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Nutritive and Economic Value of Triticale as a Feed Grain for Poultry

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Abstract

This study reviews evidence from various studies of the nutritional value of triticale (X. *Triticosecale* Wittmack) for poultry feed. The economic value of triticale as a major ingredient in poultry diets, substituting for maize, barley, sorghum, wheat, and soybean meal, is analyzed using a linear programming model to formulate optimal minimum-cost feed rations, with and without triticale, for broiler and layer chickens at different growth stages. Triticale has the potential to reduce the cost (at international feed ingredient prices) of poultry rations and substitutes completely for maize and partially for soybean meal when its price is less than or equal to that of maize. The same model is used to examine the potential use of triticale in a particular country, Tunisia, where there is great potential for triticale production, the feed industry is dependent on imports, and triticale has a 20% price discount over maize and barley. Two feed composition scenarios are considered: (1) maize, soybean meal, barley, triticale, wheat bran, and premixes (vitamins and minerals) are the only feed ingredients available, thus leading to the formulation of suboptimal rations; and (2) other energy-rich ingredients, e.g., maize gluten and soybean oil, become available, thus allowing the formulation of balanced poultry rations. Regardless of the scenario under consideration, the inclusion of triticale leads to cost savings resulting from the complete replacement of maize and from a considerable reduction of soybean meal in the rations. These results indicate that, in countries where the feed industry relies on maize and soybean meal imports, and where sufficient triticale can be produced, the inclusion of triticale in the diet has the potential to lower the cost of poultry rations and to act as a buffer when there are disruptions and/or shortages in the supply of imported feed ingredients.

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Executive Summary

Introduction

Triticale is a relatively "new" crop, a small grain cereal developed in the last century by crossing wheat and rye. Triticale is agronomically similar to wheat and requires no special production technologies or management. It appears particularly attractive as a forage and/or feed crop in certain agroclimatic conditions, such as dryland and tropical highland environments, and in certain socioeconomic situations, such as smallholder farming systems. Triticale has a competitive advantage over wheat under cool growth conditions, on sandy soils, and on acid soils (with or without high free aluminum levels). It is also still relatively resistant to many foliar diseases affecting other cereal crops.

This study examines the economic value of triticale (X. *Triticolsecale* Wittmack) as a major ingredient in poultry diets, substituting for maize, barley, sorghum, or wheat, and, to some extent, soybean meal. A linear programming model is used to specify optimal minimum-cost feed rations, with and without triticale, for broiler and layer chickens at different growth stages. The model is first run using international prices. Then it is used to examine the economic value of triticale in poultry feed rations in Tunisia, where the feed industry is dependent on imports. Results of the analysis are discussed in light of their implications for the future of triticale production and utilization by the Tunisian poultry feed industry.

Nutritional Value of Triticale for Poultry Feed

Maize, wheat, sorghum, and barley typically provide the bulk of the caloric requirements in ruminant and non-ruminant diets. Although these cereals are a relatively good source of energy, they need to be supplemented with protein from sources such as soybean meal, fish meal, maize gluten, and vitamin and mineral premixes to meet minimum nutritional requirements. Compared with other cereals, triticale has a better balance of essential amino acids, particularly lysine, the first limiting essential amino acid in most cereal grains. Threonine, another essential amino acid, is also found in relatively high levels in triticale compared to maize, wheat, and sorghum. Because of these characteristics, triticale appears to be a suitable substitute for most cereal grains used in feed.

Studies that evaluate the feeding value of triticale for poultry generally do not find any detrimental effect on growth and performance. Antinutritional factors such as trypsin inhibitors seem to be less of a problem with new triticale cultivars. Consequently, more nutritionists encourage the use of triticale in poultry diets as at least a partial substitute for maize and, to a lesser extent, for soybean meal. The inclusion of triticale depends upon 1) the availability of alternative ingredients that are competitive with respect to quality and 2) the economic incentives from including triticale in the diet. The economic issue, which is explored in this study, is the major factor that will ultimately influence large-scale utilization of triticale.

Economics of Triticale in Poultry Feed

The linear programming model — A linear programming model is used to analyze how the inclusion of triticale in poultry rations affects the composition and cost of broiler and layer diets. Two major assumptions underlie the analysis: 1) triticale has a higher protein and amino acid content but a lower energy content than maize; 2) neither feed intake nor feed conversion is affected by the ingredients composing the diet, as long as the diet meets all suggested minimum nutrient requirements. In the model, optimality is expressed in terms of minimizing the cost of producing 1 t of feed subject to a set of linear constraints representing the minimum nutrient requirements of poultry.

Three growth stages are considered for broilers: day-old to 3 weeks (starter); 3-6 weeks (grower); and 6-8 weeks (finisher). Four growth stages are considered for layers: day-old to 6 weeks (starter); 6-14 weeks (grower-1); 14-20 weeks (grower-2); and more than 20 weeks (layer).

The ingredients included in the model are: maize, soybean meal, maize gluten, fish meal, grain sorghum, triticale, barley, wheat, soybean oil, calcium carbonate, dicalcium phosphate, synthetic lysine, synthetic methionine, vitamins, minerals, and salt. Minimum requirements are set for the following essential nutrients: metabolizable energy, protein, methionine, lysine, threonine, tryptophan, calcium, and available phosphorus. Limits are imposed on salt, vitamins, and minerals so that their proportion in the ration will be exactly 0.4%, 0.5%, and 0.1%, respectively. The proportion of maize gluten and fish meal in the diet is limited to a maximum of 5% each. The amount of crude fiber in the diet is also limited to no more than 5%.

The model is run without triticale to formulate conventional maize/soybean-based diets. The output gives the cost ($/t) of the minimum-cost diet at a given growth stage, its nutritional content, and the proportions of ingredients. Next, the model is run with triticale as a potential ingredient of the diet. Along with providing the cost of the diet and the nutritional content and optimal proportion of each ingredient in the diet, the model also computes the cost difference between "conventional" and "triticale" diets at each growth stage.

Results using international prices — Since no international price is available for triticale, a base model is run in which the triticale price is equal to the maize price. Sensitivity analysis is done to determine the price range over which triticale will remain a competitive ingredient.

In the base model, sorghum, fish meal, and wheat do not enter the diets for *broilers or layers* at any growth stage. Triticale completely replaces maize and reduces the proportion of soybean meal in both broiler and layer rations, while satisfying the minimum nutrient requirements of chicks. At this triticale-to-maize price ratio, including triticale in *broiler rations* leads to a modest average cost savings of US$ 3/t of feed. The average cost reduction resulting when triticale is included in *layer diets* amounts to US$ 3.60/t. Thus triticale diets have a modest economic advantage over maize-soybean meal diets for broilers and layers when the triticale price equals the maize price (Summary Table 1).

The effects of different triticale protein and lysine values on composition and cost of the diet were also evaluated. If a diet is formulated with a triticale cultivar that has a protein content of 11% and lysine content of 0.3%, triticale must have a price that is lower than the maize price by 3.3% and 4.3% before it is worth including in starter broiler and laying hen diets, respectively. However, if triticale has a protein content of 12% and lysine content of 0.5%, it remains in the diet even at a price premium of up to 4.2% over the maize price.

The maximum price premium allowed for triticale to remain in the diet or the price decrease needed for triticale to enter the diet was also analyzed. When the triticale-to-maize price ratio is set to 0.90 (protein = 12%; lysine = 0.5%), the composition of the diet does not change. Including triticale in the diets leads to cost savings averaging US$ 10.60/t (5.6% cost reduction) for broilers and US$ 11.14/t (7.51% cost reduction) for layers. The highest cost savings occur at the finishing stage for broilers (US$ 12.60/t) and at the laying stage (>20 weeks) for layers (US$ 12.24/t) (Summary Table 1). Cost reductions of this magnitude will most likely encourage the inclusion of triticale in poultry diets.

Production, utilization, and potential of triticale in Tunisia — In maize- and soybean-deficit countries, relative prices of the main feed ingredients will likely favor the use of triticale in feed, especially if triticale yields better than other cereal crops (as in Tunisia). In such cases the triticale-to-maize price ratio is expected to be less than one, which implies that even low protein

Summary Table 1. Cost savings when triticale is included in different broiler and layer rations (international prices)

Type of ration	Cost savings (US$/t)	Cost savings (%)
Broiler and layer rations, when the triticale-to-maize price ratio = 1		
Broiler		
Starter	2.90	1.44
Grower	2.40	1.30
Finisher	4.00	2.30
Layer		
Starter	3.80	2.41
Grower-1	5.16	3.54
Grower-2	2.67	2.01
Layer	2.92	1.87
Broiler and layer rations, when the triticale-to-maize price ratio = 0.90		
Broiler		
Starter	9.07	4.50
Grower	10.06	5.44
Finisher	12.60	7.20
Layer		
Starter	11.43	7.25
Grower-1	11.68	8.00
Grower-2	9.20	6.92
Layer	12.24	7.82

(11%) and low lysine (0.3%) triticale may have potential as a poultry feed ingredient instead of maize. Also, if the feed industry relies on imported protein concentrates such as soybean meal, the use of triticale may reduce the level of soybean meal used and lower the cost of the diet.

Tunisia initiated large-scale triticale production in the early 1980s. In less than a decade, triticale area increased by more than 300%, from 4,000 ha in 1984 to more than 17,000 ha in 1991. Virtually all triticale is produced in the northern (relatively well-watered) zone. The Tunisian feed industry has also expanded in recent years, mainly because the poultry industry has grown. On average, about two-thirds of the feed produced is allocated to poultry and the remainder to livestock. In 1991 poultry feed consumption exceeded 400,000 t. Tunisia imports all the maize and soybean meal used to formulate poultry rations. Since 1981, average annual maize imports have surpassed 200,000 t; soybean meal imports have reached 100,000 t. Use of triticale in poultry feed has been negligible, even though research by the Ministry of Agriculture concluded that triticale in poultry diets (up to a 30% inclusion rate) improves weight gain.

To assess the economic value of triticale in poultry feed in Tunisia, this study uses the model described earlier to specify minimum cost rations (with and without triticale) at 1990 prices of poultry feed ingredients in Tunisia. The effect of including triticale in poultry feed is analyzed under two scenarios:

1. Maize, soybean meal, triticale, barley, and bran are the only feed ingredients available (the current situation). In this case the rations are not balanced.

2. Energy-rich ingredients such as soybean oil and maize gluten become available, thus enabling balanced rations to be formulated.

Under the first scenario, restricting the choice of ingredients leads to the formulation of energy-deficient rations regardless of whether triticale is included in the diet. At 1990 ingredient prices, when triticale is included in poultry diets, feed cost is reduced, especially for broilers and pullets — a savings of about 11.1 and 20.0 Tunisian dinars (TD) per ton. Including triticale in the diet leads to a considerable reduction of maize (a 25% average reduction for broilers and 47% for layers) and some reduction in soybean meal (6% for broilers, 30% for layers).

Under the second scenario, at 1990 prices, including triticale in the balanced rations reduces the cost of broiler diets (TD 23.2/t on average) and layer diets (TD 29.2/t on average) for all growth stages (Summary Table 2). When triticale, maize gluten (maximum of 5%), and soybean oil (maximum of 5.96%) are all available, optimal feed rations can be formulated at a lower cost than the government-prescribed (and suboptimal) feed rations (Summary Table 3).

The Tunisian government has initiated a subsidy removal program, with the likely result that triticale's 20% price advantage over barley will eventually disappear. Thus the model is run assuming an identical barley and triticale price (TD 127.5/t), with all other things being equal. An identical price does not considerably reduce the cost of the diet (Summary Table 2), implying that, even when the price of barley equals the price of triticale, barley is not a competitive feed ingredient in triticale-based poultry diets in Tunisia.

Even when the amount of triticale in the ration is limited to 20% (broilers) and 30% (layers), cost savings can still be achieved (Summary Table 2). This is especially true for layers. The inclusion of triticale also leads to the formulation of balanced diets that require much less

Summary Table 2. Cost savings when triticale is included in different broiler and layer rations (Tunisian prices)

Type of ration	Cost savings (US$/t)	Cost savings (%)
Broiler and layer rations, at Tunisian prices and using additional ingredients (maize gluten and soybean oil) to formulate balanced rations		
Broiler		
Starter	19.47	7.80
Grower	23.00	10.00
Finisher	27.23	12.40
Layer		
Starter	27.50	13.71
Grower-1	31.40	16.80
Grower-2	30.00	17.30
Layer	28.00	14.50
Layer rations, at Tunisian prices, using additional ingredients, and with the barley price set equal to the triticale price		
Starter	27.00	13.50
Grower-1	30.40	16.34
Grower-2	28.00	16.30
Layer	28.00	14.50
Broiler rations, at Tunisian prices and with the use of triticale limited to 20%		
Starter	7.53	3.02
Grower	7.17	3.11
Finisher	7.77	3.53
Layer rations, at Tunisian prices and with the use of triticale limited to 30%		
Starter	11.80	5.88
Grower-1	13.53	7.24
Grower-2	11.38	6.55
Layer	10.76	5.57
Broiler and layer rations, at Tunisian prices and using triticale with low protein content (11%) and low lysine content (0.3%)		
Broiler		
Starter	13.50	5.40
Grower	15.53	6.72
Finisher	18.42	8.37
Layer		
Starter	20.03	10.00
Grower-1	23.56	12.60
Grower-2	22.80	13.10
Layer	18.90	9.80

Note: US$ 1.0 = TD 0.92.

maize and soybean meal than the current government-prescribed rations, which are energy deficient.

Finally, the model is run assuming that low quality triticale is used (protein content = 11% and lysine = 0.3%). The proportion of triticale in the rations still remains high, ranging from around 50% for starter broilers to 84% for layers at the grower-2 stage. Triticale reduces the cost of the ration (about 7% for broilers and 11% for layers, on average), because it substitutes completely for maize at all growth stages.

Conclusions and Recommendations

It is clear that triticale has potential as a poultry feed ingredient. Triticale does not require technology or management different from that used to produce other small grain cereals; its introduction in the rainfed farming system of Tunisia requires virtually no change at the farm level. Triticale's nutritional profile and lower price relative to maize and soybean meal enables the formulation of diets nutritionally similar to maize/soybean-based diets at less cost. There are sufficient price incentives (given 1990 relative prices of feed ingredients) to encourage both feed producers and feed users to take advantage of triticale. Based on these findings, the gradual replacement of maize by triticale should be initiated in Tunisia.

On the supply side, however, the actual annual production of about 40,000 t represents only about 10% of total annual poultry feed consumption. Triticale area must expand considerably for triticale to become a major poultry feed ingredient in Tunisia. In 1991, poultry feed consumption in Tunisia was more than 400,000 t. Based on a 30% inclusion rate of triticale, on average, about 120,000 t of triticale will be required to formulate minimum cost triticale-based diets. Assuming an average triticale yield of 2 t/ha, at least 60,000 ha will have to be sown to triticale to meet feed demand. Although triticale will be cultivated at the expense of other cereals (most probably barley), the triticale area required represents less than 10% of the cultivated cereal area and less than 40% of the fallow area in the northern zone. To minimize the unwarranted displacement of any cereal crop in this zone, the production of triticale in the central zone (where the fallow area is considerable and where triticale production has a relative comparative advantage) should be initiated.

Summary Table 3. Cost of government-prescribed (PR) and optimal triticale-based poultry rations (LP) (Tunisian prices)

	Starter		Broiler		Pullet		Layer	
	PR	LP	PR	LP	PR	LP	PR	LP
Cost (TD/t)	211.6	208.0	213.7	193.0	183.4	143.7	164.9	165.1
Savings (TD/t)	3.60		20.70		39.70		-0.20	
Savings (%)	1.70		9.68		21.64		-0.12	

Note: US$ 1.0 = TD 0.92.

The increase of triticale area (from nearly 20,000 ha currently to 60,000 ha) needed to meet feed demand would most likely be gradual. It would require a sustained extension program that targets producers and users; it would also require an adequate (at least in volume) seed supply.

This study of triticale utilization as a feed grain has highlighted the conditions that might make triticale utilization advantageous in other countries as well. Triticale has the potential to reduce the cost of poultry feed in countries that can produce adequate supplies of triticale and where the feed industry relies on imported maize and soybean oil. Furthermore, the use of triticale offers the additional advantage of reducing problems caused by disruptions and/or shortages in the supply of imported feed ingredients.

Résumé

Introduction

Le triticale est une céréale de culture relativement récente, développée au cours du siècle dernier à partir d'un croisement blé-seigle. Sur le plan agronomique, le triticale ressemble au blé et ne nécessite donc aucune technique particulière de production ou de gestion. Il est particulièrement intéressant comme culture fourragère et/ou grain, notamment dans les zones de culture en sec et dans les hauts plateaux tropicaux, plus particulièrement sur les petits exploitations. Dans les zones à climat froid, sur les sols sablonneux et sur les sols acides, le triticale présente un avantage certain sur le blé. De plus, il est relativement plus résistant à plusieurs maladies foliaires qui affectent les autres cultures céréalières.

La présente étude se propose d'examiner la valeur économique du triticale (X. *Triticosecale* Wittmack) comme ingrédient principal dans l'alimentation de la volaille, en substitution au maïs, à l'orge, au sorgho ou au blé, et, dans une certaine mesure, au tourteau de soja. Un modèle de programmation linéaire est utilisé pour déterminer le coût minimum optimal des formules alimentaires, avec et sans triticale, destinées aux poulets de chair et aux poules pondeuses, à différents stades de croissance. Dans un premier temps, le modèle est exécuté en utilisant les prix internationaux des ingrédients considérés. Il est ensuite utilisé pour evaluer la valeur économique du triticale dans les formules alimentaires destinées à la volaille en Tunisie, où l'industrie de l'aliment est tributaire des importations. Les résultats de l'analyse sont ensuite examinés en fonction de leurs implications quant à l'avenir de la production du triticale et de son utilisation par l'industrie tunisienne de l'aliment concentré.

Valeur nutritionelle du triticale pour l'aliment avicole

Le maïs, le blé, le sorgho et l'orge procurent l'essentiel des besoins énergétiques des formules alimentaires des ruminants et des non-ruminants. Bien que ces céréales soient une bonne source d'énergie, elles doivent, cependant, être complétées par un apport de protéines provenant, par exemple, de la farine de soja, de la farine de poisson, du gluten du maïs, et par des vitamines et des sels minéraux, afin de satisfaire les besoins nutritionnels de base. En comparaison avec les autres céréales, le triticale a une meilleure teneur en acides aminés essentiels, notamment en lysine, principal acide aminé essentiel considéré comme premier facteur limitant dans les autres céréales. Le triticale a également une meilleure teneur en thréonine, un autre acide aminé essentiel, que le maïs, le blé et le sorgho. Compte tenu de ces caractéristiques, le triticale apparaît comme un substitut intéressant à la plupart des autres céréales utilisées dans l'alimentation animale.

Les études portant sur l'evaluation de la valeur nutritive du triticale dans l'alimentation avicole ne font, généralement, pas état d'effet négatif sur la croissance et sur le rendement de la volaille. Les facteurs anti-nutritionels, tels que les inhibiteurs de la trypsine, deviennent apparemment moins problématiques avec l'utilisation des nouvelles variétés de tritricales.

Aussi, de plus en plus de nutritionnistes encouragent l'utilisation du triticale dans l'alimentation de la volaille comme substitut, au moins partiel, au maïs et, à un degré moindre, au tourteau de soja. L'incoporation du triticale dans l'aliment avicole dépend, premièrement, de la disponibilité d'ingrédients qualitativement compétitifs, et, deuxièmement, des avantages économiques pouvant résulter de l'utilisation du triticale dans les rations alimentaires. L'aspect économique, qui est examiné dans la présente étude, constitue le principal facteur qui influencera en dernier ressort l'utilisation à grande échelle du triticale.

Le triticale dans l'alimentation des volailles: Aspect économique

Le modèle de programmation linéaire. Un modèle de programmation linéaire est utilisé pour analyser l'effet de l'incorporation du triticale dans l'aliment sur la composition et les coûts des formules alimentaires destinées aux poulets de chair et aux poules pondeuses. L'analyse repose sur deux hypothèses importantes: 1) le triticale a une meilleure teneur en protéines et en acides aminés, mais une plus faible teneur en énergie que le maïs et 2) dans la mesure où la ration satisfait aux besoins de base, ni la quantité consommée ni le taux de conversion ne sont affectés par les ingrédients utilisés. Dans le modèle l'optimisation est exprimée en termes de minimisation du coût de production d'une tonne d'aliment en présence d'un ensemble de contraintes linéaires représentant les besoins de base des deux catégories de volaille.

Trois stades de croissance sont considérés pour le poulet de chair: naissance à trois semaines (démarrage); trois à six semaines (croissance) et six à huit semaines (finition). Pour la poule pondeuse, quatre stades de croissance sont considérés: naissance à six semaines (démarrage); six à quatorze semaines (croissance No. 1); quatorze à vingt semaines (croissance No. 2); et plus de vingt semaines (ponte).

Les ingrédients inclus dans le modèle sont les suivants: maïs, tourteau de soja, gluten du maïs, farine de poisson, sorgho grain, triticale, orge, blé, huile de soja, carbonate de calcium, phosphate dicalcique, lysine et méthionine synthétiques, vitamines, minéraux et sel. Les besoins de base sont spécifiés pour les éléments suivants: énergie métabolisable, protéine, méthionine, lysine, Thréonine, tryptophane, calcium et phosphore disponible. Les taux en sel, vitamines et minéraux dans la ration sont limités à exactement 0,4%, 0,5% et 0,1%, respectivement. Une limite supérieure de 5% est fixée pour les taux de gluten de maïs et de farine de poisson. Le taux de fibres brutes de la ration est aussi limité à un maximum de 5%.

Dans un premier temps le modèle est exécuté sans présense de triticale en vue de formuler des rations conventionnelles à base de maïs et de tourteau de soja. Le résultat donne le coût de la ration à moindre coût ($/t), à un stade de croissance donné, son contenu nutritionnel et la proportion des ingrédients qui la composent. Le modèle est ensuite exécuté avec le triticale comme ingrédient potentiel. En plus du coût de la ration à moindre coût, de son contenu nutrionnel et de la proportion optimale de chaque ingrédient, le modèle calcule aussi la différence entre le coût de la ration conventionnelle et celui de la ration à base de triticale à chaque stade de croissance.

Résultats obtenus à partir des prix internationaux. Comme aucun prix international n'est disponible pour le triticale, un modèle de base est exécuté avec un prix du triticale égal à celui du maïs. Une analyse de sensibilité (analyse des plages d'invariance) est ensuite effectuée afin de déterminer la gamme de prix pour laquelle le triticale demeure un ingrédient compétitif.

Dans le modèle de base, le sorgho, la farine de poisson et le blé n'entrent pas dans la formulation des rations alimentaires des poulets de chair ni de celles des pondeuses, quel que soit le stade de croissance. Le triticale remplace complétement le maïs et réduit la part du tourteau de soja, tant pour les poulets de chair que pour les pondeuses, tout en satisfaisant les besoins nutritifs de base des poussins. Sur la base de ce rapport de prix triticale/maïs, l'incorporation du triticale dans la ration conduit à une réduction modique moyenne des coûts de l'ordre de 3,00 $US par tonne d'aliment pour le poulet de chair et de 3,60 $US pour les pondeuses. Donc, dans une telle conjoncture de prix (prix du triticale égal à celui du maïs), les rations à base de triticale offrent un avantage économique, quoique modique, sur celles à base de maïs et de tourteau de soja (voir tableau 1).

Les effets de différentes teneurs en protéines et en lysine du triticale sur la composition et le coût des rations, ont également été évalués. Si une ration est formulée avec une variété de triticale contenant 11% de protéines et 0,3% de lysine, le triticale doit avoir un prix inférieur de 3,3% et de 4,3%, relativement à celui de maïs, pour qu'il puisse être considéré comme

Tableau 1. Réduction des coûts induise par l'incoporation du triticale dans la formulation des rations des poulets de chair et des pondeuses (prix internationaux).

Type de rations	Réductions des coûts ($US/t)	Réductions des coûts (%)
Rations avec un rapport de prix triticale/maïs = 1		
Poulets de chair		
Démarrage	2,90	1,44
Croissance	2,40	1,30
Finition	4,00	2,30
Pondeuses		
Démarrage	3,80	2,41
Croissance No.1	5,16	3,54
Croissance No.2	2,67	2,01
Ponte	2,92	1,87
Rations avec un rapport de prix triticale/maïs = 0,90		
Poulets de chair		
Démarrage	9,07	4,50
Croissance	10,06	5,44
Finition	12,60	7,20
Pondeuses		
Démarrage	11,43	7,25
Croissance No.1	11,68	8,00
Croissance No.2	9,20	6,92
Ponte	12,24	7,82

ingrédient potentiel des formules alimentaires destinées aux poulets de chair (stage démarrage) et des pondeuses (stade ponte), respectivement. Par contre, un triticale ayant des teneurs de 12% en protéines et 0,5% en lysine est maintenu dans la ration même si son prix est supérieur de 4,2%, à celui du maïs.

Le prix maximum acceptable pour que le triticale soit maintenu dans la formulation de la ration alimentaire, ou la diminution du prix du triticale requise pour son incorporation dans la formule alimentaire ont aussi été analysés. Lorsque le rapport de prix triticale/maïs est fixé à 0,90 (protéine = 12%; lysine = 0,5%), la composition de la ration reste inchangée. L'incorporation du triticale dans la ration conduit à une réduction moyenne de coûts de l'ordre de 10,60 $US par tonne d'aliment (soit un réduction de 5,6%) dans le cas des poulets de chair et de 11,14 $US par tonne d'aliment (soit une réduction de 7,51%) dans le cas des pondeuses. Les réductions de coût les plus élevées sont réalisées au stade finition pour les poulets de chair (12,60 $US par tonne d'aliment) et au stade ponte pour les pondeuses (US$ 12,24 par tonne d'aliment) (tableau 1). De telles diminutions de coût vont certainement encourager l'incorporation du triticale dans la fabrication de l'aliment destiné à la volaille.

Production, utilisation et potentiel du triticale en Tunisie. Dans les pays à faible production de maïs et de soja, les prix relatifs des principaux ingrédients utilisés dans la fabrication de l'aliment concentré favoriseront vraisemblablement l'utilisation du triticale, surtout si le triticale a un meilleur rendement que les autres cultures céréalières (comme en Tunisie). Dans de tels cas, le rapport de prix triticale/maïs sera certainement inférieur à 1, ce qui implique que même un triticale ayant un faible teneur en protéines (11%) et en lysine (0,3%) pourrait être considéré comme un ingrédient potentiel dans la formulation de rations alimentaires destinées à la volaille, en remplacement du maïs. De plus, si l'industrie de l'aliment concentré est tributaire des importations de concentrés de protéines, comme le tourteau de soja, l'utilisation du triticale est susceptible de réduire la part du tourteau de soja utilisé et ainsi diminuer le coût de la ration.

La Tunisie a lancé la production du triticale au début des années 1980. En moins de dix ans, la superficie emblavée en triticale a augmenté de plus de 300%, passant de 4 000 hectares en 1984 à plus de 17 000 hectares en 1991. La quasi-totalité du triticale est produit dans la zone nord (relativement bien arrosée). L'industrie tunisienne de l'aliment s'est aussi beaucoup développée au cours des dernières années, notamment des suite au développement de l'aviculture. En moyenne, près des deux tiers de la production de concentré sont destinés à l'aviculture et le reste au bétail. En 1991, la consommation de l'aliment par l'aviculture a dépassé 400 000 tonnes. La Tunisie importe la totalité du maïs et du tourteau de soja utilisés dans la production de l'aliment de la volaille. Depuis 1981, la moyenne annuelle des importations de maïs a dépass•é les 200 000 tonnes; celle du tourteau de soja a atteint les 100 000 tonnes. L'utilisation du triticale dans l'aliment avicole a été négligeable, malgré des résultats d'études, menées par le Ministère de l'Agriculture, ayant démontré que l'incorporation (jusqu'à 30%) du triticale dans la ration conduit à une amélioration du gain en poids journalier.

Pour évaluer la valeur économique du triticale dans l'alimentation avicole en Tunisie, cette étude utilise le modèle décrit précédemment afin de préciser le coût minimum de la ration (avec et sans triticale) sur la base des prix des ingrédients en vigueur en Tunisie en 1990. Les effets de l'incorporation du triticale dans l'alimentation avicole sont analysés dans les deux cas de figure suivants:

1. Le maïs, le tourteau de soja, l'orge et le son sont les seuls ingrédients disponibles (situation actuelle). Dans ce cas, les rations ainsi formulées ne sont pas équilibrées.

2. Des ingrédients riches en énergie, tels que l'huile de soja et le gluten de maïs, deviennent disponibles, permettant ainsi la formulation de rations équilibrées.

Dans le premier cas, le fait de restreindre le choix des ingrédients conduit à la formulation de rations déficientes en énergie, indépendamment de l'incorporation du triticale dans la ration. Sur la base des prix en vigueur en 1990, lorsque le triticale est inclus dans la ration, les coûts de production sont réduits, en particulier pour les poulets de chair et les pondeuses, soit une réduction d'environ 11,1 et 20,0 dinars tunisiens (DT) par tonne d'aliment. L'incorporation du triticale dans la ration entraîne une réduction considérable du maïs (une réduction moyenne de 25% pour les poulets de chair et de 47% pour les pondeuses), ainsi qu'une légère réduction du tourteau de soja (6% pour les poulets de chair et 30% pour les pondeuses).

Dans le deuxième cas, sur la base des prix en vigueur en 1990, l'incorporation du triticale réduit le coût de la ration destinée aux poulets de chair (en moyenne 23,2 DT par tonne) et des pondeuses (en moyenne 29,2 DT par tonne), tous stades de croissance confondus (tableau 2). Lorsque le triticale, le gluten de maïs (maximum 5%) et l'huile de soja (maximum 5,96%) sont tous disponibles, des rations optimales peuvent être formulées à un coût inférieur à celui des rations (sous-optimales) actuellement prescrites par le gouvernement (tableau 3).

Le gouvernement tunisien a initié un programme de suppression des subventions qui aura probablement pour effet d'éliminer l'écart de 20% qui existe entre le prix du triticale et celui de l'orge. Aussi le modèle est exécuté en supposant un prix identique pour l'orge et le triticale (127.5 DT par tonne), toutes les autres données étant égales. Un prix identique pour le triticale et l'orge n'entraîne pas une diminution considérable du prix de la ration (tableau 2), ce qui implique que, en Tunisie, même à prix égal, l'orge n'est pas un ingrédient compétitif dans la formulation des rations à base de triticale.

Même lorsque la proportion de triticale dans la ration est limitée à 20% pour les poulets de chair et à 30% pour les pondeuses, une réduction de coût de la ration peut être obtenue (tableau 2). Cela est particulièrement vrai dans le cas des pondeuses. L'incorporation du triticale conduit également à la formulation de rations équilibrées nécessitant moins de maïs et de tourteau de soja que celles prescrites par le gouvernement qui, elles, sont déficientes en énergie.

Tableau 2. Réduction des coûts induise par l'incoporation du triticale dans la formulation des rations des poulets de chair et des pondeuses (prix tunisiens).

Type des rations	Réductions des coûts ($US/t)	Réductions des coûts (%)
Rations des poulets de chair et des pondeuses, aux prix tunisiens, avec apport d'ingrédients additionnels (gluten de maïs et d'huile de soja). Rations équilibrées.		
Poulets de chair		
Démarrage	19,47	7,80
Croissance	23,00	10,00
Finition	27,23	12,40
Pondeuses		
Démarrage	27,50	13,71
Croissance No.1	31,40	16,80
Croissance No.2	30,00	17,30
Ponte	28,00	14,50
Rations des pondeuses, aux prix tunisiens, avec ingrédients additionnels, orge et triticale au même prix		
Démarrage	27,00	13,50
Croissance No.1	30,40	16,34
Croissance No.2	28,00	16,30
Ponte	28,00	14,50
Rations des poulets de chair aux prix tunisiens, avec apport de triticale limité à 20%		
Démarrage	7,53	3,02
Croissance	7,17	3,11
Finition	7,77	3,53
Rations des pondeuses, aux prix tunisiens, avec apport de triticale limité à 30%		
Démarrage	11,80	5,88
Croissance No.1	13,53	7,24
Croissance No.2	11,38	6,55
Ponte	10,76	5,57
Rations des poulets de chair et des pondeuses, aux prix tunisiens, avec apport de triticale de faible contenu de protéine (11%) et de lysine (0,3%)		
Poulets de chair		
Démarrage	13,50	5,40
Croissance	15,53	6,72
Finition	18,42	8,37
Pondeuses		
Démarrage	20,03	10,00
Croissance No.1	23,56	12,60
Croissance No.2	22,80	13,10
Ponte	18,90	9,80

Note: 1 US$ = 0,92 DT.

Tableau 3. Coût des rations prescrites par le gouvernement (PR) et des rations optimales à base de triticale (LP) (prix tunisiens).

	Stade de démarrage		Poulets de chair		Poulettes		Pondeuses	
	PR	LP	PR	LP	PR	LP	PR	LP
Coût (DT/t)	211,6	208,0	213,7	193,0	183,4	143,7	164,9	165,1
Economies (DT/t)	3,60		20,70		39,70		-0,20	
Economies (%)	1,70		9,68		21,64		-0,12	

Note: 1 US$ = 0,92 DT.

Finalement, le modèle est éxecuté en supposant l'utilisation de triticale de moindre qualité (teneur en protéine = 11%; en lysine = 0,3%). La proportion de triticale dans la ration demeure malgré tout élevée, atteignant 50% pour les poulets de chair (stade démarrage) et 84% pour les pondeuses (stade croissance No. 2). Du fait qu'il remplace complétement le maïs à tous les stades de croissance, le triticale réduit le coût de la ration (en moyenne de 7% pour les poulets de chair et de 11% pour les pondeuses).

Conclusions et recommandations

Il est clair que le triticale posséde un potentiel comme ingrédient dans l'alimentation de la volaille. Sa production ne requiert aucune technologie ou gestion différentes de celles couramment utilisées dans la production d'autres céréales; son introduction dans le système de culture en sec en Tunisie ne nécessite pratiquement aucun changement au niveau de l'exploitation agricole. Le profil nutritionnel du triticale et son prix moins élevé, relativement au maïs et au tourteau de soja, rendent possible la formulation de rations nutritivement similaires à celles à base de maïs et de tourteau de soja à moindre coût. Les prix des ingrédients (en vigueur en 1990) sont suffisamment favorables au triticale pour encourager, tant les producteurs que les utilisateurs d'aliments, à tirer profit de l'utilisation du triticale. Sur la base de ces résultats, le remplacement graduel du maïs par le triticale devrait être initié en Tunisie.

En matière d'approvisionnement, cependant, la production annuelle actuelle d'environ 40 000 tonnes ne couvre que près de 10% de la consommation annuelle avicole. Les superficies emblavées en triticale doivent considérablement augmenter pour que le triticale devienne un ingrédient majeur dans l'alimentation de la volaille. En 1991, la consommation d'aliments de la volaille en Tunisie dépassait les 400 000 tonnes. En supposant un taux d'incorporation moyen de triticale de l'ordre de 30%, 120 000 tonnes de triticale seraient nécessaires. Sur la base d'un rendement moyen de 2 tonnes par hectare, au moins 60 000 hectares de triticale devraient être emblavées afin de répondre à la demande. Bien que le triticale serait alors cultivé au détriment d'autres cultures céréalières (très probablement au détriment de l'orge), les superficies requises représentent moins de 10% du total des superficies céréalières, et moins de 40% des superficies en jachère de la zone nord. Afin de minimiser les risques de déplacement inutile de toute céréale produite dans cette zone, la production de triticale devrait être progressivement développée dans la zone centre où le taux de jachère est élevé et où le triticale offre un avantage comparatif.

Afin de répondre à la demande en aliment, l'augmentation de la superficie de triticale (de 20 000 à 60 000 hectares) ne pourrait se faire que progressivement. Ceci exigera la mise en place d'un programme soutenu de vulgarisation ciblant aussi bien les producteurs que les utilisateurs et un approvisionnement adéquat en semence (du moins en volume).

Cette étude sur l'utilisation du triticale comme ingrédient dans l'alimentation de la volaille a mis en lumière les conditions qui rendraient cette utilisation avantageuse dans d'autres pays également. Le triticale a le potentiel de r3duire le coût de la ration dans les pays qui peuvent en produire en quantité suffisante et où l'industrie de l'aliment est dépendante de l'importation de maïs et du tourteau de soja. De plus, l'utilisation du triticale offre l'avantage supplémentaire de diminuer les risques de rupture de stocks et/ou de pénuries dans l'approvisionnement en ingrédients importés.

Nutritive and Economic Value of Triticale as a Feed Grain for Poultry

Abderrezak Belaid

Introduction

Cereals (maize, wheat, sorghum, and barley) provide the bulk of the caloric requirements in ruminant and non-ruminant diets. However, although cereals are a relatively good source of energy, they need to be supplemented with protein from sources such as soybean meal, fish meal, maize gluten, and vitamin and mineral premixes to meet minimum nutritional requirements.

Lysine is the most limiting amino acid in conventional cereal-based diets. Because triticale has a relatively good protein and essential amino acid profile, it would appear to be a suitable substitute for most cereal grains used in feed diets. For example, Hill and Utley (1986) reported that the triticale cultivar Beagle 82 may substitute for half or all of the conventional grains in finishing steer diets without any significant detrimental effect on feed intake, overall digestibility, or performance. The positive results obtained in recent triticale feeding (forage, silage, and grain) trials with ruminants suggest that feed intake-depressing traits reported in older cultivars are no longer present in the newer cultivars. As a nutritionist, Hill (1991) sees no problem with utilizing the "excellent triticale grain" in livestock diets.[1]

With respect to triticale used for human consumption, poor milling performance was reported for older cultivars. However, as a result of improvements in grain plumpness and test weights, better triticale flour yields were achieved.[2] The potential of triticale for use in different food products, either directly (e.g., in unleavened products) or in combination with wheat flour (e.g., in bread) has been well documented. According to NRC (1989), triticale also has potential for use in the brewing and distilling industries, where it has performed as well as maize and rice, two grains extensively used by these industries as carbohydrate sources.[3]

Because triticale is a new crop, there is little experience with utilizing it either for food or as feed. Contradictory findings about its feed value, especially in trials with older cultivars, have been reported in the literature. Although large-scale utilization has yet to occur, it may be worthwhile to examine triticale's feed potential based on research

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1 Studies documenting the positive effect of triticale on livestock performance include: Felix, Hill, and Winchester (1985), Hill and Utley (1986, 1989), Benbelkacem (1987), Charmley and Greenhalgh (1987), Wright et al. (1989), Wright, Agyare, and Jessop (1991), Zobell, Goodewardene, and Engstrom (1990), and Yuanshu and Chongyi (1990).

2 As pointed out by Amaya and Peña (1991), although in the late 1970s less than 2% of CIMMYT International Triticale Screening Nursery lines had flour yields comparable to wheat, the number had risen to 35% by the late 1980s.

3 A study conducted in Gatton College (Queensland, Australia) has shown that a 7% reduction in egg cholesterol content is obtained when hens are fed a triticale-based diet instead of wheat-based rations (Phelps 1991).

results reported in the literature, as well as to analyze its economic value as a complete or partial substitute for conventional feed ingredients, especially in feed-deficit countries. Tunisia, which has a great potential for triticale production and whose feed industry is quite dependent on imports, appears to be a good case to study.

This paper focuses on the potential of triticale as a feed grain for poultry. Its objectives are two-fold:

1. To review evidence from various poultry feeding studies of the nutritional value of triticale as a feed ingredient.

2. To estimate the economic value of triticale as a major ingredient in poultry diets in Tunisia, as a substitute for maize, barley, sorghum, wheat, and soybean meal.

To provide a sense of the context of this study, the major triticale research achievements and recent developments in triticale production are described. This is followed by a review of the nutritional value of triticale with respect to parameters such as metabolizable energy, crude protein and amino acid content, and variability and antinutritional factors. Next, triticale feeding studies are reviewed, and the findings on the effect of triticale on the growth and performance of poultry are summarized. A linear programming model is used to analyze how the inclusion of triticale in poultry rations affects the composition and cost (at international prices) of broiler and layer diets. The model is then used to analyze the impact of triticale on the nutritional value and cost of poultry diets in Tunisia, using 1990 ingredient prices. The conclusion discusses the potential of triticale as a poultry feed ingredient, in light of the linear programming model results, and presents general recommendations.

Triticale Research and Development

Triticale (X. *Triticosecale* Wittmack) is a cross between the genera *Triticum* and *Secale*.[4] The cross was first made by Alexander Stephen Wilson in Scotland in 1876. In 1891 a German botanist, Wilhelm Rimpeau, obtained the first partially fertile triticale plant, but triticale plants yielding viable seed were not developed until 1938, when Arne Muntzing, a Swedish plant geneticist, applied a colchicine treatment to his wheat/rye hybrids.

The first triticale plants were hybrids obtained through crosses of bread wheat and rye, leading to "octoploid triticales." Crosses involving durum wheat and rye, on the other hand, produce "hexaploid triticales," which have superior breeding qualities compared to octoploids.

The first commercial triticales were "primitive," plagued with various agronomic and other deficiencies such as lack of wide adaptation, low grain yield, shriveled grain,

[4] The following paragraphs draw heavily from Skovmand, Fox, and Villreal (1984), NRC (1989), and Varughese, Barker, and Saari (1987).

poor seed weight, preharvest sprouting, low fertility, excessive height, late maturity, and low baking quality. Despite these disappointing results, triticale research continued. In 1967 a breakthrough in triticale research occurred when the "Armadillo" strain, possessing almost complete fertility, one dwarfing gene, and superior plant type, appeared spontaneously in CIMMYT plots at a national experiment station in northern Mexico (the Centro de Investigaciones Agrícolas del Noroeste, now the Campo Experimental del Valle del Yaqui). In the 1970s, CIMMYT launched an intensive research effort leading to the establishment of an international testing program which now spans more than 100 locations in 71 countries (Varughese, Barker, and Saari 1987). This testing program resulted in two major findings in the early 1980s:

- Triticale exhibited good yield potential when grown in certain stress environments.

- In stress environments "complete" triticales (which have all seven rye chromosomes) tended to yield more than "substitute" types (in which one wheat chromosome substitutes for a rye chromosome).

The performance of triticale under certain types of stress led CIMMYT triticale research to emphasize the development of improved triticales for rainfed stress environments, where the crop complements wheat (Varughese, Barker, and Saari 1987).

One of the most important unresolved problems in triticale breeding is abnormal endosperm formation. The shriveling of the triticale grain leads to low test weights that reduce milling and baking quality, and the shriveled grain is unattractive to farmers and consumers. However, over the last decade, triticale seed type has dramatically improved. Recent triticale lines exhibit test weights nearly as high as those of wheat.

Preharvest sprouting is another problem. Although the sprouting resistance of new triticale lines has improved greatly, the problem remains in some locations, e.g., the tropical highlands.

In general, triticale is agronomically similar to wheat and requires no special production technologies or management (Skovmand, Fox, and Villareal 1984). It is recognized that triticale has a relatively good competitive advantage over wheat under cool growth conditions, on sandy soils, and on acid soils (with or without high free aluminum levels). In the savanna region of Brazil, for example, the biomass of triticale is usually twice that of wheat (NRC 1989). Despite significant achievements in the development of bread wheat lines with aluminum tolerance, the level of tolerance exhibited by triticale has not been matched. For example, Varughese, Barker, and Saari (1987) reported that, in 1983 in Brazil, in a trial comparing 10 of CIMMYT's best triticale lines with CIMMYT's 10 most aluminum-tolerant bread wheat lines, the least productive triticale yielded better than the best bread wheat line. Triticale is also still relatively resistant to many common cereal foliar diseases.[5]

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[5] However, as the area of triticale expands, the crop's present resistance to small grain cereal diseases may eventually break down. Stem rust (*Puccinia graminis*), not originally a problem for triticale, recently caused serious damage to the crop in Australia (NRC 1989).

Triticale has growth characteristics which may render it particularly attractive as a forage and/or feed crop in certain agroclimatic conditions, such as dryland and tropical highland environments, and in certain socioeconomic situations, such as smallholder farming systems (Carney 1990). Because of its advantage under cool growth conditions, triticale may also provide greater flexibility in crop rotations in high elevations.

Worldwide, nearly two million hectares are now planted to triticale (Table 1). Poland, France, and the former USSR account for more than 60% of the world triticale area. In 1989, more than 700,000 ha, representing over one-third of the world triticale area, were devoted to the crop in Poland (Wolski 1991). Triticale adoption in developing countries, on the other hand, has been relatively slow. These countries account for only about 5% of the world triticale area. Brazil leads the group, sowing 30,000 ha. Owing to breeding achievements in resolving many of the crop's problems, and as utilization and markets expand, triticale area is expected to grow, particularly in wheat- and/or feed-deficit developing countries.

Table 1. World distribution of triticale, 1990

Developed countries[a]	Growth habit[b]	Area (ha)	Developing countries[a]	Growth habit[b]	Area (ha)
Australia	S	160,000	Argentina	S	10,000
Austria	W	1,000	Brazil	S	30,000
Belgium	W	5,000	Chile	S	5,000
Bulgaria	W	10,000	China	S+W	25,000
Canada	S+W	6,500	India	S	500
France	S+W	300,000	Mexico	S	8,000
Germany	W	30,000	Morocco	S	5,000
Hungary	W	5,000	Tanzania	S	400
Italy	S	15,000	Tunisia	S	14,000
Luxembourg	W	400	Total		97,900
Netherlands	W	1,000			
Poland	W	700,000			
Portugal	S	80,000			
South Africa	S+W	15,000			
Spain	S	30,000			
Sweden	W	1,000[c]			
Switzerland	W	5,000			
UK	W	16,000			
USA	S+W	60,000			
Former USSR	W	250,000			
Total		1,739,900			
Grand total					**1,839,800**

Source: Varughese, Barker, and Saari (1987), Carney (1990), and Belaid (1991a, 1991b).

a Greece, Kenya, Madagascar, New Zealand, and Pakistan also grow triticale on small areas.

b S = spring habit; W = winter habit.

c 1992 area (Pettersson, pers. comm., 1992).

Nutritional Value of Triticale

Older triticale lines were characterized by a relatively high protein profile; for example, Villegas, McDonald, and Guilles (1968) reported protein levels ranging between 11.8 and 22.5. As pointed out by Skovmand, Fox, and Villareal (1984), triticale lines with such high levels of protein were characterized by poor grain type (shriveled grain). Pettersson (pers. comm.) indicated that these older triticales were also characterized by a high content of dietary fiber. As the grain plumpness of newer lines has improved, protein content has fallen and is now equal to or slightly higher than that of bread wheat; for example, Pfeiffer (1991) has evaluated the protein content of 952 complete caryotype triticales from advanced lines and has found that more than 86% have a protein content ranging between 12 and 14%. However, on a unit area basis, the reduction of protein content may have been more than offset by much higher yields in the new lines.[6]

Compared with other cereals, triticale has a better balance of essential amino acids, particularly lysine, the first limiting essential amino acid in most cereal grains. Threonine, another essential amino acid, is also found in relatively high levels in triticale compared to maize, wheat, and sorghum.

The first triticale varieties were reported to have some antinutritional factors such as trypsin and chymotrypsin inhibitors, which may interfere with the performance of animals fed triticale-based diets. Knoblauch (1985) screened over 625 triticale lines along with 150 rye and 80 wheat lines for trypsin inhibitor levels. The trypsin units inhibited (TUI) levels in triticale ranged from the mean of the wheat lines (low TUI, i.e., 18 TUI) to the mean of the rye lines (high TUI, i.e., 80 TUI). Knoblauch also observed a significant variation of TUI levels by season and location (season was more important). In general, however, newer triticale cultivars such as Beagle 82 (Hale, Morey, and Myer 1985) and B858 (Coffey and Gerrits 1988) were found to have low trypsin inhibitor activity. Myer and Barnett (1985) reported similar trypsin inhibitor values in triticale and maize. Therefore, it seems that the trypsin inhibitor activity of recent triticale cultivars is less likely to limit the incorporation of triticale in animal feed.

Variation in the nutritional profile of triticale cultivars has been reported in the literature. For example, Coffey and Gerrits (1988) indicated that crude protein, lysine, threonine, crude fiber, and metabolizable energy content varies considerably among triticale cultivars (some reported ranges are shown in Table 2). This weather-related and/or environmentally induced variation in nutritional value may explain the contradictory results obtained in triticale feeding studies.[7] Also, as indicated by

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6 Although some of the first triticale lines that had a high protein content produced, on average, around 400 kg/ha of protein, newer lines, having a lower protein content but yielding more grain, produce up to 1 t/ha of protein (NRC 1989).

7 It is worth pointing out that variation in protein, metabolizable energy, and amino acid content is also reported for wheat and barley varieties. See, for example, Boldaji et al. (1986) and Johnson and Eason (1987); for a study of the same wheat variety over time, see Rundgren (1988). This lack of uniformity in the nutrient content of wheat and barley varieties does not seem to constitute a major limitation to their use in feed rations.

Pettersson (pers. comm.), since dietary fibers may have a considerable metabolic influence, differences in metabolizable energy content may be attributed to differences in dietary fiber content and composition, particularly from the older shriveled lines and those closely resembling the rye parents. However, as pointed out by McGinnis, Reddy, and Peterson (1985), variation in the amino acid values of triticale might be influenced more by the laboratory and/or the analytical procedure followed than by genetic differences among cultivars.[8]

Boldaji et al. (1986) conducted two experiments with 28-week old single comb white leghorn roosters to measure apparent metabolizable energy (AME), true metabolizable energy (TME), and N-corrected metabolizable energy (TMEn) values of maize, triticale, wheat, and barley cultivars. They found no significant differences among triticale varieties or wheat varieties for the three energetic expressions. However, significant differences were found among the barley varieties; the cultivar Hesk had significantly lower AME and TMEn values than the two other barleys (Table 3).[9] In another

Table 2. Reported ranges of crude protein, lysine, threonine, crude fiber, and metabolizable energy encountered in triticale cultivars

Source and number of cultivars evaluated	Crude protein (%)	Lysine (%)	Threonine (%)	Crude fiber (%)	Metabolizable energy (kcal/kg)
Erickson et al. 1979 (4)	11.70-12.93	0.37-0.53	0.32-0.36	..	..
Bushuk and Lartner 1980 (12)	12.80-18.50	0.50-0.71	..	..	..
Farrell, Chan, and McCrae 1980 (8)	08.30-16.10	0.33-0.53	0.30-0.59	..	..
Zombade, Chawla, and Ichhponani 1983 (3)	12.10-14.40	..	..	2.67-2.85	2,985-3,246
McGinnis, Reddy, and Peterson 1985 (22)	11.78-18.70	..	..	..	..
Owsley, Haydon, Lee 1987 (7)	13.75-18.54	0.45-0.52	..	3.16-4.11	3,210-3,241
Ruiz et al. 1987 (2)	11.50-11.90	..	..	2.10-2.40	..
Johnson and Eason 1988 (9)	11.34-14.08	0.39-0.44	0.39-0.47	..	3,148-3,406
Myer, Comb, and Barnett 1991 (3)	11.80-13.40	0.41-0.45	..	2.50-2.80	..
NRC (Poultry) 1984	15.80	0.52	0.57	4.0	3,163
This study 1992	12.00	0.50	0.57	3.0	3,142

[8] McGinnis, Reddy, and Peterson (1985) reported striking differences in the amino acid content of the same triticale sample (grown at Washington State University) analyzed by two laboratories. For example, the arginine value (percentage of total protein) of the triticale sample was given as 1.10 by one laboratory and 5.73 by the other laboratory. Similarly, valine values were reported at 7.80 and 4.43; leucine, at 3.26 and 6.49. McGinnis et al. also found that crude protein concentration was influenced by the method of analysis (Kjeldahl vs. Technicon NIR instrument).

[9] The issue of which energy expression to use for formulating poultry diets remains controversial (Boldaji et al. 1986).

experiment (1-21 day-old broiler chickens) involving one maize, nine triticale, and two wheat cultivars, Johnson and Eason (1988) found no significant differences in AME or metabolizability (ratio of AME to gross energy) among triticale cultivars or between triticale and the best wheat cultivar.[10] However, the AME and metabolizability of maize was significantly higher (P<0.05) than triticale and wheat. Johnson and Eason found no evidence of low metabolizability (resulting from reduced starch digestion) in triticale.

Triticale in Poultry Nutrition

Poultry (and monogastrics in general) digest protein in the stomach and absorb amino acids and short peptides in the small intestines (Hill 1991). Depending upon their growth stage, chickens may have relatively high nutrient requirements. For leghorn chickens, for example, protein requirements range from 12% (for 14-20 week-old

Table 3. Apparent metabolizable energy (AME), true metabolizable energy (TME), and N-corrected true metabolizable energy (TMEn) of maize and different varieties of triticale, wheat, and barley (kcal/kg)

Cereal grain and cultivar	AME[a]	TME[a]	TMEn[a]
Experiment 1[b]			
Maize, yellow[c]	3,350	4,000	3,020
Triticale			
Sel-Triticale-B-79-2954	2,960[a]	3,560[a]	2,920[a]
Triticale-84-76884	2,930[a]	3,490[a]	2,830[a]
Triticale Flora	2,990[a]	3,650[a]	3,070[a]
Wheat			
8313-Wheat	2,980[a]	3,550[a]	2,970[a]
Hill-81-Wheat	3,070[a]	3,670[a]	3,040[a]
8113-Wheat	2,980[a]	3,540[a]	2,810[a]
Experiment 2[d]			
Barley			
Hesk	2,380[b]	3,220[a]	2,170[b]
Spring Malt Kg/M22/Karl	2,810[a]	3,370[a]	2,700[a]
Scio	2,840[a]	3,440[a]	2,880[a]
Maize (yellow)[c]	3,470	4,050	3,690

Source: Adapted from Boldaji et al. (1986).

a Average of four replicates.

b Experiment 1: means within a grain class within a column with the same superscript are not significantly different (P>0.01).

c Yellow maize AME, TME, and TMEn presented as reference values.

d Experiment 2: means within a column with different superscripts are highly significantly different (P<0.01).

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10 The second wheat cultivar had a significantly lower AME (P<0.05) and metabolizability than triticale, the other wheat cultivar, and maize.

leghorns) to 23% (for 0-3 week-old leghorns) (NRC 1984). Furthermore, for optimum growth, monogastrics require specific amino acids such as lysine, methionine, and threonine, instead of just proteins (Erickson 1984). Triticale is a potentially valuable source of protein and amino acids compared to maize and other cereals; its relatively high content of lysine enhances its potential as an ingredient in diets for monogastrics (Hill 1991).

After reviewing a large number of feeding studies, Erickson (1984) concluded that "triticale can replace at least 50% if not 100% of all cereal grains if it is gradually introduced in feed, replacing an equal weight of maize or wheat for both non-ruminants and ruminants." However, conflicting results on performance and feed efficiency have been reported in triticale feeding studies. This part of the paper summarizes results from poultry feeding studies.

Since the early 1970s, there has been an extensive body of research on the use of triticale in *broiler diets* (Bragg and Sharby 1970; Fernandez and McGinnis 1974; Wilson and McNab 1975; Yaqoob and Netke 1975; Rao et al. 1976; Reddy et al. 1979; Shimada and Avila 1981; Charles 1985; McGinnis, Reddy, and Peterson 1985; Ruiz et al. 1987; Pettersson and Aman 1988, 1991; Rundgren 1988; Johnson and Eason 1988, Maurice et al. 1989) and *laying hen diets* (Fernandez et al. 1973; Yaqoob and Netke 1975; Kim et al. 1976; Shingari et al. 1976; Zombade, Chawla, and Ichhponani 1983; Nagra, Pannu, and Chawla 1987; Leeson and Summers 1987).

For example, Zombade, Chawla, and Ichhponani (1983) studied the effect of substituting, on a weight-for-weight basis, triticale for maize in diets fed to starter, grower, and egg-producing white leghorns. Three triticale cultivars were used in the trial (TL 238, TL 257, and TL 319). Their metabolizable energy levels ranged between 12.49 and 13.58 MJ/kg of dry matter. Zombade et al. reported that during the starter phase substituting triticale for maize in the conventional (high cereal) diet enhanced the birds' growth response and significantly improved their feed conversion. Furthermore, they found that, during the production phase, egg mass, feed conversion, and energetic efficiency were greatly improved by triticale. Based on the results of this feeding trial, Zombade et al. concluded that triticale can indeed substitute for maize in conventional diets for laying hens during growth and production phases. McGinnis, Reddy, and Peterson (1985) indicated that, based on biological and feeding studies they conducted at Washington State University, triticale can constitute a high percentage of the total diet and serve as the only cereal grain in diets for either laying hens or chicks.

Al-Athari and Guenter (1988), in a study of broiler chicks from 2 to 29 days of age, increased the proportion (from 0 to 100%, in 25% increments) of triticale in the diet at the expense of wheat. They measured the effect on growth, feed consumption, and feed-to-weight gain ratio and found that increasing triticale levels in the ration resulted in significantly ($P<0.05$) improved chick weight gain compared to the control wheat ration. Chick performance was also better on the triticale-based diet when the ingredients (triticale and wheat) were formulated into isonitrogenous and isoenergetic diets. Furthermore, Al-Athari and Guenter found that weight gain and feed intake were not affected when triticale rations were supplemented with L-lysine and/or DL-methionine. They concluded that triticale can be used as the sole grain in chicken starter and finisher rations, provided that these rations are formulated based on the nutrient content of the triticale cultivars used.

Pettersson and Aman (1991) found no difference in the performance of broiler chickens in a feeding experiment that substituted various levels of wheat (5, 10, and 20%) and triticale (2, 10, 20, and 40%) for maize. No difference in digestibility was reported between the maize, wheat, and triticale diets. In an earlier study, Shimada, Cline, and Rogler (1974) found that chick growth (average daily gain) was superior on triticale-based diets than on maize-based diets when the comparison was made on an equal weight basis. Shimada et al. also found that chick performance was similar when both ingredients were supplemented with soybean meal to provide adequate amounts of dietary protein, but the amount of soybean meal needed to balance the diet was much smaller in the triticale-based diets.

Maurice et al. (1989) conducted a study to determine the potential of Florida 201, a new triticale cultivar, as a feed ingredient for broiler chickens. Crude protein and lysine contents were 33% and 37.5% higher, respectively, whereas metabolizable energy was 8% lower than that of maize. Maurice et al. found no difference in growth parameters (body weight gain, feed consumption, and feed-to-weight gain ratio) of chickens at 3, 6, or 7 weeks of age between triticale- and maize-based diets. They also found a trend towards improved feed efficiency with triticale-based diets and evidence of a linear decline in early chick mortality as the amount of triticale in the diet increased.[11] They concluded that Florida 201 can partially (40%) or even completely (provided the diet is formulated according to the nutrient content of the triticale cultivar used) replace maize in broiler diets with no detrimental effect on growth and feed efficiency.

It is worth pointing out, however, that protein and amino acid levels of triticale reported by NRC (1984) are considerably higher than those determined by most authors, especially for new cultivars. For example, the determined values of cultivar Florida 201 used in the study by Maurice et al. (1989) were 74% of the NRC (1984) values for protein, 63% of the values for lysine, and 61% of the values for threonine.

In contrast to the results just described, some authors have reported detrimental effects of triticale-based diets on the performance of broilers and/or layers. For example, in one of the earliest studies of triticale as a potential feed ingredient, Sell, Hodgson, and Shebeski (1962) found triticale to be inferior to wheat as a feed ingredient for chicks.[12] Wilson and McNab (1975) found that substituting triticale for maize (at a 50% level) resulted in lower live weights for broiler chickens (measured at 28 days of age). Ruiz et

11 They pointed out that neither aflatoxin nor pesticide residue was detected in the maize used in their experiments.

12 It must be pointed out, however, that the chemical composition of early triticale cultivars hardly compares with that of recent ones, as indicated in the earlier discussion of differences in trypsin inhibitor activity in recent and older cultivars.

al. (1987) reported that the growth response of broiler chicks from 1 to 21 days of age was inconsistent with triticale-based diets (cultivar Beagle 82). However, Ruiz et al. pointed out that triticale-based diets resulted in better feed efficiency compared to maize-based diets. Leeson and Summers (1987) reported that the body weight of growing leghorn pullets was not affected by diets containing up to 70% triticale (in place of maize). However, feeding similar diets to layers resulted in reduced egg production and higher feed intake. Proudfoot and Hulan (1988) found a fairly consistent linear growth depression with triticale-based diets fed to broilers during the first three weeks of age. Increasing the levels of triticale in the finisher diets resulted in similar, although not consistent, negative effects on growth. Proudfoot and Hulan concluded that the evidence from their study suggests that growth inhibition associated with triticale limits its use to no more than 15% in broiler diets.

As indicated by some authors, e.g., Maurice et al. (1989), the conflicting findings related to triticale's influence on poultry growth and feed efficiency may result from variation in the nutrient content of the triticale cultivars used in the feeding studies (see footnote 7) and the failure of most researchers to adjust the formulation of diets based on the nutrient content of these cultivars. Tabulated values of triticale, such as the NRC tables, may be of limited use in feeding studies and hence may lead to misleading results.

Clearly, there is a lack of large-scale experience with triticale-based poultry diets.[13] But despite the contradictory results, there appears to be sufficient evidence that triticale, especially recent cultivars, is worth considering as an alternative feed grain in poultry diets. Based on the evidence reviewed, the inclusion of triticale in poultry diets is expected to depend upon two major factors:

- *The availability of alternative ingredients which are competitive with respect to quality.* In other words, if the feed industry has easy access to a wide choice of good quality ingredients, then the inclusion of triticale in the diet may indeed be minimal. However, if the feed industry is faced with a limited choice of ingredients, then triticale, provided a sufficient supply is available, will certainly be worth considering for poultry feed production.

- *The economic incentives resulting from including triticale in the diet.* Given the nutritional profile of triticale, its utilization will undoubtedly be enhanced if it significantly reduces the cost of feed.

The next part of this paper addresses this economic issue, which is expected to be the major factor that will ultimately influence the large-scale utilization of triticale.

[13] For major (and conventional) feed ingredients such as maize and soybean meal, extensive and fairly reliable nutritional evaluations have been conducted over the years, but the information for triticale is much more limited and appears to be less reliable (Waldroup 1990). Hence, further research may be needed to improve the consistency of the triticale nutrient profile.

Economics of Triticale in Poultry Feed

Two major assumptions underlie the following analysis:

- Triticale has a higher protein and amino acid content but a lower energy content than maize.
- Neither feed intake nor feed conversion is affected by the ingredients composing the diet, as long as the diet meets all suggested minimum nutrient requirements (Table 4).

The effect of triticale inclusion on the cost of the diet will most likely be an important determinant of the future of triticale as a major ingredient in poultry feed rations. A linear programming model is used to formulate optimal minimum-cost feed rations, with and without triticale, for broiler and layer chickens at different growth stages.[14] The rations consist of a combination of ingredients that meets all minimum nutrient requirements (metabolizable energy, protein, amino acids, etc.) specified in the constraint set, at the lowest cost.

The nutrient content of each ingredient included in the model is shown in Table 5. As indicated by Allen (1990), ingredient analysis tables are, in general, based on mean values compiled from various published sources, which implies that ingredient samples among and/or within countries may depart from the values shown on such tables. Therefore, values presented in Table 6 should be considered as reference values only.

Table 4. Average composition of ingredients used in the linear programming model (all **ingredients expressed as percentage of diet except for metabolizable energy, which is expressed in kcal/kg of diet)**

	Mze	Soym	Trit	Barl	Mzgl	Fish	Sorg	Ccal	CaPh	Soil	Wht	Lysn	Meth
ME	3,310	2,250	3,142	2,646	3,730	2,855	3,220	0.0	0.0	8,800	3,200	0.0	0.0
CP	8.2	44.0	12.0	11.5	60.0	60.0	9.0	0.0	0.0	0.0	10.0	0.0	0.0
CF	2.5	6.5	3.0	6.5	2.5	1.0	2.70	0.0	0.0	0.0	2.20	0.0	0.0
Meth	0.18	0.65	0.20	0.17	1.78	1.36	0.16	0.0	0.0	0.0	0.15	0.0	0.98
Lysn	0.24	2.80	0.50	0.39	1.15	4.10	0.22	0.0	0.0	0.0	0.30	0.78	0.0
Trip	0.07	0.63	0.15	0.14	0.40	0.62	0.08	0.0	0.0	0.0	0.12	0.0	0.0
Thre	0.30	1.90	0.57	0.38	2.00	2.30	0.31	0.0	0.0	0.0	0.32	0.0	0.0
Calc	0.01	0.40	0.05	0.03	0.02	7.0	0.02	38.0	20.0	0.0	0.05	0.0	0.0
AvPh	0.08	0.14	0.14	0.16	0.20	3.40	0.09	0.0	18.5	0.0	0.14	0.0	0.0

Source: Hubbell (1991).

Note: Mze = maize; Soym = soybean meal; Trit = triticale; Barl = barley; Mzgl = maize gluten; Fish = fish meal; Sorg = sorghum; Ccal = calcium carbonate; CaPh = calcium phosphate; Soil = soybean oil; Wht = wheat; ME = metabolizable energy; CP = crude protein; CF = crude fiber; Lysn = lysine; Meth = methionine; Trip = tryptophan; Calc = calcium; AvPh = available phosphorus.

[14] The model is run using the General Algebraic Modeling System (GAMS) software for personal computers (Brooke, Kendrick, and Meeraus 1988). The author has greatly benefited from a GAMS program developed by López-Pereira (1992).

Table 5. Essential nutrient recommendations for broiler and layer diets (all ingredients expressed as percentage of diet except for metabolizable energy, which is expressed in kcal/kg of diet)

	Broilers (age in weeks)			Layers (age in weeks)			
	0-3	3-6	6-8	0-6	6-14	14-20	>20
Met. energy	3,200	3,200	3,200	2,900	2,900	2,900	2,900
Prot.	23.0	20.0	18.0	18.0	15.0	12.0	14.5
Meti.	0.50	0.38	0.32	0.30	0.25	0.20	0.32
Lysi.	1.20	1.00	0.85	0.85	0.60	0.45	0.64
Tryp.	0.23	0.18	0.17	0.17	0.14	0.11	0.14
Thre.	0.80	0.74	0.68	0.68	0.57	0.37	0.45
Calc.	1.00	0.90	0.80	0.80	0.70	0.60	3.40
AvPh	0.45	0.40	0.35	0.40	0.35	0.30	0.32

Source: NRC (1984).
Note: Met. energy = metabolizable energy; Prot. = crude protein; Meti. = methionine; Lysi. = lysine; Tryp = tryptophan; Thre = threonine; Calc = calcium; and AvPh = available phosphorus.

Table 6. International prices of ingredients used in the linear programming model

Ingredient	International price (US$/t)	Ingredient	International price (US$/t)
Maize	119.5	Soybean meal	197.3
Sorghum	116.6	Barley	92.0
Maize gluten	260.7	Wheat	128.1
Fish meal	471.8	Soybean oil	450.3
Calcium carbonate	70.0	Calcium phosphate	228.0
Lysine	3,037.0	Methionine	3,712.0

Source: Maize, sorghum, soybean meal, soybean oil, and fish meal prices taken from World Bank commodity price data (annual averages, Jan.-July 1991), August 1991; barley from International Wheat Council (PMR 194, August 1, 1991); Maize gluten from USDA ERS, *Feed: Situation and Outlook Report* (August 1991); and calcium, phosphorus, lysine, and methionine prices from *Chemical Marketing Reporter* (August 26, 1990).

Note: Soybean meal: US, 44% extraction, CIF Rotterdam; soybean oil: Dutch, crude, FOB ex-Mill; fish meal: any origin, 64-65%, CIF Hamburg; sorghum: US No. 2 Milo Yellow, FOB Gulf ports; maize: US No. 2 Yellow, FOB Gulf ports; wheat: US No. 2 Soft Red Winter, export price, delivered at Gulf ports for prompt or 30-day shipment; barley: US No. 2, CIF Rotterdam (import quotation, July 1991); calcium carbonate: Medium (4 to 9 microns) FOB works; calcium phosphate dibasic: Feed Grade 18.5%, bulk FOB works; l-Lysine monohydrochloride: Feed Grade; methionine: Feed Grade, 99% minimum; salt: bulk; maize gluten: 60% protein, Illinois points. An amount of US$ 13.25/t is added to FOB prices for ocean freight from US Gulf ports to Rotterdam for maize, sorghum, wheat, and soybean oil. An amount of US$ 23/t is added to FOB prices for ocean freight from origin to Rotterdam for calcium carbonate, calcium phosphate, lysine, methionine, salt, and maize gluten. In addition to these ingredients, vitamin and mineral complements and salt were also included in the model. These are referred to as constants in the tables that follow. Prices for vitamins were set at US$ 3,470/t; minerals were US$ 430/t, and salt was US$ 60/t.

Synthetic lysine and methionine are also included in the model, since they usually constitute the limiting amino acids when cereals are the only or major sources of protein in the diet. The linear programming model uses international prices of ingredients. These prices and their sources are listed in Table 6. Since no international price is available for triticale, a base model is run in which the triticale price is equated to the maize price. Sensitivity analysis is then done to determine the price range over which triticale will remain a competitive ingredient.[15] The linear programming model presented here can be adjusted easily to reflect specific situations (e.g., in individual countries) by manipulating the price vector and/or the number and type of ingredients used.[16]

This part of the paper is divided into three sections. The first section presents the structure of the model and the constraint set with the relevant coefficients used. The next section presents and discusses the model results for poultry when international prices are used. The final section briefly describes the production and utilization of triticale in Tunisia and explores its economic potential as a poultry feed ingredient there.

Structure of the Linear Programming Model

In this model, optimality is expressed in terms of minimizing the cost of producing 1,000 kg (1 t) of feed subject to a set of linear constraints representing the minimum nutrient requirements of poultry. The model is formulated as follows:

Minimize: $$C = \sum_{i=1}^{n} P_i X_i \qquad (1)$$

Subject to: $$\sum_{j=1}^{m} N_{ij} X_i >= B_j \qquad (2)$$

$$\sum_{i=1}^{n} X_i = 1{,}000 \qquad (3)$$

$$\Sigma_i >= 0 \qquad (4)$$

i = 1,2,...,n ingredients
j = 1,2,...,m nutrients

Where:

- C = the total cost ($) of producing 1,000 kg of feed rations for a given stage of growth;
- P_i = the price ($/kg) of ingredient i in the ration;

[15] This choice of maize price is justified on the grounds that triticale will most likely substitute for maize. Since conventional maize-based diets represent the bulk of poultry rations, and given the nutrient profiles of both ingredients, most of the substitution will occur between triticale and maize.

[16] For example, ingredients such as cotton meal, sunflower meal, bone meal, molasses, etc., not considered here, are widely used in some countries, such as Morocco.

X_i = the amount (kg) of ingredient i in the ration;
N_{ij} = the amount (in percent, except for energy, expressed in kcal/kg of feed) of nutrient j in ingredient i; and
B_j = the minimum amount (%) of nutrient j required in the ration.[17]

Equation 1 is a linear objective function. Equation 2 represents a set of linear constraints of nutrient requirements. Equation 3 forces the sum of the ingredients in the solution to equal 1,000 kg. Equation 4 is a non-negativity constraint.

Three growth stages are considered for broilers: day-old to 3 weeks (starter); 3-6 weeks (grower); and 6-8 weeks (finisher). Four growth stages are considered for layers: day-old to 6 weeks (starter); 6-14 weeks (grower-1); 14-20 weeks (grower-2); and more than 20 weeks (layer).

The ingredients included in the model are: maize, soybean meal, maize gluten, fish meal, grain sorghum, triticale, barley, wheat, soybean oil, calcium carbonate, dicalcium phosphate, synthetic lysine, synthetic methionine, vitamins, minerals, and salt.

Minimum requirements are set for the following essential nutrients: metabolizable energy, protein, methionine, lysine, threonine, tryptophan, calcium, and available phosphorus.

Limits are imposed on salt, vitamins, and minerals so that their proportion in the ration will be exactly 0.4%, 0.5%, and 0.1%, respectively. The proportion of maize gluten and fish meal in the diet is limited to a maximum of 5% each.[18] The amount of crude fiber in the diet is also limited to no more than 5%.

The model is run without triticale to formulate conventional maize/soybean-based diets. The output gives the price ($/t) of the minimum-cost diet at a given growth stage, its nutritional content, and the proportions of ingredients. Next, the model is run with triticale as a potential ingredient of the diet. In addition to providing the cost of the diet and the nutritional content and optimal proportion of each ingredient in the diet, the model also computes the cost difference between "conventional" and "triticale" diets at each growth stage.

Model Results Using International Prices

The model is first run using the international prices listed in Table 6, with the triticale-to-maize price ratio equal to 1. The composition of the ration at different growth stages, the cost of the rations with and without triticale, and the cost difference are shown for broilers in Table 7 and layers in Table 8.

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17 For the fiber constraint, B_j represents the maximum amount allowed in the ration.

18 These proportions were suggested by poultry feed manufacturers contacted by the author.

As indicated earlier, triticale has a better amino acid and crude protein profile than most cereal grains, although maize has a clear energy advantage over triticale.[19] Depending on the energy-protein tradeoff, triticale is expected to substitute partially or completely for cereal grains in poultry diets, and also partially for soybean meal, especially in "low protein" diets such as those for layers. Given the prices (Table 6) and the nutritive value of the ingredients (Table 5) used in the model, sorghum, fish meal, and wheat do not enter the diets for broilers or layers at any growth stage. Barley represents a large proportion of feed for layers from 1 day to 20 weeks of age, i.e., the first three growth stages.[20]

Table 7. Composition, calculated analyses, cost, and cost differences of rations for broilers at different growth stages when the triticale-to-maize price ratio = 1

	Starter		Grower		Finisher	
Ingredient	Without triticale	With triticale	Without triticale	With triticale	Without triticale	With triticale
Composition						
Maize (%)	46.74	..	57.97	..	64.64	..
Soybean meal (%)	36.74	31.35	27.83	21.17	22.80	15.54
Triticale (%)	..	51.71	..	64.06	..	71.88
Maize gluten (%)	5.00	5.00	5.00	5.00	4.93	4.22
Soybean oil (%)	7.27	7.77	5.32	5.96	4.13	4.93
Ccal (%)	1.23	1.31	1.19	1.29	1.12	1.22
CaPh (%)	1.90	1.75	1.65	1.46	1.40	1.18
Lysine (%)	0.002	0.008	0.030	0.040	..	0.009
Methionine (%)	0.120	0.110	0.006	0.030	..	..
Constants (%)[a]	1.00	1.00	1.00	1.00	1.00	1.00
Calculated analyses						
Met. energy (kcal/kg)	3,200	3,200	3,200	3,200	3,200	3,200
Protein (%)	23.00	23.00	20.00	20.00	18.30	18.00
Methionine (%)	0.525	0.501	0.380	0.380	0.352	0.320
Lysine (%)	1.200	1.200	1.000	1.000	0.850	0.850
Tryptophan (%)	0.284	0.295	0.236	0.249	0.209	0.223
Threonine (%)	0.865	0.928	0.747	0.825	0.680	0.758
Calcium (%)	1.000	1.000	0.900	0.900	0.800	0.800
Phosphorus (%)[b]	0.450	0.450	0.400	0.400	0.350	0.350
Crude fiber (%)	3.680	3.710	3.380	3.420	3.220	3.270
Cost (US$/t)	**201.68**	**198.79**	**184.96**	**182.56**	**175.64**	**171.64**
Cost difference (US$/t)	**2.90**		**2.40**		**4.00**	
Cost difference (%)	**1.44**		**1.30**		**2.30**	

Source: Modeling results.
Note: Due to rounding, composition of ration may not add to 100.
a Constant ingredients include: salt (0.4%); vitamin premix (0.5%); and trace mineral mix (0.1%).
b Available phosphorus.

19 Sorghum and wheat also have a slight energy advantage over triticale.

20 The "conventional" diets, i.e., diets that do not contain triticale, are quite similar to reference diets used in the literature (for example, see Maurice et al. 1989). Neither barley nor bran (in the case of Tunisia below) is considered in broiler diets, following suggestions from various feed producers.

The results also show that triticale completely replaces maize and reduces the proportion of soybean meal in both broiler and layer rations, while satisfying the minimum nutrient requirements of chicks. When triticale is included in starter broiler diets, the proportion of soybean meal remains relatively large (about 31%), but substantial reductions in the proportion of soybean meal occur at the grower and finisher stages when triticale is included. For broilers, for example, the proportion of soybean meal in the diet is reduced by 15% for starters, 24% for growers, and 32% for finishers. Maize gluten is utilized at its upper limit, i.e., 5%, in starter and grower broiler rations. Because broilers have high metabolizable energy requirements (3,200 kcal/kg), a relatively substantial quantity of soybean oil is used to balance the diet. The proportion of synthetic methionine and synthetic lysine is negligible. Threonine and tryptophan content is higher in triticale-based diets. At this triticale-to-

Table 8. Composition, calculated analyses, cost, and cost difference of rations for layer at different growth stages when the triticale-to-maize price ratio = 1

	Starter		Grower-1		Grower-2		Layer	
Ingredient	Without triticale	With triticale	Without triticale	With triticale	Without triticale	With triticale	Without triticale	With triticale
Composition								
Maize (%)	58.53	..	50.50	..	51.16	..	70.60	..
Soybean meal (%)	21.93	15.90	12.30	5.68	5.71	0.21	13.00	4.87
Triticale (%)	..	63.90	..	54.50	..	54.56	..	77.88
Barley (%)	11.55	12.60	29.00	32.00	38.80	40.40	..	..
Maize gluten (%)	4.38	3.15	5.00	3.80	1.40	1.20	5.00	5.00
Soybean oil (%)	..	0.96	..	0.81	..	0.77	0.97	1.75
Ccal (%)	1.00	1.09	1.00	1.10	0.94	1.03	8.12	8.24
CaPh (%)	1.60	1.42	1.28	1.12	1.01	0.85	1.27	1.05
Lysine (%)	..	..	..	..	..	..	0.06	0.07
Methionine (%)	..	..	..	..	..	..	0.02	0.04
Constants (%)	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Calculated analyses								
Met. energy (kcal/kg)	2,900	2,900	2,900	2,900	2,900	2,900	2,900	2,900
Protein (%)	18.41	18.00	15.90	15.00	12.00	12.00	14.50	14.50
Methionine (%)	0.346	0.309	0.309	0.268	0.220	0.200	0.320	0.320
Lysine (%)	0.850	0.850	0.635	0.600	0.450	0.450	0.640	0.640
Tryptophan (%)	0.213	0.226	0.173	0.178	0.132	0.144	0.151	0.168
Threonine (%)	0.680	0.745	0.570	0.605	0.426	0.492	0.532	0.687
Calcium (%)	0.80	0.80	0.70	0.70	0.60	0.60	3.40	3.40
Phosphorus (%)[a]	0.40	0.40	0.35	0.35	0.30	0.30	0.32	0.32
Crude fiber (%)	3.75	3.85	4.07	4.18	4.20	4.30	2.73	2.78
Cost (US$/t)	**157.64**	**153.84**	**145.84**	**140.67**	**132.68**	**130.02**	**156.71**	**153.71**
Cost difference (US$/t)	**3.80**		**5.16**		**2.67**		**2.92**	
Cost difference (%)	**2.41**		**3.54**		**2.01**		**1.87**	

Source: Modeling results.
Note: Due to rounding, composition of ration may not add to 100.
a Available phosphorus.

maize price ratio, however, including triticale in broiler rations leads to relatively modest cost savings, averaging only US$ 3/t of feed. Whether this small savings is a sufficient incentive to include triticale in broiler diets depends upon the relative availability of maize and triticale. If the supply of triticale is less reliable than the supply of maize, then the proportion of triticale in the diet will likely be minimal, despite the lower cost of the triticale-based diet.

In layer diets, triticale also replaces maize and reduces the proportion of soybean meal in the ration. Due to the relatively low protein and metabolizable energy requirements of layer diets, the utilization of high-cost protein supplements (i.e., maize gluten) and high-cost energy ingredients (i.e., soybean oil) is negligible. Layer diets contain a fairly significant proportion of barley before the laying stage, particularly during the two grower stages. In fact, triticale and barley represent nearly 95% of the diet for layers from 14 to 20 weeks of age, with virtually no supplementation of soybean meal, lysine, and methionine, and a crude fiber content of 4.3% (Table 8).[21] The average cost reduction resulting when triticale is included in the diet amounts to US$ 3.60/t, slightly higher than the savings obtained for broiler diets (US$ 3/t). Based on these results, it appears that triticale diets have a modest economic advantage over conventional (maize-soybean meal) diets for broilers and layers when the price of triticale is the same as the maize price.

Tables 9 and 10 depict the effects of different triticale protein and lysine values on composition and cost of the diet, and the maximum price premium allowed for triticale to remain in the diet or the price decrease needed for triticale to enter the diet.[22] Table 9

Table 9. Effect of different protein and lysine values of triticale on composition and cost of starter broiler diets when the triticale-to-maize price ratio = 1

Protein (%)	Lysine (%)	Diet composition (%)			Cost of diet (US$/t)	Allowable increase (%)[a]	Necessary decrease (%)[a]
		Triticale	Maize	Soybeans			
	0.30	0.00	46.74	36.74	201.68	..	3.30
11	0.40	42.13	7.21	33.58	201.06	1.00	..
	0.50	49.85	0.00	33.00	200.35	2.00	..
	0.30	0.00	46.74	36.74	201.68	..	2.80
12	0.40	51.55	0.00	31.39	200.88	1.30	..
	0.50	51.71	0.00	31.35	198.79	4.20	..
	0.30	0.00	46.74	36:74	201.68	..	2.00
14	0.40	55.43	0.00	27.82	200.74	1.40	..
	0.50	55.61	0.00	27.76	198.48	4.60	..

Source: Modeling results.
a Percentage relative to maize price.

21 The merits of this type of diet need to be investigated. Large-scale experience with triticale/barley-based diets is lacking.

22 For a given protein and lysine content, an allowable price increase is defined as the maximum price premium (%) that triticale can have over maize but still remain in the diet. The necessary price decrease, on the other hand, is the minimum price discount (%) that triticale should receive to enter the diet.

presents results for starter broilers (day-old to 3 weeks of age) and Table 10 presents results for laying hens (layers more than 20 weeks old).[23] If a diet is formulated with a triticale cultivar that has a protein content of 11% and lysine content of 0.3%, triticale must have a price that is lower than the maize price by 3.3% and 4.3% before it is worth including in starter broiler and laying hen diets, respectively.[24] However, if triticale has a protein content of 12% and lysine content of 0.5%, it remains in the solution with a price premium of up to 4.2% over the maize price.

When the triticale-to-maize price ratio is set to 0.90 (protein = 12%; lysine = 0.5%), the composition of the diet remains unchanged (Tables 11 and 12). However, including triticale in the diets leads to cost savings averaging US$ 10.60/t (5.6% cost reduction) for broilers and US$ 11.14/t (7.51% cost reduction) for layers. The highest cost savings occur at the finishing stage for broilers (US$ 12.60/t) and at the laying stage (>20 weeks) for layers (US$ 12.24/t). Cost reductions of this magnitude will most likely encourage the inclusion of triticale in poultry diets.

Aside from triticale's advantage in protein and amino acids, triticale's content of available phosphorus is better than that of maize. With respect to these nutrients, the value of triticale is greater on a weight-to-weight basis. Despite this nutritional advantage, the potential of triticale as a poultry feed ingredient is substantially reduced when triticale costs more than maize. In fact, a 4.5% price premium over maize is sufficient to considerably reduce the competitiveness of triticale (protein = 12%; lysine = 0.5%).

Table 10. Effect of different protein and lysine values of triticale on composition and cost of laying hen diets when the triticale-to-maize price ratio = 1

Protein (%)	Lysine (%)	Diet composition (%)			Cost of diet (US$/t)	Allowable increase (%)[a]	Necessary decrease (%)[a]
		Triticale	Maize	Soybeans			
	0.30	0.00	70.56	12.98	156.63	..	4.30
11	0.40	0.00	70.56	12.98	156.63	..	1.00
	0.50	50.0	23.72	9.62	155.06	2.00	..
	0.30	0.00	70.56	12.98	156.63	..	3.75
12	0.40	0.00	70.56	12.98	156.63	..	0.50
	0.50	77.98	0.00	4.87	153.91	3.50	..
	0.30	0.00	70.56	12.98	156.63	..	3.00
14	0.40	80.67	2.51	0.00	155.90	0.70	..
	0.50	83.58	0.00	0.00	152.55	4.00	..

Source: Modeling results.
a Percentage relative to maize price.

23 These two growth stages of broilers and layers require the highest nutrient levels (energy, protein, and lysine) of all growth stages.

24 Except for protein and lysine content of triticale, all other values remain as shown in Table 5.

Results of the model show that triticale has potential in both broiler and layer diets. This potential depends on the quality of triticale (its protein and lysine content) and its price relative to maize. Although triticale-based rations have only a relatively small economic advantage over maize-based rations when triticale has the same price as maize, when triticale is included in broiler rations it completely replaces maize and substantially reduces the content of soybean meal. The results also show that the economic potential of triticale as a feed ingredient for broilers and layers is enhanced when triticale has a price advantage over maize (i.e., a 5% price discount), even when it has a relatively low nutritional value (i.e., 11% protein content and 0.3% lysine content).[25]

Table 11. Composition, calculated analyses, cost, and cost difference of rations for broilers at different growth stages, when the triticale-to-maize price ratio = 0.90

	Starter		Grower		Finisher	
Ingredient	**Without triticale**	**With triticale**	**Without triticale**	**With triticale**	**Without triticale**	**With triticale**
Composition (%)						
Maize	46.74	..	57.97	..	64.64	..
Soybean meal	36.74	31.35	27.83	21.17	22.80	15.54
Triticale	..	51.71	..	64.06	..	71.88
Maize gluten	5.00	5.00	5.00	5.00	4.93	4.22
Soybean oil	7.27	7.77	5.32	5.96	4.13	4.93
Ccal	1.23	1.31	1.19	1.29	1.12	1.22
CaPh	1.90	1.75	1.65	1.46	1.40	1.18
Lysine	0.002	0.008	0.03	0.04	..	0.009
Methionine	0.12	0.11	0.006	0.03	..	..
Constants[d]	1.00	1.00	1.00	1.00	1.00	1.00
Calculated analyses						
Met. energy (kcal/kg)	3,200	3,2,00	3,200	3,200	3,200	3,200
Protein (%)	23.00	23.00	20.00	20.00	18.30	18.00
Methionine (%)	0.525	0.501	0.380	0.380	0.352	0.320
Lysine (%)	1.200	1.200	1.000	1.000	0.850	0.850
Tryptophan (%)	0.284	0.295	0.236	0.249	0.209	0.223
Threonine (%)	0.865	0.928	0.747	0.825	0.680	0.758
Calcium (%)	1.00	1.00	0.900	0.900	0.800	0.800
Phosphorus (%)[e]	0.450	0.450	0.400	0.400	0.350	0.350
Crude fiber (%)	3.68	3.71	3.38	3.42	3.22	3.27
Cost	**201.68**	**192.61**	**184.96**	**174.90**	**175.64**	**163.05**
Cost difference (US$/t)	**9.07**		**10.06**		**12.60**	
Cost difference (%)	**4.50**		**5.44**		**7.20**	

Source: Modeling results.
Note: Due to rounding, composition of ration may not add to 100.

[25] Again, a price premium (over maize) as low as 4.5% is sufficient to considerably reduce the proportion of triticale in the ration, regardless of its nutritional value.

In maize- and soybean-deficit countries, relative prices of the main feed ingredients will likely favor the use of triticale in feed, especially in countries such as Tunisia and Morocco, where triticale has a substantial production edge over other commonly grown cereals. In such cases the triticale-to-maize price ratio is expected to be less than one, which implies that even low protein (11%) and low lysine (0.3%) triticale may have potential as a feed ingredient for poultry instead of maize. Also, in countries where the feed industry relies on imported protein concentrates such as soybean meal, the use of triticale in poultry diets may substantially reduce the level of soybean meal used and hence reduce the cost of the diet. Another advantage of using triticale would be its "buffering" effect in the event of disruptions and/or shortages in the supply of imported ingredients, especially maize and soybean meal. The next section of this paper examines the production and utilization of triticale in Tunisia, where triticale is expected to have great potential as a feed ingredient in poultry diets.

Table 12. Composition, calculated analyses, cost, and cost difference of rations for layers at different growth stages, when the triticale-to-maize price ratio = 0.90

	Starter		Grower-1		Grower-2		Layer	
Ingredient	**Without triticale**	**With triticale**	**Without triticale**	**With triticale**	**Without triticale**	**With triticale**	**Without triticale**	**With triticale**
Composition (%)								
Maize	58.53	..	50.50	..	51.16	..	70.60	..
Soybean meal	21.93	12.30	16.52	5.68	5.71	0.21	13.00	4.87
Triticale	..	63.90	..	54.50	..	54.56	..	77.88
Barley	11.55	12.60	29.00	32.00	38.80	40.40	..	..
Maize gluten	4.38	5.00	2.00	3.80	1.40	1.20	5.00	5.00
Soybean oil	..	0.96	..	0.81	..	0.77	0.97	1.75
Ccal	1.00	1.09	1.00	1.10	0.94	1.03	8.12	8.24
CaPh	1.60	1.42	1.28	1.12	1.01	0.85	1.27	1.05
Lysine	..	..	..	..	..	..	0.06	0.07
Methionine	..	..	..	..	..	..	0.02	0.04
Constants	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Analyses								
Met. energy(kcal/kg)	2,900	2,900	2,900	2,900	2,900	2,900	2,900	2,900
Protein (%)	18.41	18.00	15.90	15.00	12.00	12.00	14.50	14.50
Methionine (%)	0.346	0.309	0.309	0.268	0.220	0.200	0.320	0.320
Lysine (%)	0.850	0.850	0.635	0.600	0.450	0.450	0.640	0.640
Tryptophan (%)	0.213	0.226	0.173	0.178	0.132	0.144	0.151	0.168
Threonine (%)	0.680	0.745	0.570	0.605	0.426	0.492	0.532	0.687
Calcium (%)	0.80	0.80	0.70	0.70	0.60	0.60	3.40	3.40
Phosphorus (%)	0.40	0.40	0.35	0.35	0.30	0.30	0.32	0.32
Crude fiber (%)	3.75	3.85	4.07	4.18	4.20	4.30	2.73	2.78
Cost	**157.64**	**146.20**	**145.84**	**134.16**	**132.68**	**123.50**	**156.64**	**144.40**
Cost difference (US$/t)	**11.43**		**11.68**		**9.20**		**12.24**	
Cost difference (%)	**7.25**		**8.00**		**6.92**		**7.82**	

Source: Modeling results.
Note: Due to rounding, composition of ration may not add to 100.

Production, Utilization, and Potential of Triticale in Tunisia

In Tunisia large-scale triticale production was initiated in the early 1980s. In less than a decade, triticale area increased by more than 300% (from 4,000 ha in 1984 to more than 17,000 ha in 1991) (Table 13). Virtually all triticale production takes place in the northern (relatively well-watered) zone.

Data from the Ministry of Agriculture show that average production of triticale exceeds that of durum wheat, barley, and, to a lesser extent, bread wheat (Table 14). The data also show substantial yield variability among provinces and between years within a province.[26]

In Tunisia, the feed industry has grown substantially over the last two decades, mainly because of the development of the poultry industry. On average, about two-thirds of the feed produced is allocated to poultry and the remainder to livestock. In 1991 poultry feed consumption reached over 400,000 t (Figure 1). Tunisia imports all the maize and soybean meal used in formulating poultry rations. Since 1981, average annual maize imports have surpassed 200,000 t; soybean meal imports have reached 100,000 t (Figure 2).

A research program that aims to evaluate the nutritional value of triticale and its effect on poultry performance was initiated by the Ministry of Agriculture in the early 1970s. This research revealed that using triticale in poultry diets (up to a 30% inclusion rate) improves weight gain. However, despite these encouraging results, the incorporation of triticale in poultry diets has been negligible at best.

Table 13. Triticale area, yield, and production in Tunisia, 1983-84 to 1991-92

Year	Area (ha)	Yield (t/ha)	Production (t)
1983-84	4,344	2.0	8,710
1984-85	4,832	2.5	1,198
1985-86	12,734	1.3	16,401
1986-87	14,531	2.5	36,590
1987-88	11,610	0.6	7,003
1988-89	14,400	1.1	15,460
1989-90	14,187	2.2	29,957
1990-91	17,092	2.6	44,200
1991-92	22,000 [a]	..	..

Source: Tunisia Ministry of Agriculture (unpublished data).
a Projected area.

Table 14. Wheat, barley, and triticale yields in the northern zone of Tunisia, 1983-84 to 1988-89

Year	Yield (t/ha)[a] Durum wheat	Bread wheat	Barley	Triticale
1983-84	1.04	1.40	0.90	2.00
1984-85	1.60	2.25	1.26	2.50
1985-86	0.75	0.89	0.39	1.30
1986-87	1.80	2.35	1.53	2.50
1987-88	0.33	0.55	0.14	0.60
1988-89	0.55	0.59	0.39	1.10

Source: DGPV, Ministry of Agriculture, Tunis.
a Farmers' average yields in the northern zone.

26 For more details on triticale production and utilization in Tunisia, see Belaid (1991a).

Some authors, such as Kristjanson et al. (1990), have indicated that the nutritional value of ingredients imported by Tunisia (such as maize and soybean meal) is sometimes below international standards.[27] Furthermore, as Table 15 shows, government-prescribed poultry feed rations remain deficient in some nutrients, especially energy, even when formulated with "good quality" ingredients.[28]

For this study, minimum cost rations (with and without triticale) were formulated using 1990 prices of poultry feed ingredients in Tunisia.[29] The effect of including triticale in poultry feed is analyzed under two scenarios:

1. Maize, soybean meal, triticale, barley, and bran are the only feed ingredients available (this is the current situation). In this case the rations are not balanced.[30]

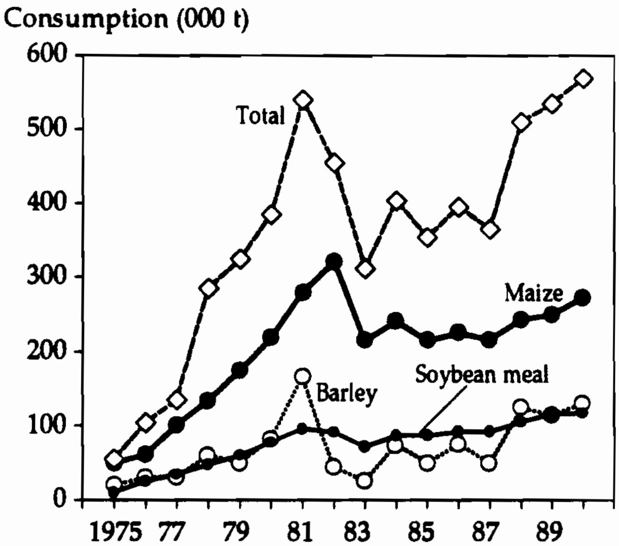

Figure 1. Consumption of feed ingredients in Tunisia, 1975-90.
Source: Data from Kristjanson et al. (1990).

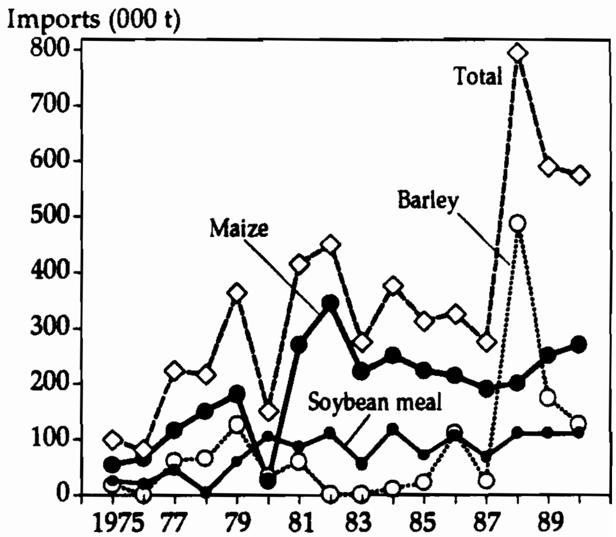

Figure 2. Imports of feed ingredients in Tunisia, 1975-90.
Source: Data from Kristjanson et al. (1990).

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27 For example, the protein content of imported soybean meal was reported to be below 44%.

28 In Tunisia, minimum nutritional requirements and the composition of feed diets are specified by government regulations. Calculated analyses are based on the ingredient composition shown in Table 5.

29 Ingredient prices in effect in Tunisia as of October 1991 were: maize = TD 158.1/t; soybean meal = TD 255/t; barley = TD 158.0/t; triticale = TD 127.5/t; bran = TD 65/t; calcium carbonate = TD 31/t; bicalcium phosphate = TD 213/t; salt = TD 82/t; lysine = TD 3,740/t; and methionine = TD 3,600/t. Vitamin, mineral, maize gluten, and soybean oil prices are estimated using c.i.f. prices listed in Table 6, inflated by an import tax (17%) and a margin to cover handling costs (5%), leading to the following prices (US$ 1 = TD 0.92): maize gluten = TD 292.60/t; soybean oil = TD 529.55/t; vitamins = TD 3,894.72/t; and minerals = TD 482.63/t.

30 This scenario is included to show that adding triticale to the rations can lower their cost even with the limited ingredients available: maize, soybean meal, barley, and bran. As mentioned in the text, limiting the supply of raw materials to these ingredients leads to the formulation of rations that are suboptimal compared to the minimum nutritional requirements set by the NRC.

2. Energy-rich ingredients such as soybean oil and maize gluten become available, thus enabling balanced rations to be formulated.

Details of the composition and cost of particular rations under the different scenarios are provided in the tables in Appendix A; costs are summarized in Table 17.

Under the first scenario, restricting the choice of ingredients leads to the formulation of energy-deficient rations regardless of whether or not triticale is included in the diet. At 1990 ingredient prices, when triticale is included in poultry diets, feed cost is reduced, especially for broilers and pullets — a savings of about 11.1 and 20.0 Tunisian dinars (TD) per ton, i.e., US$ 12.1 and 21.7 per ton, respectively (Table 16).[31] Furthermore, including triticale in the diet leads to a considerable reduction of maize (a 25% reduction on average for broilers and 47% for layers). Likewise, less soybean meal is used (a reduction of 6% for broilers and 30% for layers).

Table 15. Composition, calculated analyses, and cost of government-prescribed poultry rations in Tunisia

Ingredient	Starter[a]	Broiler[b]	Pullet[c]	Layer[d]
Composition				
Maize	60.5	59.6	68.0	65.0
Soybean	35.5	35.4	16.5	13.5
Bran	..	..	10.5	11.0
CaCo3	..	..	..	5.5
CMV[e]	4.0	5.0	5.0	5.0
Calculated analyses[f]				
ME (kcal/kg)	2,800	2,769	2,795	2,637
	(3,200)	(3,200)	(2,900)	(2,900)
Protein (%)	20.6	20.45	14.5	12.9
	(23.0)	(18.0)	(12.0)	(14.5)
Tryptophan (%)	0.266	0.265	0.182	0.162
	(0.230)	(0.170)	(0.140)	(0.140)
Threonine (%)	0.785	0.781	0.537	0.480
	(0.800)	(0.680)	(0.570)	(0.450)
Cost (TD/t)	211.60	213.74	183.40	164.90

Source: Government-prescribed rations are for 1990 as indicated by Kristjanson et al. (1990). Calculated analyses are based on average composition of ingredients as shown in Table 4 (derived from Hubbell 1991).

a Starter broiler diets fed from 3 to 6 weeks of age.
b Broiler diets fed from 6 to 8 weeks of age.
c Pullet diets fed from 14 to 20 weeks of age.
d Layer diets fed for over 20 weeks of age.
e Concentrate of minerals and vitamins.
f Figures in parentheses show NRC suggested requirements. It is assumed that methionine, lysine, calcium, and phosphorus (if not sufficiently supplied by ingredients), and vitamin and mineral requirements, are all covered by CMV.

31 US$ 1.0 = TD 0.92.

Under the second scenario, the availability of maize gluten and soybean oil allows balanced feed rations to be formulated. The composition of balanced rations with and without triticale, at NRC growth stages and at Tunisian ingredient prices, is shown in Appendix Tables A4 and A5.[32] At 1990 prices, including triticale in the diet leads to a cost reduction in broiler diets (TD 23.2/t on average) and layer diets (TD 29.2/t on average) for all growth stages. The highest cost reduction is obtained for grower-1 layers (TD 31.4/t) and the lowest for starter broilers (TD 19.5/t) (Table 17). In broiler diets, triticale substitutes completely for maize and partially for soybean meal. At the finisher growth stage, the proportion of triticale in the diet reaches 72.6% (the highest for broilers) and the level of soybean meal is less than 15%. The proportion of maize gluten is at its upper level (5%) and soybean oil content ranges between 7.7% and 4.1%.

Table 16. Composition, calculated analyses, and cost (TD/t) of suboptimal, government-prescribed poultry rations (PR) and triticale-based poultry rations (LP) (at Tunisian prices)

	Starter		Broiler		Pullet		Layer	
Ingredient	**PR**	**LP**	**PR**	**LP**	**PR**	**LP**	**PR**	**LP**
Composition (%)								
Maize	60.5	46.70	59.6	42.3	68.0	30.36	65.0	33.40
Soybean	35.5	33.80	35.4	32.5	16.5	11.60	13.5	9.40
Triticale	..	15.70	..	21.9	..	44.40	..	38.00
Bran[a]	..	..	..	..	10.5	10.90	11.0	10.00
Ccal	..	1.14	..	1.05	..	0.93	5.0	8.24
CaPh	..	1.58	..	1.30	..	0.830	..	1.01
Lysine	..	..	..	..	..	..	..	0.06
Methionine	..	0.05	..	0.02	..	..	..	0.10
Constants	4.0	1.00	5.0	1.00	5.0	1.00	1.4	1.00
Calculated analyses								
Met. energy (kcal/kg)	2,800	2,800	2,769	2,817	2,795	2,795	2,637	2,637
Protein(%)	20.60	20.60	20.50	20.50	14.50	14.50	12.90	12.90
Methionine (%)	0.36	0.380	0.36	0.331	0.26	0.237	0.23	0.320
Lysine (%)	1.25	1.140	1.24	1.12	0.74	0.683	0.60	0.640
Tryptophan (%)	0.266	0.269	0.264	0.267	0.182	0.193	0.162	0.169
Threonine (%)	0.784	0.805	0.780	0.804	0.536	0.576	0.479	0.509
Calcium (%)	0.905	0.905	0.805	0.805	0.60	0.60	3.40	3.40
Phosphorus (%)	0.40	0.40	0.35	0.35	0.30	0.30	0.32	0.32
Crude fiber (%)	3.82	3.83	3.79	3.82	3.93	4.04	3.71	3.69
Cost (TD/t)	**211.6**	**205.7**	**213.7**	**202.6**	**183.4**	**163.4**	**164.9**	**162.4**
Savings (TD/t)	**5.90**		**11.14**		**20.00**		**2.50**	
Savings (%)	**3.0**		**5.2**		**11.0**		**1.0**	

Source: Kristjanson et al. (1990) and modeling results.
Note: Due to rounding, weight of ration may not add to 100.
a The nutritional profile of bran used in the model is: ME = 1,235 kcal; protein = 14.5; methionine = 0.17; lysine = 0.58; threonine = 0.50; tryptophan = 0.29; calcium = 0.08; AvPhos = 0.13; and crude fiber = 11.

32 Throughout this paper, barley and bran are considered to be potential feed ingredients for layers only.

In layer diets, adding triticale leads to the complete substitution of maize and a considerable reduction of soybean meal. No maize or soybean meal is included in grower-2 diets. Given the relatively high price of barley (TD 158/t) and the low price of bran (TD 65/t), barley is not included in any of the layer diets, either with or without

Table 17. Cost savings when triticale is included in different broiler and layer rations, at Tunisian prices

Type of ration	Cost savings (US$/t)	Cost savings (%)
Broiler and layer rations, at Tunisian prices and using additional ingredients (maize gluten and soybean oil) to formulate balanced rations		
Broiler		
Starter	19.47	7.80
Grower	23.00	10.00
Finisher	27.23	12.40
Layer		
Starter	27.50	13.71
Grower-1	31.40	16.80
Grower-2	30.00	17.30
Layer	28.00	14.50
Layer rations, at Tunisian prices, using additional ingredients, and with the barley price set equal to the triticale price		
Starter	27.00	13.50
Grower-1	30.40	16.34
Grower-2	28.00	16.30
Layer	28.00	14.50
Broiler rations, at Tunisian prices and with the use of triticale limited to 20%		
Starter	7.53	3.02
Grower	7.17	3.11
Finisher	7.77	3.53
Layer rations, at Tunisian prices and with the use of triticale limited to 30%		
Starter	11.80	5.88
Grower-1	13.53	7.24
Grower-2	11.38	6.55
Layer	10.76	5.57
Broiler and layer rations, at Tunisian prices and using triticale with low protein content (11%) and low lysine content (0.3%)		
Broiler		
Starter	13.50	5.40
Grower	15.53	6.72
Finisher	18.42	8.37
Layer		
Starter	20.03	10.00
Grower-1	23.56	12.60
Grower-2	22.80	13.10
Layer	18.90	9.80

Source: Appendix A.

triticale.[33] In contrast, barley accounts for 32% of the triticale-based diet at the grower-1 stage and 40.4% at the grower-2 stage (with a triticale-to-maize price ratio of 0.90, and at international prices) (Appendix Table A5). The proportion of bran in the diets during the first three growth stages is relatively low and does not appear to be affected by whether or not triticale is included in the diet. Given the low energy requirements of layers compared to broilers, soybean oil comprises a very small proportion of the diet (with or without triticale). The amount of triticale included in layer diets ranges between 73.4% (starter layers) and 85.6% (grower-2 layers). Such levels may appear too high by Tunisian standards, but to the author's knowledge, no evidence suggests that a proportion of triticale of this magnitude would impair hen growth and/or production.[34]

Table 18 compares the currently prescribed government rations with optimal (balanced) triticale-based rations. When triticale, maize gluten (maximum of 5%), and soybean oil (maximum of 5.96%) are all available, optimal feed rations can be formulated at a lower cost than the government-prescribed (and suboptimal) feed rations. At the pullet growth stage, for example, an optimal ration can be formulated using locally produced ingredients — 85.6% triticale and 10.4% bran — and a small proportion of imported ingredients — such as 0.8% soybean oil and 0.4% maize gluten — at a lower cost than the actual maize/soybean-based, energy-deficient ration. At all growth stages the inclusion of triticale and energy-rich ingredients leads to complete substitution of maize and partial substitution of soybean meal in the ration while improving the quality of the diet. In other words, given the ingredient prices prevailing in Tunisia, triticale-based optimal rations have the double advantage of improving the quality and lowering the cost of poultry diets.

Until October 1991, the price of barley (for feed) was similar to that of triticale (TD 127.5/t), versus TD 155/t for maize.[35] The sudden, substantial barley price increase (from TD 127.5/t to TD 158/t, a 24% increase) and the modest maize price increase (from TD 155/t to TD 158.1/t, a 2% increase) could enhance the attractiveness of triticale to the feed industry, but only temporarily. The Tunisian government has initiated a subsidy removal program, so the same price policy is expected to be extended to triticale, with the likely result that triticale's current price advantage over barley will vanish.[36] Therefore, the model is also run assuming an identical barley and triticale price, i.e., TD 127.5/t, with all other things being equal. An identical barley and triticale price does not considerably reduce the cost of the diet (Table 17, Appendix Table A3), implying that, even when the price of barley equals the price of triticale, barley is not a competitive feed ingredient in triticale-based poultry diets in Tunisia.

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33 Feed ingredients are imported and distributed by the cereal grain board (Office des Céréales). Prices at which ingredients are sold to feed manufacturers are fixed by the government.

34 Again, the nutritional profile of the triticale used in the rations is assumed to be as shown in Table 5. The case of a low quality triticale (protein = 11% and lysine = 0.30%) is shown in Table A7.

35 In 1990, producer prices of locally produced feed ingredients were TD 155/t for barley and TD 170/t for triticale. The prices charged to feed blenders were TD125/t for barley and TD 127.5/t for triticale.

36 However, the maize/triticale and soybean meal/triticale price differentials are likely to remain at current levels (according to officials at the Office des Céréales).

Even when the amount of triticale in the ration is limited to 20% (broilers) and 30% (layers), cost savings can still be achieved (Table 14 and Appendix Tables A4 and A5). This is especially true for layers. The inclusion of triticale also leads to the formulation of balanced diets that require much less maize and soybean meal than the actual government-prescribed rations, which are energy deficient.

Finally, the model is run assuming that low quality triticale is used (i.e., protein content = 11% and lysine = 0.3%). Under this scenario the proportion of triticale in the rations remains high, ranging from around 50% for starter broilers to 84% for layers at the grower-2 stage (Appendix Tables A6 and A7). Despite its low nutritional profile, triticale reduces the cost of the ration (about 7% for broilers and 11% for layers, on average), because it substitutes completely for maize at all growth stages (Table 17).

Table 18. Comparison between composition, calculated analyses, and cost of government-prescribed (PR) and optimal triticale-based poultry rations (LP) (at Tunisian prices)

	Starter		Broiler		Pullet		Layer	
Ingredient	**PR**	**LP**	**PR**	**LP**	**PR**	**LP**	**PR**	**LP**
Composition (%)								
Maize	60.5	..	59.6	..	68.0	..	65.0	..
Soybean	35.5	21.17	35.4	14.3	16.5	..	13.5	4.87
Triticale	..	64.06	..	72.6	..	85.63	..	78.00
Barley	..	..	..	..	..	..	..	..
Bran	..	..	..	..	10.5	10.35	11.0	..
Maize gluten	..	5.00	..	5.00	..	0.37	..	5.00
Soybean oil	..	5.96	..	4.70	..	0.77	..	1.75
Ccal	..	1.29	..	1.23	..	0.97	5.0	8.24
CaPh	..	1.46	..	1.18	..	0.90	..	1.05
Lysine	..	0.04	..	0.04	..	..	..	0.07
Methionine	..	0.03	..	..	..	0.04	..	0.04
Constants	4.0	1.00	5.0	1.00	5.0	1.00	1.4	1.00
Calculated analyses								
Met. energy (kcal/kg)	2,800	3,200	2,769	3,200	2,795	2,950	2,637	2,900
Protein (%)	20.60	20.00	20.50	18.00	14.50	12.00	12.90	14.50
Methionine (%)	0.36	0.38	0.36	0.327	0.26	0.200	0.23	0.320
Lysine (%)	1.25	1.00	1.24	0.850	0.74	0.492	0.60	0.640
Tryptophan (%)	0.266	0.249	0.264	0.219	0.182	0.160	0.162	0.168
Threonine (%)	0.784	0.825	0.780	0.757	0.536	0.547	0.479	0.627
Calcium (%)	0.905	0.900	0.805	0.800	0.60	0.600	3.40	3.40
Phosphorus (%)	0.40	0.40	0.35	0.35	0.30	0.30	0.32	0.32
Crude fiber (%)	3.82	3.42	3.79	3.23	3.93	3.72	3.71	2.78
Cost (TD/t)	**211.6**	**208.0**	**213.7**	**193.0**	**183.4**	**143.7**	**164.9**	**165.1**
Savings (TD/t)	**3.60**		**20.70**		**39.70**		**-0.20**	
Savings (%)	**1.70**		**9.68**		**21.64**		**-0.12**	

Source: Kristjanson et al. (1990); modeling results.
Note: Due to rounding, weight of ration may not add to 100.

In conclusion, it is clear that triticale has potential as a poultry feed ingredient. The combination of its nutritional profile and its lower price relative to maize and soybean meal enables the formulation of balanced diets nutritionally similar to maize/soybean-based diets at less cost. Even when a low quality triticale is used, it substitutes completely for maize and leads to cost savings. Furthermore, restricting the amount of triticale (to 20% of broiler rations and 30% of layer rations, for example) enables the formulation of balanced diets with less maize and soybean meal and sufficiently attractive cost savings. Based on these cost savings, and considering that triticale feeding studies conducted in Tunisia (Production Animale, INAT) indicate that triticale in poultry diets does not impair chicks' growth, the gradual replacement of maize by triticale should be initiated in Tunisia. There are sufficient price incentives (given relative prices of feed ingredients) to encourage both feed producers and feed users to take advantage of triticale. On the supply side, however, the actual annual production of about 40,000 t represents only about 10% of total annual poultry feed consumption, implying that triticale area would have to expand substantially for triticale to become a major poultry feed ingredient in Tunisia.

In 1991, poultry feed consumption in Tunisia was more than 400,000 t. Based on a 30% inclusion rate of triticale, on average, about 120,000 t of triticale will be required to formulate minimum cost triticale-based diets. Assuming an average triticale yield of 2 t/ha, at least 60,000 ha will have to be sown to triticale to meet feed demand. Although triticale will be cultivated at the expense of other cereal crops (most probably barley), the required triticale area represents less than 10% of the cultivated cereal area and less than 40% of the fallow area in the northern zone. To minimize the unwarranted displacement of any cereal crop in this zone, the production of triticale in the central zone (where the fallow area is considerable and where triticale production has a relative comparative advantage) should be initiated. As mentioned earlier, triticale does not require any technology or management different from that used to produce other small grain cereals, which implies that its introduction in rainfed farming system is feasible with virtually no change (machinery, knowledge) at the farm level.

Considering the cost savings resulting when triticale is included in poultry diets, and given the yield advantage of triticale, especially its advantage over barley in the northern zone (Table 14), it can be concluded that triticale producers as well as users will benefit from triticale cultivation in Tunisia.

The very substantial increase of triticale area (from nearly 20,000 ha currently to 60,000 ha) needed to meet feed demand (based on 30% triticale in the diet) would most likely be gradual. It would require an important, sustained extension program that targets producers and users; it would also require an adequate (at least in volume) seed supply.[37]

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37 Although quite substantial, this increase in triticale area is feasible in a relatively short period of time. As Table 13 shows, triticale area has already increased from nearly 4,500 ha in 1984 to more than 17,000 ha in 1991, despite constraints to production (e.g., unavailability of seed) and utilization.

Conclusion

The results reported in this paper clearly show that triticale has potential as an alternative feed ingredient for poultry diets. There is sufficient evidence indicating that triticale exhibits good adaptability to difficult environemnts. Its relatively good competitive advantage over barley under well-watered conditions (owing to its lodging resistance) and over wheat and barley on sandy soils and acid soils is well documented. In Tunisia, for example, in areas where waterlogging and soil scidity severely constrain cereal production (for example, the northern zone), triticale was found to be better adapted than wheat and barley. It is also recognized that triticale exhibits good resistance to most common cereal foliar diseases. These positive characteristics make triticale a particularly attractive option for farmers in areas plagued by such production cosntraints.

The technology for producing triticale does not significantly differ from that commonly used for barley production, which implies relatively similar production costs per unit area. Furthermore, considering that triticale generally yields better than barley in areas where such production constraints as foliar diseases, insect pests (e.g., Hessian fly in Morocco) (Belaid 1991b), lodging, and acid soils are relatively high, net returns per unit area will favor triticale when the producer price is similar for both crops. Under such circumstances, it is reasonable to expect that farmers will be better off by substituting (at least partially) triticale for barley in this risky environment when the triticale producer price is the same as that of barley.

Extrapolating from the linear programming results, one may infer that triticale production will not only benefit crop producers in risky environments but also poultry producers, because of the reduced cost of rations containing triticale, especially when the price of triticale is less than or equal to the price of maize. Furthermore, in countries where the feed industry depends on imported maize and soybean meal to formulate poultry diets, the use of triticale will reduce the risk associated with potential import disruptions (provided the local triticale supply meets the industry's demand), which in turn adversely affect the local poultry supply and thus the price consumers pay for poultry. In Tunisia, for example, the demand for feed ingredients has experienced considerable growth since 1975, outstripping the growth of domestic supply. As a result, the feed industry has become increasingly dependent on imports, which currently represent approximately 80% of total feed ingredient consumption. The volume of imported feed ingredients has been growing at a steady rate, averaging more than 300,000 t for 1982-90. Imports reached a record high of nearly 800,000 t in 1988, when production was low because of drought (Figure 2). With the exception of 1988, maize and soybean meal account for the bulk of imported feed ingredients over the period. The Tunisian example reviewed in this paper reveals the nutritional as well as economic gains which may result from using triticale in poultry diets in countries where the environment severely constrains the production of maize and soybeans under rainfed conditions.

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Appendix A

Composition and Cost of Poultry Diets with and without Triticale

Table A1. Composition, calculated analyses, cost, and cost differences of rations for broilers at different growth stages (at Tunisian prices and using additional ingredients)

	Starter		Grower		Finisher	
Ingredient	Without triticale	With triticale	Without triticale	With triticale	Without triticale	With triticale
Composition (%)						
Maize	46.74	..	57.97	..	64.64	..
Soybean meal	36.74	31.35	27.83	21.17	22.80	14.30
Triticale	..	51.71	..	64.06	..	72.60
Maize gluten	5.00	5.00	5.00	5.00	4.93	5.00
Soybean oil	7.27	7.77	5.32	5.96	4.13	4.70
Ccal	1.23	1.31	1.19	1.29	1.12	1.23
CaPh	1.90	1.75	1.65	1.46	1.40	1.18
Lysine	0.002	0.008	0.03	0.04	..	0.04
Methionine	0.12	0.11	0.006	0.03	..	..
Constants[a]	1.00	1.00	1.00	1.00	1.00	1.00
Calculated analyses						
Met. energy (kcal/kg)	3,200	3,200	3,200	3,200	3,200	3,200
Protein (%)	23.00	23.00	20.00	20.00	18.30	18.00
Methionine (%)	0.525	0.501	0.380	0.380	0.352	0.327
Lysine (%)	1.200	1.200	1.000	1.000	0.850	0.850
Tryptophan (%)	0.284	0.295	0.236	0.249	0.209	0.219
Threonine (%)	0.865	0.928	0.747	0.825	0.680	0.757
Calcium (%)	1.0	1.0	0.90	0.90	0.80	0.80
Phosphorus (%)	0.45	0.45	0.40	0.40	0.35	0.35
Crude fiber (%)	3.68	3.71	3.38	3.42	3.22	3.23
Cost (TD/t)	**249.70**	**230.20**	**231.00**	**208.00**	**220.21**	**193.00**
Cost difference (TD/t)	**19.47**		**23.00**		**27.23**	
Cost difference (%)	**7.80**		**10.00**		**12.40**	

Source: Modeling results.

Note: Due to rounding, composition of ration may not add to 100.

[a] In this and subsequent tables, "constants" are vitamin and mineral complements and salt.

Table A2. Composition, calculated analyses, cost, and cost difference of rations for layers at different growth stages (at Tunisian prices and using additional ingredients)

Ingredient	Starter		Grower-1		Grower-2		Layer	
	Without triticale	With triticale	Without triticale	With triticale	Without triticale	With triticale	Without triticale	With triticale
Composition (%)								
Maize	66.35	..	70.02	..	76.52	..	70.60	..
Soybean meal	22.16	15.11	12.64	3.67	6.11	..	13.00	4.87
Triticale	..	73.42	..	78.73	..	85.63	..	78.00
Barley	..	..	..	..	..	..	..	..
Bran	3.54	3.65	9.02	9.30	12.30	10.35	..	..
Maize gluten	4.32	3.35	5.00	4.32	2.10	0.37	5.00	5.00
Soybean oil	..	0.94	..	0.77	..	0.77	0.97	1.75
Ccal	0.98	1.08	0.94	1.07	0.87	0.97	8.12	8.24
CaPh	1.64	1.43	1.38	1.16	1.14	0.90	1.27	1.05
Lysine	..	..	..	..	..	..	0.06	0.07
Methionine	..	..	..	..	..	0.04	0.02	0.04
Constants	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Calculated analyses								
Met. energy (kcal/kg)	2,900	2,950	2,900	2,950	2,900	2,950	2,900	2,900
Protein (%)	18.30	18.00	15.61	15.00	12.00	12.00	14.50	14.50
Methionine (%)	0.346	0.311	0.313	0.274	0.236	0.200	0.320	0.320
Lysine (%)	0.850	0.850	0.632	0.600	0.450	0.492	0.640	0.640
Tryptophan (%)	0.214	0.229	0.178	0.185	0.136	0.160	0.151	0.168
Threonine (%)	0.680	0.761	0.570	0.644	0.437	0.547	0.532	0.627
Calcium (%)	0.80	0.80	0.70	0.70	0.60	0.60	3.40	3.40
Phosphorus (%)	0.40	0.40	0.35	0.35	0.30	0.30	0.32	0.32
Crude fiber (%)	3.60	3.67	3.70	3.73	3.71	3.72	2.73	2.78
Cost (TD/t)	**200.5**	**173.0**	**187.0**	**155.6**	**173.7**	**143.7**	**193.1**	**165.1**
Cost difference (TD/t)	**27.50**		**31.40**		**30.00**		**28.00**	
Cost difference (%)	**13.71**		**16.80**		**17.30**		**14.50**	

Source: Modeling results.
Note: Due to rounding, composition of ration may not add to 100.

Table A3. Composition, calculated analyses, cost, and cost difference of rations for layers at different growth stages (at Tunisian prices, using additional ingredients, and with the barley price equal to the triticale price)[a]

	Starter		Grower-1		Grower-2		Layer	
Ingredient	Without triticale	With triticale	Without triticale	With triticale	Without triticale	With triticale	Without triticale	With triticale
Composition (%)								
Maize	58.53	..	50.46	..	51.16	..	70.60	..
Soybean meal	21.93	15.11	12.26	3.67	5.72	..	13.00	4.87
Triticale	..	73.42	..	78.73	..	85.63	..	78.00
Barley	11.55	..	29.00	..	38.79	..	..	..
Bran	..	3.65	..	9.30	..	10.35	..	..
Maize gluten	4.38	3.35	5.00	4.32	1.38	0.37	5.00	5.00
Soybean oil	..	0.94	..	0.77	..	0.77	0.97	1.75
Ccal	1.00	1.08	1.00	1.07	0.94	0.97	8.12	8.24
CaPh	1.60	1.43	1.27	1.16	1.01	0.90	1.27	1.05
Lysine	..	..	..	..	..	..	0.06	0.07
Methionine	..	..	..	..	..	0.04	0.02	0.04
Constants	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Calculated analyses								
Met. energy (kcal/kg)	2,900	2,950	2,900	2,950	2,900	2,950	2,900	2,900
Protein (%)	18.41	18.00	15.87	15.00	12.00	12.00	14.50	14.50
Methionine (%)	0.346	0.311	0.309	0.274	0.236	0.200	0.320	0.320
Lysine (%)	0.850	0.850	0.635	0.600	0.450	0.492	0.640	0.640
Tryptophan (%)	0.213	0.229	0.173	0.185	0.132	0.160	0.151	0.168
Threonine (%)	0.680	0.761	0.570	0.644	0.426	0.547	0.532	0.627
Calcium (%)	0.80	0.80	0.70	0.70	0.60	0.60	3.40	3.40
Phosphorus (%)	0.40	0.40	0.35	0.35	0.30	0.30	0.32	0.32
Crude fiber (%)	3.75	3.67	4.07	3.73	4.20	3.71	2.73	2.78
Cost (TD/t)	**200.0**	**173.0**	**186.0**	**155.6**	**171.7**	**143.7**	**193.1**	**165.1**
Cost difference (TD/t)	**27.00**		**30.40**		**28.00**		**28.00**	
Cost difference (%)	**13.50**		**16.34**		**16.30**		**14.50**	

Source: Modeling results.
Note: Due to rounding, composition of ration may not add to 100.
[a] The price of barley is assumed to be equivalent to that of triticale, i.e., TD 127.5/t, rather than set at the 1990 price of TD 158/t.

Table A4. Comparison between composition, calculated analyses, and cost of conventional and triticale-based (balanced) broiler rations (at Tunisian prices and with the use of triticale limited to 20%)

Ingredient	Starter		Grower		Finisher	
	Conventional diet	Triticale-based diet	Conventional diet	Triticale-based diet	Conventional diet	Triticale-based diet
Composition (%)						
Maize	46.74	28.70	57.97	39.87	64.64	47.54
Soybean meal	36.74	34.66	27.83	25.75	22.80	19.78
Triticale	..	20.00	..	20.00	..	20.00
Maize gluten	5.00	5.00	5.00	5.00	4.93	5.00
Soybean oil	7.27	7.46	5.32	5.52	4.13	4.16
Ccal	1.23	1.26	1.19	1.22	1.12	1.16
CaPh	1.90	1.84	1.65	1.59	1.40	1.33
Lysine	0.002	0.004	0.03	0.03	..	0.03
Methionine	0.12	0.11	0.006	0.01	..	..
Constants	1.00	1.00	1.00	1.00	1.00	1.00
Calculated analyses						
Met. energy (kcal/kg)	3,200	3,200	3,200	3,200	3,200	3,200
Protein (%)	23.00	23.00	20.00	20.00	18.30	18.00
Methionine (%)	0.525	0.516	0.380	0.380	0.352	0.343
Lysine (%)	1.200	1.200	1.000	1.000	0.850	0.850
Tryptophan	0.284	0.288	0.236	0.240	0.209	0.208
Threonine	0.865	0.889	0.747	0.771	0.680	0.693
Calcium (%)	1.00	1.00	0.90	0.90	0.80	0.80
Phosphorus (%)	0.45	0.45	0.40	0.40	0.35	0.35
Crude fiber (%)	3.68	3.69	3.38	3.39	3.22	3.20
Cost (TD/t)	**249.70**	**242.13**	**231.00**	**223.80**	**220.21**	**212.50**
Cost difference (TD/t)	7.53		7.17		7.77	
Cost difference (%)	3.02		3.11		3.53	

Source: Modeling results.

Note: Due to rounding, composition of diet may not add to 100. Conventional diet consists of balanced conventional rations, i.e., without triticale; the triticale diet consists of balanced triticale-based rations (triticale inclusion limited to 20%).

Table A5. Comparison between composition, calculated analyses, and cost of conventional and triticale-based (balanced) layer rations (at Tunisian prices and with the use of triticale limited to 30%)

Ingredient	Starter		Grower-1		Grower-2		Layer	
	Conv. diet	Trit.-based diet	Conv. diet	Trit.-based diet	Conv. diet	Trit.-based diet	Conv. diet	Trit.-based diet
Composition (%)								
Maize	66.35	41.05	70.02	45.06	76.52	50.46	70.60	43.42
Soybean meal	22.16	19.57	12.64	8.60	6.11	3.21	13.00	9.86
Triticale	..	30.00	..	30.00	..	30.00	..	30.00
Bran	3.54	2.33	9.02	8.60	12.30	11.36	..	..
Maize gluten	4.32	3.47	5.00	4.46	2.10	2.00	5.00	5.00
Soybean oil	..	..	..	..	..	..	0.97	1.27
Ccal	0.98	1.02	0.94	1.00	0.87	0.91	8.12	8.16
CaPh	1.64	1.56	1.38	1.30	1.14	1.05	1.27	1.18
Lysine	..	..	..	..	..	..	0.06	0.07
Methionine	..	..	..	..	..	..	0.02	0.03
Constants	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Calculated analyses								
Met. energy (kcal/kg)	2,900	2,950	2,900	2,950	2,900	2,950	2,900	2,900
Protein (%)	18.30	18.00	15.61	15.00	12.00	12.00	14.5	14.5
Methionine (%)	0.346	0.327	0.313	0.291	0.236	0.227	0.320	0.320
Lysine (%)	0.850	0.850	0.632	0.600	0.450	0.450	0.640	0.640
Tryptophan (%)	0.214	0.218	0.178	0.173	0.136	0.142	0.151	0.158
Threonine (%)	0.680	0.708	0.570	0.525	0.437	0.474	0.532	0.569
Calcium (%)	0.80	0.80	0.70	0.70	0.60	0.60	3.40	3.40
Phosphorus (%)	0.40	0.40	0.35	0.35	0.30	0.30	0.32	0.32
Crude fiber (%)	3.60	3.54	3.70	3.64	3.71	3.67	2.73	2.75
Cost (TD/t)	**200.5**	**188.7**	**187.0**	**173.4**	**173.7**	**162.3**	**193.1**	**182.3**
Cost difference (TD/t)	**11.80**		**13.53**		**11.38**		**10.76**	
Cost difference (%)	**5.88**		**7.24**		**6.55**		**5.57**	

Source: Modeling results.

Note: Due to rounding, composition of diet may not add to 100. Conventional diet consists of balanced conventional rations, i.e., without triticale; triticale diet consists of balanced triticale-based rations (triticale inclusion limited to 30%).

Table A6. Comparison between composition, calculated analyses, and cost of conventional and triticale-based broiler rations, at Tunisian prices and using triticale with a low protein content (11%) and low lysine content (0.3%)

	Starter		Grower		Finisher	
Ingredient	Conventional diet	Triticale-based diet	Conventional diet	Triticale-based diet	Conventional diet	Triticale-based diet
Composition (%)						
Maize	46.74	..	57.97	..	64.64	..
Soybean meal	36.74	33.04	27.83	23.26	22.80	16.67
Triticale	..	49.66	..	61.52	..	69.68
Maize gluten	5.00	5.00	5.00	5.00	4.93	5.00
Soybean oil	7.27	8.06	5.32	6.63	4.13	5.10
Ccal	1.23	1.30	1.19	1.27	1.12	1.21
CaPh	1.90	1.75	1.65	1.47	1.40	1.18
Lysine	0.002	0.08	0.03	0.14	..	0.15
Methionine	0.12	0.10	0.006	0.02	..	..
Constants	1.00	1.00	1.00	1.00	1.00	1.00
Calculated analyses						
Met. energy (kcal/kg)	3,200	3,200	3,200	3,200	3,200	3,200
Protein (%)	23.00	23.00	20.00	20.00	18.30	18.00
Methionine (%)	0.525	0.500	0.380	0.380	0.352	0.337
Lysine (%)	1.200	1.200	1.000	1.000	0.850	0.850
Tryptophan (%)	0.284	0.303	0.236	0.259	0.209	0.230
Threonine (%)	0.865	0.945	0.747	0.846	0.680	0.781
Calcium (%)	1.00	1.00	0.90	0.90	0.80	0.80
Phosphorus (%)	0.45	0.45	0.40	0.40	0.35	0.35
Crude fiber (%)	3.68	3.76	3.38	3.48	3.22	3.30
Cost (TD/t)	**249.70**	**236.16**	**231.00**	**215.44**	**220.21**	**201.78**
Cost difference (TD/t)	**13.50**		**15.53**		**18.42**	
Cost difference (%)	**5.40**		**6.72**		**8.37**	

Source: Modeling results.

Note: Due to rounding, composition of diet may not add to 100. Conventional diet consists of balanced conventional rations, i.e., without triticale; triticale diet consists of triticale based rations with low protein (11%) and low lysine (0.3%) triticale.

Table A7. Comparison between composition, calculated analyses, and cost of conventional and triticale-based layer rations, at Tunisian prices and using triticale with a low protein content (11%) and low lysine content (0.3%)

	Starter		Grower-1		Grower-2		Layer	
Ingredient	Conv. diet	Trit.-based diet	Conv. diet	Trit.-based diet	Conv. diet	Trit.-based diet	Conv. diet	Trit.-based diet
Composition (%)								
Maize	66.35	..	70.02	..	76.52	..	70.60	..
Soybean meal	22.16	21.56	12.64	11.62	6.11	3.34	13.00	7.41
Triticale	..	72.90	..	78.36	..	84.17	..	74.90
Bran	3.54	0.23	9.02	5.05	12.30	8.76	..	..
Maize gluten	4.32	0.77	5.00	0.89	2.10	..	5.00	5.00
Soybean oil	..	1.05	..	0.91	..	0.81	0.97	2.20
Ccal	0.98	1.02	0.94	0.99	0.87	0.94	8.12	8.21
CaPh	1.64	1.44	1.38	1.16	1.14	0.90	1.27	1.19
Lysine	..	..	..	..	..	..	0.06	0.07
Methionine	..	..	..	..	..	..	0.02	0.04
Constants	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Calculated analyses								
Met. energy (kcal/kg)	2,900	2,950	2,900	2,950	2,900	2,950	2,900	2,900
Protein (%)	18.30	18.00	15.61	15.00	12.00	12.00	14.5	14.5
Methionine (%)	0.346	0.300	0.313	0.257	0.236	0.205	0.320	0.320
Lysine (%)	0.850	0.850	0.632	0.600	0.450	0.450	0.640	0.640
Tryptophan (%)	0.214	0.249	0.178	0.209	0.136	0.173	0.151	0.179
Threonine (%)	0.680	0.799	0.570	0.687	0.437	0.580	0.532	0.653
Calcium (%)	0.80	0.80	0.70	0.70	0.60	0.60	3.40	3.40
Phosphorus (%)	0.40	0.40	0.35	0.35	0.30	0.30	0.32	0.32
Crude fiber (%)	3.60	3.63	3.70	3.68	3.71	3.70	2.73	2.85
Cost (TD/t)	200.5	180.4	187.0	163.4	173.7	150.9	193.1	174.2
Cost difference (TD/t)	20.03		23.56		22.80		18.90	
Cost difference (%)	10.00		12.60		13.10		9.80	

Source: Modeling results.

Note: **Due to rounding, composition of diet may not add to 100. Conventional diet consists of balanced conventional rations, i.e., without triticale; triticale diet consists of triticale based rations with low protein (11%) and low lysine (0.3%) triticale.**

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