.5	2.1	2.7	5.4
Total wheat (million TD/yr)	4.1	8.2	22.8	11.0	46.2
Total wheat percentage	8.9	17.7	49.6	23.8	100.0
Number of farmers	63,000	20,250	2,250	NA	85,500
Average contribution of HYVs per farmer	65	405	10,178	NA	412

Sources: Distribution of wheat areas and impact of HYVs computed from INRAT/ICARDA survey data; distribution of number of farmers by size from République Tunisienne (1987, p. 18).

Impact at the national level

The dramatic growth in wheat genetic yield gain, particularly for durum wheat during the 1980s, has resulted in an equally dramatic increase in aggregate wheat production (Figures 8 and 9). In 1990/91, for instance, both durum and bread wheat production in the North reached record levels: more than 10 million qx of durum wheat and 2.9 million qx of bread wheat. Genetic gains alone were estimated to have accounted for about 5.6 and 0.8 million qx of durum and bread wheat production, respectively.

Table 12. Percentage of survey farmers reporting changes in input use associated with the cultivation of wheat HYVs

Input change	Durum wheat (n=221)	Bread wheat (n=79)
Increased number of tilling operations	60	61
Higher seeding rates	66	71
Higher rates of nitrogen application	71	67
Higher rates of phosphate application	62	57
Higher incidence of herbicide use	46	46

Source: INRAT/ICARDA survey data.

For the 1981-91 period, average durum wheat production in the North amounted to 5.77 million qx; bread wheat production was 1.59 million qx. The average genetic gain during that period was 2.40 million qx of durum wheat and 0.35 million qx of bread wheat. During the 1980s, Tunisia imported an average of 2.67 million qx of durum wheat and 5.24 million qx of bread wheat (average 1981-88) (Newman et al. 1989), valued at about 148 million US$, based on international market prices in 1993.[3] Without HYVs, average wheat imports would have amounted to about 5.1 and 5.6 million qx of durum and bread wheat, respectively, valued at about 202 million US$ (1993 dollars). Therefore, during the 1981-91

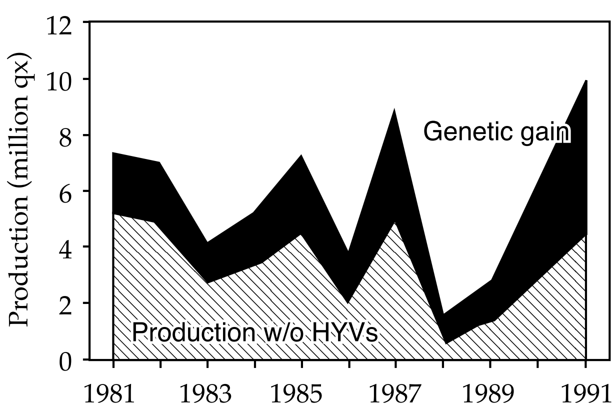
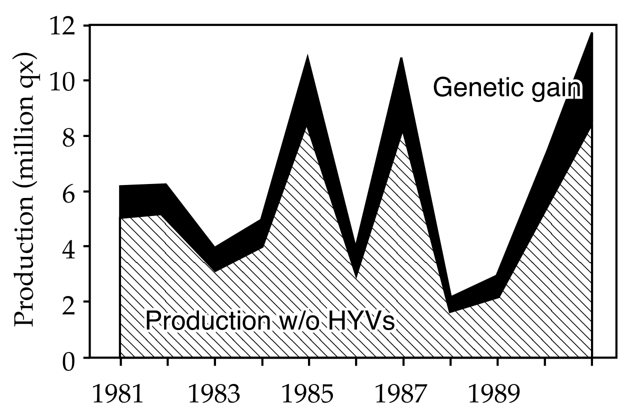


Figure 8. Impact of HYVs on total durum wheat production, northern Tunisia, 1981-1991.
Source: Computed from INRAT/ICARDA survey data.



1991

Figure 9. Impact of HYVs on total bread wheat production, northern Tunisia, 1981-1991.

[3] CIF (cargo, insurance, and freight) prices are for Tunisian imports, estimated at US$ 197/ton for durum wheat and US$ 182/ton for bread wheat. These figures are based on international market prices in March 1993 of US$ 162/ton for durum wheat (Canada No. 1 CW Amber Durum, FOB Thunder Bay) and US$ 147/ton for bread wheat (U.S. No. 2 Hard Winter Ord. Prot. FOB Gulf Ports), augmented by a US$ 35/ton for ocean freight from U.S. or Canadian ports to Tunis. Source: USDA-FAS (1993).

period, the widespread adoption of wheat HYVs saved Tunisia an average of about 54 million US$ per year in foreign exchange that would have been spent on additional wheat imports. That savings amounted to about 17% of Tunisia's total food imports, which averaged 315 million US$ during the 1980s (Thabet, Boughzala, and Ben Ammar 1993).

To estimate the impact of wheat HYVs on the Tunisian economy as a whole, the value of the net decline in wheat imports owing to the use of HYVs must be adjusted to include all the import costs incurred by the Office des Céréales (port charges, handling, storage, financial costs, etc.), estimated at about 5% of the total value (Kristjanson et al. 1990). These adjustments are needed to calculate Import Parity Prices (IPPs), which are commonly used in economic analysis to value tradable commodities (see Scandizzo and Bruce 1980; Gittinger 1982; Westlake 1987; Byerlee and Morris 1993). Furthermore, any increase in domestic wheat production necessarily implies an increase in transport and handling costs by the Office des Céréales to transfer the additional output from collection centers throughout Tunisia to Tunis, the main point of wheat consumption. When IPPs are calculated, such transfer costs need to be deducted from import prices in order to reflect the true value of the wheat output to the Tunisian economy. In 1992, these transfer costs amounted to 4.8 TD/qx for durum wheat and 4.5 TD/qx for bread wheat (Office des Céréales, unpublished data).

Using an average exchange rate of 0.95 TD per US$, the IPPs of durum and bread wheat in 1993 can he calculated as follows:

IPP (TD/qx) = CIF price ($/qx) x 0.95 TD/US$ + Import costs (5%) - Transfer costs

Thus, IPP durum wheat = 19.7 x 0.95 + 0.94 - 4.8 = 14.9 TD/qx
and IPP bread wheat = 18.2 x 0.95 + 0.86 - 4.5 = 13.6 TD/qx

In other words, the true economic value of each additional qx of durum and bread wheat produced in Tunisia in 1993 is estimated at 14.9 TD and 13.6 TD, respectively. These figures compare to the 1993 official producer prices of 26 TD/qx for durum wheat and 22.5 TD/qx for bread wheat. Therefore, wheat producers in Tunisia seem to be highly protected, with a nominal protection coefficient (NPC)[4] of 1.74 for durum wheat and 1.65 for bread wheat.

Given average genetic gains of 2.40 million qx of durum wheat and 0.35 million qx of bread wheat during the 1981-91 period, the average contribution of wheat HYVs to the Tunisian economy is thus estimated at 40.6 million TD per year based on 1993 prices (35.8 million TD for durum wheat and 4.8 million TD for bread wheat). It is important to note that such estimated annual benefits to the Tunisian economy are gross benefits since they do not include the import (or foregone export) costs of the increase in inputs associated with the adoption of wheat HYVs. Furthermore, the costs incurred by the Tunisian Ministry of Agriculture and other public or private agencies associated with the development and diffusion of wheat HYVs were also not included in the calculations. These costs include,

[4] NPC = Official producer price divided by the import parity price.

among others, the research budgets of INRAT and other research institutions allocated for wheat breeding and related activities, and the costs of on-farm varietal trials and extension activities undertaken by the Office des Céréales. The inclusion of these costs and the discounting of all costs and benefits over time constitute crucial elements in estimating the rate of return to public investments in wheat breeding research in Tunisia.[5] Such determinations, however, are beyond the scope of this study. One should note, however, that the average annual benefits of 40.6 million TD from wheat HYVs were more than three times as high as the entire agricultural research budget in Tunisia for 1985, which amounted to less than 13 million TD, including contributions from international cooperation (République Tunisienne, Ministère de l'Agriculture and ISNAR 1987, p.37).

Summary and Conclusions

The main goal of this study was to estimate the extent to which HYVs have been adopted in northern Tunisia and to assess their impact on farmers and the nation. The study was based on data collected by a 1991 INRAT/ICARDA survey of a random sample of 247 wheat growers located in the sub-humid and semi-arid zones of the North, and on results of on-station and on-farm wheat varietal trials conducted by INRAT and the Office des Céréales.

Survey results clearly show that HYVs have been adopted almost completely in northern Tunisia, accounting for 98.19% of total wheat area in 1990/91. Semidwarf varieties accounted for the vast majority (97.9%) of the durum wheat area and for 84.6% of the bread wheat area. Even small farmers and farmers in the semi-arid zones allocated the bulk of their durum wheat area to semidwarf varieties. In contrast, semidwarf bread wheat varieties accounted for only 52.8% of bread wheat area in the drier parts of the North (Zone 3) and for 43.5% of the bread wheat area grown by small farmers (i.e., those with 5 to 20 ha).

The durum variety Karim (derived from CIMMYT's Bittern cross), released in 1980, was clearly the most popular variety, covering 63% of the durum area (or about 315,000 ha). Next came Razzak (derived from a cross made by INRAT using Karim as a parent), released in 1987, which accounted for 34.8% of the durum area (174,000 ha). The most widely grown bread wheat varieties, Salambo (released in 1980) and Byrsa (1987), were both derived from CIMMYT crosses. Salambo (49.4% of total bread wheat area) was more dominant in Zone 2 (upper semi-arid), whereas Byrsa (26.5% of total bread wheat area) was slightly more dominant in Zone 3 (sub-humid). In Zone 3, however, the tall variety Ariana 66 (derived from a French cross and released in 1966) was clearly the most widely adapted bread wheat variety, accounting for more than 45% of the bread wheat area.

Bread wheat HYVs were adopted by farmers much earlier than durum HYVs. In 1975, HYVs covered close to one-third of the bread wheat area but only 17% of durum wheat area. The tall durum variety INRAT 69 was reasonably successful during the 1970s, with peak adoption of about 23% of durum area in 1981, but semidwarf varieties had very limited adoption prior to the release and widespread diffusion of Karim in 1980. In contrast,

[5] Refer to Chapter 3 in Byerlee and Moya (1993) for a detailed discussion of methods used in measuring benefits and costs of wheat breeding research.

earlier bread wheat semidwarf varieties were reasonably successful, accounting for close to 40% of the bread wheat area in 1979. The variety Tanit (derived from CIMMYT's Bluejay cross), released in 1980, was at first widely adopted by farmers; by 1986, it covered 31% of bread wheat area. However, Tanit soon proved to be highly susceptible to septoria and yellow rust, which resulted in its rapid decline down to less than 5% of bread wheat area in 1991.

Results of on-station and on-farm varietal yield trials clearly indicate that genetic yield gains were substantially higher for durum wheat HYVs than for bread wheat HYVs. The most productive durum variety, Razzak, outyielded the local variety Mahmoudi by an average of 137%. In contrast, the average yield of the most productive bread wheat variety, Byrsa (although 20% higher than Razzak's yields), was only 55% higher than the old variety Florence Aurore. This difference, however, is a result of the relatively good productivity of Florence Aurore, which outyielded Mahmoudi by about 80%.

When these genetic yield gains were weighted to reflect the total area grown to each variety in 1991, the results show that the adoption of HYVs in northern Tunisia resulted in average yield increases of about 128% for durum wheat and 22% for bread wheat. For the 1977-1991 period, durum yield in the North averaged 11.4 qx/ha compared to 5.1 qx/ha during the 1959-1968 period; the average yield of bread wheat increased from 6.8 to 15.3 qx over the same period. Although durum and bread wheat yields grew at the same average rate of 1.68% per year, HYV adoption accounted for about two-thirds of the increase in durum yield compared to only 35% for bread wheat.

The yield increases for bread wheat and durum wheat seem to have been influenced somewhat differently: for bread wheat, management factors (such as fertilizer application, herbicide use, and mechanization) have clearly been the main contributors; for durum wheat, the adoption of HYVs has been instrumental over the past thirty years. Between 1959-1968 and 1977-1991, genetic gains in durum wheat grew at an average of 1.19% per year, compared to 1.82% per year between 1977-1991. These rates are comparable to highest rates attained during similar periods in countries such as Mexico, India, and Argentina—where the widespread adoption of wheat HYVs was a crucial element in the Green Revolution.

The primary beneficiaries of wheat HYVs have been those farmers who were able to substantially increase their wheat production and, by implication, their incomes. For the 1981-1991 period, the average contribution of wheat HYVs to gross farm income (i.e., excluding costs of higher input use associated with the cultivation of HYVs) is estimated at 46.2 million Tunisian Dinars (TD) per year (about US$ 49 million), the bulk (88%) of which reflects the adoption of durum HYVs. However, these gross benefits were highly concentrated among large private farmers with more than 100 ha (50% of total gross benefits) and state farms (24% of total gross benefits), primarily because the skewed distribution of wheat areas in the North favors these farms. In fact, the contribution of wheat HYVs to gross farm income amounted to 65 TD/year for the average small farmer (those with 5 to 20 ha), compared to more than 10,000 TD/year for the average large private farmer.

At the national level, widespread HYV adoption resulted in net increases in Tunisia's average durum and bread wheat production amounting to 240,000 tons and 35,000 tons, respectively (average 1981-1991). Such substantial increases saved Tunisia an average of about US$ 54 million (1993 dollars) per year in foreign exchange that would have been spent on additional wheat imports. These additional wheat imports would have added about 17% to Tunisia's total food-import costs. Savings in wheat imports may have played at least a partial role in allowing Tunisia to continue to maintain its heavy subsidies on the consumption of bread and couscous, which are crucial to the economic survival of a large number of low-income urban consumers.

Based on 1993 Import Parity Prices of wheat, the average (1981-1991 period) contribution of wheat HYVs to the Tunisian economy is estimated at 40.6 million TD per year. These estimates, however, do not include the import (or foregone export) costs of the increase in inputs associated with the adoption of HYVs, nor do they cover agricultural research and extension costs incurred in the development and diffusion of wheat HYVs throughout the 1970s and 1980s. Nonetheless, such benefits clearly point out the substantial contribution to the Tunisian economy of wheat breeding research at INRAT and at the International Agricultural Research Centers, particularly at CIMMYT. These estimated annual benefits were more than three times as high as the entire agricultural research budget in Tunisia for 1985 (including contributions from international cooperation).

The implications seem clear: public funds allocated for wheat breeding research ought to be substantially increased. Such increases, however, may be difficult to achieve in light of recent budgetary constraints. However, given that large farmers were, to date, the primary beneficiaries of wheat breeding research in Tunisia, additional public funds for wheat research could be raised by taxing part of the benefits of wheat HYVs, either through a special tax on large farms or an additional levy on the sales price of certified wheat seeds.

Contrary to negative assessments of the Green Revolution's impact in Tunisia (Purvis 1972; Gafsi 1976; Roe and Nygaard 1980; Pearse 1980), this study clearly suggests that wheat breeding research has had a substantial positive impact, particularly during the 1980s. The magnitude of this impact is expected to increase given that, by the early 1990s, wheat HYVs were almost completely adopted by farmers in the North. Thus far, however, impacts have been restricted to that region. Adoption of wheat HWs in central Tunisia continues to be very limited due to the lack of drought-tolerant varieties. Future research should thus focus more on developing high yielding wheat varieties adapted to the drier central region, which accounts for more than one-third of the nation's total wheat area, but less than 20% of its production.

Finally, the results of this study clearly confirm the conclusions of earlier studies which suggest that large farmers have been the main beneficiaries of wheat HYVs in northern Tunisia. Unlike those earlier studies, however, this study has found that the main reason for this skewed incidence of benefits is the high concentration of wheat production on larger farms. Thus, although the majority of those with small farms have adopted wheat HYVs, their share of total benefits has been proportional to their share of the total land grown to wheat.

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