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TOWARDS SUSTAINABLE MILK PRODUCTION IN EGYPT: AN ANALYTICAL POLICY FRAMEWORK

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ABSTRACT

The current research provides an exhaustive analysis on the tendencies in the Egyptian dairy industry in relation to the efficacy of conflicts, future directions, and strategies for an improved efficiency in the dairy food security in the Egyptian dairy sector. Within this context, using economic models between 2005 and 2023, it was evident that there was a tremendous rise in the cow milk industry in terms of an average annual increase of 47.1 thousand tons at an annual compounded rate of 1.4%, while there was a tremendous drop in the buffalo milk industry as well as the goat milk industry with an annual rate of 3.7% and 6.6%, respectively. Therefore, even though there was a drop in the wheat-green fodder area under cultivation from 2.58 million acres to 1.75 million acres, the growth in the efficiency level of dry and concentrated feed with 40% and 43% improvement in efficiency, respectively, assisted in raising the productivity level due to the effective implementation of modern management practices, feed management, & technology implementation in the industry. The total milk production increased from 5.55 million tons to 7.37 million tons. The correlation study proved the existence of a positive relation between total dairy production and measures of quality of feed, hence establishing the effectiveness of optimal input management. The partial genetic substitute approach with a 25% replacement of local genetic strains of cows and buffaloes with superior foreign breeds projected an expected increase in total dairy production of 86%, thus meeting and exceeding the local needs of milk production for possible exports.

Keywords: Dairy production, Food Security, Self-sufficiency, Breed Improvement, Agricultural Policy, Egypt.

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INTRODUCTION

The dairy industry plays a prominent role in the global and national food security agenda as a source of quality animal proteins and as a tool for enhancing rural economies (FAO, 2020; Goma and Phillips, 2021; OECD, 2023). Milk has also gained prominent place as a nutrient-dense food rich in an ideal mixture of proteins, fats, carbohydrates, vitamins, and minerals (Haug *et al.*, 2007; Walther *et al.*, 2008). Especially in developing nations like Egypt, dairy products are recognized as one of the most readily and cheapest sources of animal proteins for the poor sections of society and are a major tool for the promotion of a particular health component (Muehlhoff *et al.*, 2013; Abd Alah., 2022).

The Egyptian dairy industry is a crucial part of the country's livestock industry and makes a significant contribution to agricultural GDP and the rural household sector's earnings (CAPMAS, 2023; MALR, 2023). Yet despite the fact that the industry has attained a high degree of self-sufficiency of around 88%, it is faced with inherent and environmental challenges such as the lack of pasture for the production of feed for the animals, high costs of production, lack of genetic improvement in the native breeds, poor milk cool chain facilities, as well as adverse climatic effects on the productivity of the animals in the country (El-Wakeel and Matar, 2023).

Over the past twenty years, Egypt's dairy industry has progressed steadily in its modernization process, with the development of specialized farming units that use high-productivity foreign breeds (MALR, 2023). However, small-scale or regular farming practices continue to be the norm in Egypt, accounting for the major source of milk production, often in conditions that are less-than-ideal in productivity (FAO, 2019; Abd Alah., 2022; OECD, 2023). Such a difference in productivity between specialized and small-scale dairy farming units is a major area of interest of agricultural policies, particularly in the light of the growth in domestic demand patterns in Egypt and its strategic outlook of attaining full self-sufficiency in milk (Negm *et al.,* 2025). In this sense, the policy entailing breeds enhancement, creation of feeding systems, advancement of supply chains and creation of rural infrastructure facilities in dairy industry is regarded as vital in enhancing Egyptian capability in milk production (Goma and Phillips., 2021; Walther *et al.,* 2008).

This study is therefore aimed at investigating the current situation of the dairy industry in Egypt, the effectiveness of the existing policies and coming up with alternative policies through the application of agricultural economics analysis, best practices and the ultimate goal of the dairy industry in Egypt developing in a sustainable way in terms of milk production, a fact that will see food security in Egypt.

MATERIALS AND METHODS

To explore the factors that influence milk production and discuss potential implications of suggested policy measures, the following econometric models were applied in the given research:

Simple Linear Regression: The time trend model was used to determine the rate of increase of milk production during the period under study (2005-2023) as follows:

$$\hat{Y}t = \alpha + \beta 1\, x + \varepsilon$$

Where:

Y^t: Predicted or expected value on the dependent variable Y at time t or at observation t.

α: The constant term or the value of Y when X=0.

β1: The slope coefficient; this measures the amount of change for a unit change in the independent variable (X).

X: The Independent Variable or Explanatory Variable used to predict Y.

ε: The error term. This is assumed to take random values and includes those aspects of Y that are not predictable from X. It is generally assumed to have mean 0 and to be distributed normally around 0. It is usually symbol

Simulation Model for Breed Improvement Scenario: For evaluating the result of genetic improvement policy, a simulation model using a replacement of 25% of local breeds by high-yielding breeds originating from other countries was developed.

$$Q' = Q + [(Pf - Pl) \times R \times N]$$

Where:

- Q′ = Projected total milk production after replacement (tons/year)
- Q= Current total milk production (tons/year)
- P_f= Average annual milk yield per foreign-breed animal (tons/head)
- P_l= Average annual milk yield per local-breed animal (tons/head)
- R= Replacement ratio (25% = 0.25)
- N = Total number of local-breed animals targeted for replacement

Data sources: This study uses secondary information gathered from a pool of officially recognized sources over the years (2005-2023). The most significant sources of information in the country are the Ministry of Agriculture and Land Reclamation (MALR) via its Economic Affairs Sector (http://www.agri.gov.eg), the Central Agency for Public Mobilization and Statistics (CAPMAS) (http://www.capmas.gov.eg), the Ministry of Planning and Economic Development (http://www.mped.gov.eg), and the National Planning Institute (http://www.npi.gov.eg). It was these bodies that offered critical information regarding investment in agriculture.

RESULTS

Economic Analysis of Food Security and the Role of the Livestock and Dairy Sector in Egypt:

Economic Contribution of the Livestock Sector to GDP and Food Security: The agricultural sector is an essential part of the Egyptian economy, accounting for about 11.64% of the country's GDP. It is evident from this information about Egypt's GDP sources that its relevance to our lives cannot be overestimated. The crop sector is contributing approximately 6.25% in the expanding industry of agriculture with the livestock sector having an estimated contribution of 4.26 to the GDP. It seems to be only 4.26% in the agricultural sector, but its significance is more justified when one examines its significance to the creation of jobs. Agricultural sector is a big job creator, it employs approximately 25.4% of the total number of employable individuals. Among them, the crop sector accounts for around 15% of the total percentage, while the livestock sector supports around 9.5% of the unemployed. It is essential to remember that all of these roles have a place in maintaining our communities and lifestyle. On the other hand, although the fisheries industry is not as major a contributor, it still has a contribution of 1% to our economy. Although its contribution may seem smaller compared to others, it is still part of the elaborate fabric of our agricultural scene because every aspect of agriculture, big and small, contributes to sustaining the economy as well as the people behind that economy (MALR,2023).

In the livestock industry, milk production is the biggest contributor with 1.99% to GDP, followed by red meat with 1.07% and poultry with 0.63%. Beekeeping activities and miscellaneous livestock-related activities also make small contributions to GDP at 0.39% and 0.20%, respectively. However, wool and hair production make negligible contributions to GDP. This further shows that there is considerable dominance by milk production and some unrealized growth areas here (CAPMAS 2023).

Trends in Food Energy Supply Adequacy: The information relayed through Figure 1 indicates an image showing the average food energy supply adequacy for Egypt, which records an erratic level of stability with fluctuations between 2009 and 2021. Therefore, between the periods covering 2009 to 2011, there was an enhancement in the level of the adequacy ratio, which improved from 141% to the highest level of 145% between the periods covering 2014 to 2017. This four percentage-point enhancement attests to an agricurally stable period, which was probably complemented by either an augmented domestic output level or specialized food import trends.

However, with the progression of years to 2016 through 2018, there was an element of reduction in the ratio level, which fell to 141% between the periods covering 2018 to 2020. This likely contraction was based on the effect related to a combination of various factors, including instabilities related to climate changes, rising food prices, and ineffective food supply patterns, among others.

The light at the end of the tunnel has been a recovering trend in the years 2019 to 2021 where the adequacy ratio has increased to 143%. However, it is also important to mention in this connection that the ratio continues to stay below the historical highs, thus, one should not forget about the challenge. The economic policy point of view to the above story is also the sensitivity of food security to external factors.

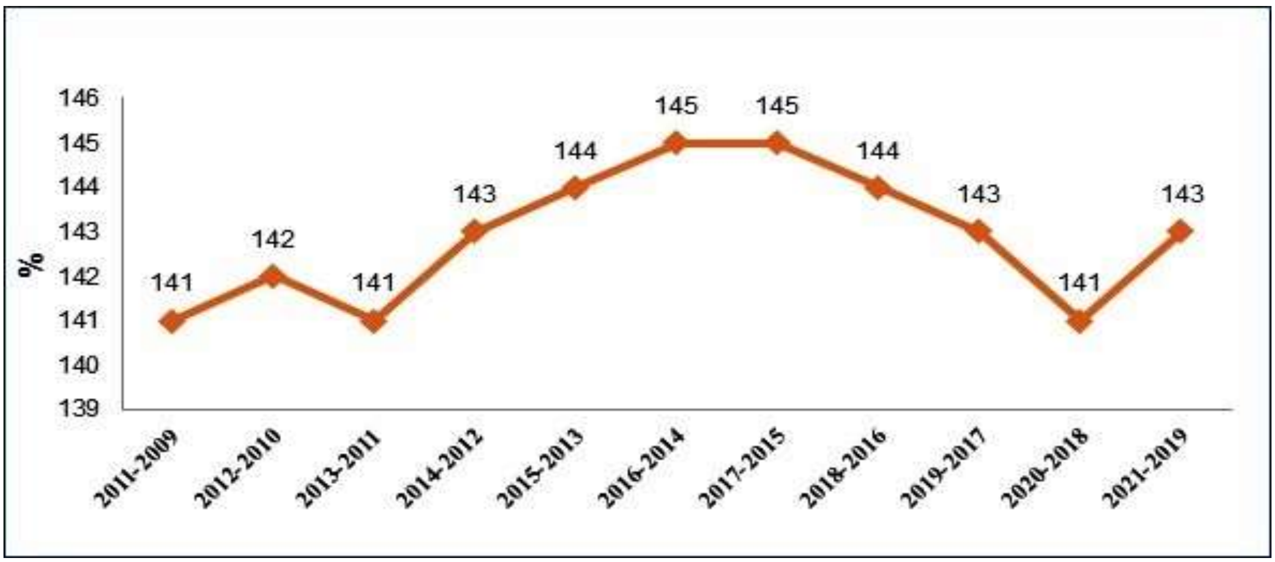

Figure 1: Average Adequacy of Food Energy Supplies to the Populations % in Egypt
Source: Authors Work based on the CAPMAS Data (2009-2021)

Protein Supply and Nutritional Security: The animal protein supplies have been fluctuating significantly with time as shown in Figure 2. There was an increase between 2009-2011 and 2011-2013 with a high of 25.3 grams per capita per day. It can be attributed to the fact that livestock production and economic performance are enhanced. A drop in the number of grams per capita per day to 23.7 was recorded between 2014 and 2016 possibly because of increased cost of production, transmission of animal diseases, and the increase in consumer purchasing power. Subsequently, supplies stabilized between 2015 and 2017, between 24.7 and 25 grams per capita per day, which may indicate a trend toward increased imports and improved production efficiency. The pursuit of food security will remain under constant pressure unless the supply of animal protein remains stable and reliable.

Production Dynamics and Structural Changes in the Dairy Sector: We now begin a critical evaluation of the process of milk production and consumption in Egypt, during the period of 2005-2023. It is a period during which Egypt hopes to become self-sufficient regarding dairy products. We can now analyze together the various differences which exist within this process of milk production and consumption. We will then be able to determine the important elements which contributed towards this process. It will allow us to better understand the numbers and the elements which lie upon.

Milk Production Trends: The data for milk production in cows showed a significantly increasing trend. The average production volume was approximately 3445.7 thousand tons with a yearly growth of about 47.1 thousand tons. The Average Annual Growth Rate was 1.4%. The coefficient of determination indicates that the variation in the data concerning the production of milk in cows by about 50% can be accounted for by the increase in time. The coefficient of determination value is represented by R^2=0.50.

On the contrary, buffalo-cum-dairy farming sectors have been found to have negative repercussions on milk production to the tune of 82.5 thousand tons per annum, and it is highly significant at the 1% level of significance. The calculated t-statistic of (-6.72) measures the strength of the above-stated negative relationship. Moreover, apart from the above, the coefficient of determination or R^2 = 0.73 measures the explanation of the time variable in explaining the changes of the buffalo milk production over the years; this implies the declining trend of the above-stated sector over the years.

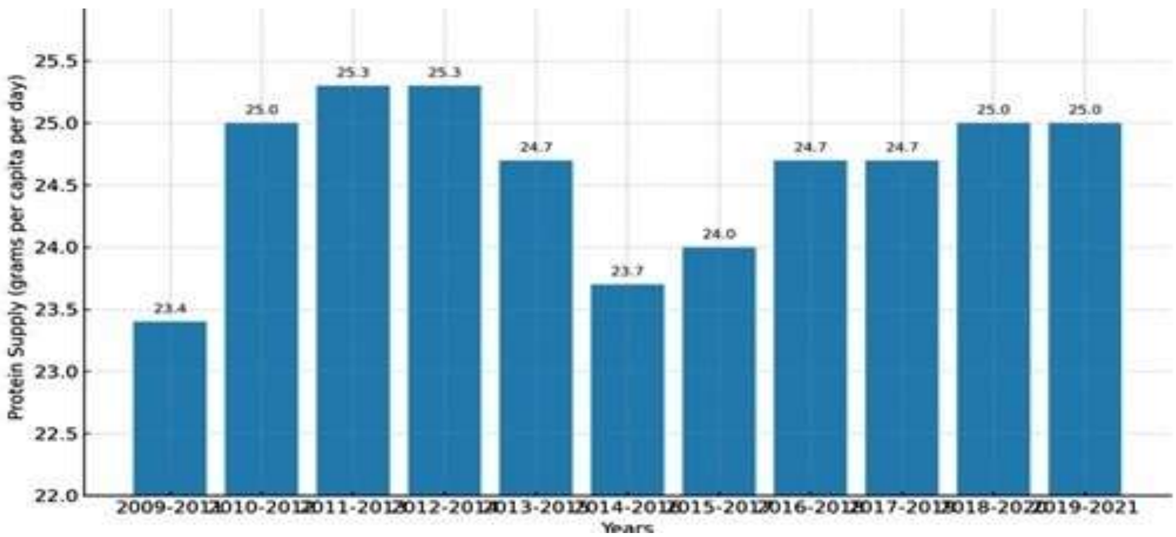

Figure 2: Average protein supply per capita of Animal Origin in Egypt

Source: Authors Work based on the CAPMAS Data (2009-2021)

Table 1: Simple Linear Regression of Domestic Milk Production in Egypt over the period (2005–2023)

Dependent Variable	Equations	R^2	F	Average	Annual change % rate
Number of Dairy Cows (1000 heads)	Ŷi = 1695.2 + 2.29 X (0.83)	0.00	0.69	1717.1	___
Dairy Production from Cows (1000 tons)	Ŷi = 2275 + 47.1 X (4.16)**	0.50	*17.35*	3445.68	1.4
Number of Milking Buffalo (1000 heads)	Ŷi = 1645.7 + 0.78X (0.36)	0.00	0.13	1653.1	___
Dairy Production from Buffalo (1000 tons)	Ŷi = 3047 – 82.5 X (-6.72)**	0.73	*45.13*	2222.11	3.7
Dairy Production from Goats (1000 tons)	Ŷi = 160.5 – 6.36 X (-6.99)**	0.74	*48.82*	96.84	6.6
Total Dairy Production (1000 tons)	Ŷi = 5482 + 28.2 X (1.24)	0.08	1.53	5733.1	__
Imports (1000 tons)	Ŷi = 1026 + 12.7 X (1.07)	0.06	1.14	1153.16	__
Exports (1000 tons)	Ŷi = 277.6+ 10.36 X (1.55)	0.12	2.4	381.21	__
Available for Consumption (1000 tons)	Ŷi = 6173 + 33.3 X (1.64)	0.14	2.7	6505.74	__
Gap (1000 tons)	Ŷi = 626 + 15.4 X (1.04)	0.4	1.56	772.7	___
Average Per Capita (kg/year)	Ŷi = 89.67 – 1.43 X (-5.95)**	0.67	35.5	67	1.9
Self-Sufficiency Rate (%)	Ŷi = 88.82 – 0.01 X (-0.03)	0.01	0.00	88.75	__

Where: Ŷt: Estimated value of the dependent variable; Xi: Time variable where i = (1. 2. 3.……. 19).

The value in parentheses indicates the calculated (T) value, (R^2) the coefficient of determination and (F) the significance of the model as a whole (**) at a significance level of (0.01).

Source: Calculated from the Ministry of Agriculture and Land Reclamation, Economic Affairs Sector, Livestock Statistics, 2023, www.agri.gov.eg.

Likewise, the production of dairy from goats has a large negative time trend, as shown by the results of the model, which indicate that, on average, the production decreases by about 6.36 thousand tons yearly at the 1% significance level. The t-value of –6.99 supports this consistent decrease. The model has a high explanatory power of 0.74, implying that about 74% of the changes in the production of goat milk are influenced by time. The percentage decrease of about 6.6% of the average production in a year indicates a low and weak economic motivation and a decrease in the profitability of goat milk production, especially due to the lack of adequate technical help and advances in production inputs.

Aggregate Dairy Supply and Self-Sufficiency: Domestic production of total dairy products showed a small positive trend; nonetheless, the model was insignificant in terms of the time trend. Imports and exports of dairy products showed a steady increase in data over the periods; in fact, the models were insignificant. The amount of product available for consumption showed a marginal increase, while the dairy gap showed a steady rise.

Per capita consumption of dairy products showed a statistically significant trend of decline, reducing by 1.43 kg every year, due to increasing prices. The ratio of self-sufficiency remained constant at 88.75% per year on an average, which does not show a statistically significant trend, meaning the demand is not being met by the increasing level of home production.

Comprehensive Economic Analysis: Egyptian Dairy Sector Performance (2005-2023):

Green Fodder Area (GFA): As illustrated in Table 2 above over the 18 years of 2005-2023, the trend of dramatic economic transformation in the dairy industry in Egypt is a successful paradigm shift towards a new era of production efficiency that is not dependent on the government but on the market. The Green Fodder Area (GFA) illustrates strategic decline in the area coverage of 2.58 million acres to 1.75 million acres in 2005 and 2023 respectively with a compound annual rate of growth of -2.1%. The area covered a reduction in green fodder area, yet still recorded significant improvements in every aspect of quality production.

Quantity of Dry Feed (QDF): The Quantity of Dry Feed (QDF) showed the largest improvement and rose drastically from 42.74 million tons in 2020 to 60.05 million tons by 2023. This is an indication and emphasis on the overall strategy aimed at providing year-round feed to dairy farmers through investments in production and techniques for production and preservation of hay and silage. Such investments minimize dependence on green fodder.

Quantity of Concentrated Feed (QCF): Similarly, QCF has also increased regularly from 6.09 million tons to 8.72 million tons. This is representative of the systematic strengthening of capacity in the feed industry, improved nutritional formulations, and better feed conversion efficiencies-essentials for ensuring the maximization of yields per animal and sustainable productivity growth in Egypt's dairy sector.

The World Market Price (WMP): This represents the least consistent but potentially most profitable factor, as it strides from a low of just 2.3 in the year 2005 to a staggering 14.9 in the year 2023. It displays a CAGR of a staggering 10.8% but remains extremely fluctuating, reaching a peak of 13.6 in the year 2020 but dropping to a trough of 10.4 in the year 2021 due to the outbreak of the COVID-19 pandemic. But as of the end of 2023, it displays a staggering potential for export opportunities to emerge as a whole Middle East dairy hub.

Table 2: Economic Analysis of Factors Affecting Milk Production in Egypt over the Period (2005–2023)

Year	Green Fodder Area (million acres)	Quantity of Dry Feed (million tons)	Quantity of Concentrated Feed (million tons)	Wholesale Milk Price (EGP/kg)	Total Dairy Production 1000 tons
2005	2.58	36.86	6.09	2.3	5551
2006	2.24	33.47	6.29	2.4	5787
2007	2.44	34.90	7.53	2.7	5925
2008	2.03	37.83	8.10	3.0	5980
2009	1.85	36.06	6.20	3.3	5624
2010	1.92	36.39	6.29	3.6	5774
2011	1.91	35.82	6.74	4.3	5803
2012	1.78	38.14	7.60	4.7	5848
2013	1.67	38.38	7.87	5.0	5554
2014	1.53	39.46	8.02	5.8	5666
2015	1.60	37.93	7.80	6.1	5245
2016	1.76	36.65	7.93	6.7	5089
2017	2.10	32.55	8.05	10.4	5395

2018	1.64	37.87	8.18	12.7	5173
2019	1.95	37.65	8.30	13.5	5227
2020	1.89	42.74	8.43	13.6	5578
2021	1.55	55.03	8.55	10.4	6165
2022	1.68	57.53	8.68	12.1	6769
2023	1.75	60.05	8.72	14.9	7375
Average	**1.89**	**40.28**	**7.65**	**7.24**	**5765**
Minimum	**1.53**	**32.55**	**6.09**	**2.3**	**5089**
Maximum	**2.58**	**60.05**	**8.72**	**14.9**	**7375**

Source: Calculated from the Ministry of Agriculture and Land Reclamation, Economic Affairs Sector, Dairy Production and Livestock Statistics, 2023. www.agri.gov.eg

Total Dairy Production (TDP) Exhibits sincere growth yet despite fluctuations, increasing significantly from 5.551 thousand tons in the year 2005 to 7.375 thousand tons in the year 2023, showing a sudden boost from the year 2020 to date, reflecting the achievement of quality parameters and the implementation of efficient strategies for increasing productive capabilities.

Efficiency within the sector's economy is indicated by the fact that it is inversely proportional to both reduced support from the government and increased outputs produced, with a 32% reduction in financial support and a 33% increment in total production outputs.

Table 3: Descriptive Statistics for Economic Factors of Milk Production over the period (2005-2023)

Variable	Mean	Std. Dev.	Min	Max	CV (%)
Total Dairy Production	5765.26	668.85	5089	7375	11.60
Green Fodder Area	1.89	0.28	1.53	2.58	14.81
Quantity of Dry Feed	40.28	8.96	32.55	60.05	22.25
Quantity of Concentrated Feed	7.65	0.82	6.09	8.72	10.72
Wholesale Milk Price	7.24	4.33	2.3	14.9	59.81

Source: Calculated by Authors based on the data in table (2).

Analysis on the coefficient of variation reveals that total dairy products (TDP) have a stable growth rate (11.60%), but whole milk powder (WMP) is volatile (59.81%). Such a scenario creates the potential for premium pricing when the conditions are ideal; however, it also provides risks that are best dealt with by using sophisticated methods for hedging. There are four economic phases that the analysis reveals, these being

- **Foundational period (2005–2010):** steady growth with gradual support reduction;
- **Adaptation phase (2011–2016):** slower growth due to political and economic disruptions, though quality continued to improve;
- **Recovery and reform period (2017–2019):** renewed production growth accompanied by rising global prices;
- **Transformation phase (2020–2023):** faster growth, quality innovations, and more high-quality positions on the premium market.

Impact of Feed Quality and Market Dynamics on Dairy Production and Competitiveness: A Correlation-Based Analysis: The patterns of correlation show that production scales with quality indicators are strongly and positively correlated, which is an indicator of the successful economies of scale and feasible expansion strategies into the premium market segments. Within a broader macro-economic approach, the industry reflects the extensive reform agenda in Egypt in a manner that the targeted liberalization has enhanced competitiveness and provided appropriate protection to the food security elements. Nevertheless, the continued volatility of prices gives us a reason to consider advanced risk-management instruments such as hedging of commodities, agricultural insurance and forwards contracts.

This tremendous improvement in quality, particularly the sharp increase in the QDF between 32.55 and 60.05-a rise in QDF of 85% in a relatively brief time-nearly certainly places the Egyptian dairy products in the category of high-income overseas markets, which, in turn, may turn into a booming foreign exchange revenues, and, thus, improves the balance of payment status, and offers massive-scale employment opportunities in the rural areas.

This is supported in Table 5 where Total Dairy Production (TDP) shows that it has high positive correlations with World Market Price (WMP), Quantity of Dry Feed (QDF), and Quantity of Concentrated Feed (QCF) which established that the success of the dairy industry is directly affected by better quality and better global conditions. Conversely, there is a negative relationship between Green Fodder Area (GFA) and the variables TDP, QDF, and WMP, which forms a structural transformation of the traditional designs to the more efficient and global oriented designs towards better farming which further underlines the evidence of appropriate allocation and enhanced conversion rates.

Table 4: Correlation Matrix for Economic Factors of Milk Production in Egypt over the period (2005-2023)

Variable	TDP	GFA	QDF	QCF	WMP
Total Dairy Production (TDP)	1.000	-0.312	0.742	0.658	0.823
Green Fodder Area (GFA)	-0.312	1.000	-0.534	-0.289	-0.467
Quantity of Dry Feed (QDF)	0.742	-0.534	1.000	0.445	0.692
Quantity of Concentrated Feed (QCF)	0.658	-0.289	0.445	1.000	0.578
Wholesale Milk Price (WMP)	0.823	-0.467	0.692	0.578	1.000

Source: Calculated by Authors based on the data in table (2).

Also, the positive correlation between quality factors (QDF, QCF) and premium global factors (WMP) is high, which also underlines the usefulness of quality improvement in creating superior pricing and global competitiveness.

Economic Analysis of Factors affecting Milk Production

Model 1: GFA = f(TDP): This regression analysis, as seen in Table 5, reveals that the model identifies that there is a strongly negative relationship between GFA (dependent variable) and TDP (independent variable). In fact, for every one-unit increase in TDP, GFA declines by 0.0001224 units, which is highly significant at the 5% significance level (p = 0.042).

The highly significant model constant of 2.595 (p = 0.000) suggests that at the value of TDP = 0, the value of GFA at which the curve crosses the y-intercept is 2.595. However, the explanatory power of this model is rather weak and can be seen through its $R^2 = 0.220$, implying that TDP explains only 22% of the variation in GFA, while the other 78% is attributed by other variables.

The adjusted R-squared of 0.174 is a more conservative measure of how well the models fit a dataset given the degrees of freedom. The F-statistic of 4.79 with a significance of 0.042 further strengthens the overall significance of the models, indicating that it is not a random occurrence, but then again the low value of the R-squared statistic again reiterates that multiple models are required for more accurate prediction of the variation in GFA.

Model 2: QDF = f(TDP): The regression equation's result, as shown in Table 5, shows that there is a strong and substantial positive relationship between the dependent variable and TDP. For every unit increase in TDP, the regression equation shows that the dependent variable increased by 0.01337 units. This is a significant and trustworthy outcome since the t-value is 6.68 and its corresponding p-value is less than 0.001. Since the p-value is 0.005 and since the dependent variable would be -36.71 units if TDP = 0, the negative crossover point of -36.71 is also a significant and trustworthy outcome. The regression equation fits well, $R^2 = 0.724$ indicates that 72.4% in the dependent variable is accounted by TDP. In meeting the social

The strength is further supported by the fact that the adjusted $R^2 = 0.708$, while adjusting for degrees of freedom. The fact that F-statistic = 44.6 with a very low p-value of less than 0.001 provides extremely strong evidence about the statistical significance of the model, in general, in being due to chance; this particular relationship being due to chance is very, very unlikely. The extremely high value of t for the coefficient of TDP is 6.68; p-value being very low indicating's a very precise linear relationship that helps in making this model much more predictable than other models having lower R^2 values.

Model 3: QCF = f(TDP): The results obtained above are given in Table (5), depicting a strongly positive significant correlation of the dependent variable with TDP, because the coefficient allows a 0.001012 unit augmentation of the dependent variable by a unit augmentation of TDP with T=6.33, p=0.001. The non-significant intercept of 1.81 with a significance of 0.064 represents the absence of a plate in the section or the insignificant fixed point of TDP=0. The R^2 value of 0.702 along with R^2 of 0.684 signifies a highly optimized model. The evidence of the enhanced linear correlation is provided by the F-test value of 40.1, p<0.001. The non-significant value of the maximal resolution of the size of the intercept is given below.

Table 5: Correlation Between Key Feed Resources, Milk Price, and Total Dairy Production over the period (2005-2023)

Parameter	Coefficient	Std. Error	t-value	p-value	Significance
Correlation between green fodder area and total dairy production					
Model 1: GFA = f(TDP)					
Intercept	2.595	0.324	8.01	0.000	***
Total Dairy Production	-0.0001224	0.0000559	-2.19	0.042	**
R^2 = 0.220	Adjusted R^2 = 0.174	F-statistic = 4.79		p-value = 0.042	
The relationship between quantity of dry feed and total dairy production					
Model 2: QDF = f(TDP)					
Intercept	-36.71	11.52	-3.19	0.005	***
Total Dairy Production	0.01337	0.002	6.68	0.000	***
R^2 = 0.724	Adjusted R^2 = 0.708	F-statistic = 44.6		p-value < 0.001	
The relationship between quantity of concentrated feed and total dairy production					
Model 3: QCF = f(TDP)					
Intercept	1.81	0.92	1.97	0.064	ns
Total Dairy Production	0.001012	0.00016	6.33	0.000	***
R^2 = 0.702	Adjusted R^2 = 0.684	F-statistic = 40.1		p-value < 0.001	
The relationship between wholesale milk price and total dairy production					
Model 4: WMP = f(TDP)					
Intercept	-30.15	4.85	-6.22	0.000	***
Total Dairy Production	0.00649	0.00084	7.73	0.000	***
R^2 = 0.778	Adjusted R^2 = 0.765	F-statistic = 59.7		p-value < 0.001	

Source: Calculated by Authors based on the data in table (2).

Model 4: WMP = f(TDP: Table (5) presents the regression test results, and it can be seen that the regression result is highly significant and strongly positively correlated between the dependent variable and the value of TDP. A one-unit increase in the value of TDP raises the dependent variable by 0.00649 units (7.73 t-statistic, p = 0.001). The highly significant regression equation intercept value of −30.15 suggests that the value of the dependent variable for TDP = 0.

The goodness of fit of the model has come out to be very strong with a value of $R^2 = 0.778$ and adjusted $R^2 = 0.765$. The significance of the model has come out to be highly significant with a value

In brief, a great level of predictability is noticed in the case of TDP for all dependent variables, where quality factors and market price are influenced at an R^2 level above 0.70, and a weak but significant relationship can also be identified between allocation factors and allocation, measuring 0.22 at the R^2 scale.

Innovative Breeding Replacement Strategy for Egypt's Dairy Sector: One of the ways to achieve self-reliance in the sector, based on the results of the quantitative analyses of the factors of influence on the production of milk, would entail the reformation of the breeds of Egypt’s cattle population in terms of the replacement of local breeds with a low production rate by breeds imported from abroad but characterized by a high production rate. It can be observed in the data of the above table (6) that the number of local and cross breeds of cows averaged 1.48 million per annum between the years 2019 and 2023, with a corresponding total annual production of 1.97 million tons of milk, calculated on the basis of an individual’s total production of 1.3 tons of milk per annum. In contrast, the average number of imported breeds stood at merely 236 thousand, but the total annual production of milk was 2.74 million tons, based on an individual’s total production of 11.7 tons of milk a year – or a staggering 8.7 times the production of the local breeds. A similar difference in the order of 4.4 times was observed between the local and Italian breeds of buffaloes.

Scenario 1: Success of the Current 25% Replacement Strategy: A simulation of partial replacement involving 25% local & crossbreed cattle and 25% local buffalo with more efficient foreign breeds indicated that the level of replacement involving 370 thousand cows & 414 thousand buffalo could increase the total milk level to 11.27 million tons per year, as opposed to 6.07 million tons per year prior to the level of replacement. The level of this composition can potentially raise milk production by 86% to cover the deficit in the milk requirement, currently estimated at 4.3 million tons per year.

This situation mirrors the performance being made under the current 25% replacement rate of Egypt’s 25% breeding rate system of improved breeds of cattle being imported into Egypt. There has also been 8.7 times more production performance of 11.59 tons per head compared to 1.33 tons per head when compared to the native breeds of cattle. There has also been 4.5 times more production performance of 3.66 tons per head compared to 0.82 tons per head for the Egyptian buffalo. Consequently, there has been a major average annual production surplus in the dairy industry amounting to 4,330.7 thousand tons, at a value of $2.6 billion. This goes a long way in showing just how much it is advantageous to upgrade the genetic makeup in the industry, in addition to the potential for further growth through faster replacement programs.

Scenario 2: Accelerated 40% Breeding Replacement Strategy (10-Year Plan): This scenario outlines an accelerated 10-year replacement Breeding Plan that will enable the Egyptian dairy industry to develop along lines that promote a technology-oriented, genetically superior industry. This plan has three phases:

Phase 1 (1-3 years) – Genetic Upgrade: This stage aims to quickly enhance the production of milk through a genetic improvement process where 592,000 native cattle will be replaced with Holstein-Friesian and Simmental breeds producing 12-14 tons per cattle, and also 663,000 native buffalo will be replaced with Mediterranean Italian buffalo producing 4.2-4.5 tons per buffalo. The investment for this phase will be $1.2 billion and will form the biological base for enhancing production to achieve a significant output of total milk production, as well as efficient usage of land and water resources.

Phase 2 (4-6 years) – Precision Livestock Farming: Based on genetic improvement, this phase focuses on efficiency and sustainability by adopting AI-driven genetic selection, genomic analysis, and efficient herd management practices. An investment of $800 million would help create 15 regional breeding farms with precision feeding and health analysis technology, which would improve feed efficiency and water savings and lower carbon emissions, and accelerate the achievement of break-even by Year 4 with a high return on investment.

Phase 3 (Years 7-10) – Market Integration & Export Growth: This phase focuses: The third phase brings emphasis to the area of value addition and competitiveness in the global market by establishing 50 modern collection centers for milk as well as the introduction of organic and quality lines of dairy products. This phase requires an outlay of $600 million, with the objective of securing a 25% market share in the overseas market, increasing the earnings of exports as well as establishing the sector as a major hub for quality dairy products in the Middle East with a focus on overall annual surpluses of $4.8 billion, exports of $1.5 billion, as well as the generation of 180.000 jobs.

Table 6: Effect of Replacing Foreign Cattle and Buffalo Breeds on Milk Production in Egypt

Before Replacement

Years	Local & Crossbred Cows (1000 heads)	Milk Production from Local & Crossbred Cows (1000 tons)	Foreign Cows (1000 heads)	Milk Production from Foreign Cows (1000 tons)	Egyptian Buffalo (1000 heads)	Milk Production from Egyptian Buffalo (1000 tons)	Total Milk from Cows & Buffalo (1000 tons)
2019	1592	1876	216	2091	1698.9	1226	5193
2020	1544	2020	278	2261	1707.8	1265	5546
2021	1423	1982	215	2812	1616.7	1337	6131
2022	1406	1957	247	3335	1625.6	1445	6737
2023	1442	2007	224	3181	1638.4	1554	6742
Average	**1481.4**	**1986.4**	**236**	**2736**	**1657.48**	**1365.4**	**6069.8**

After Replacement (25%)

Years	Replaced Local Cows (1000 heads)	Milk Production from Replaced Cows (1000 tons)	Milk Production from Non-Replaced Cows (1000 tons)	Replaced Buffalo (1000 heads)	Italian Buffalo Productivity (1000 tons)	Milk Production from Replaced Buffalo (1000 tons)	Milk Production from Non-Replaced Buffalo (1000tons)	Total Production after Replacement (1000 tons)	Milk Consumption (1000 tons)	Milk Surplus/ Gap (1000 tons)
2019	398	3852.9	1407	424.7	3.4	1432.2	1274.2	10057.3	5934	4123.3

2020	386	3139.4	1515	427	305	1499.4	1280.9	9695.7	6693	3002.7
2021	355.7	4652.9	1486.6	404.2	307	1476.5	1212.5	11640.5	6822	4818.5
2022	351.5	4746	1467.5	406.4	3.8	1541.5	1219.2	12309.2	7294	5015.2
2023	360.5	5119.4	1505.2	409.6	3.9	1611.4	1228.8	12645.8	7952	4693.8
Average	**370.34**	**4302.12**	**1476.26**	**414.38**	**3.66**	**1512.2**	**1243.12**	**1269.7**	**6939**	**4330.7**

Source: Calculated from the Ministry of Agriculture and Land Reclamation, Economic Affairs Sector, Dairy Production and Livestock Statistics, 2023. www.agri.gov.eg

Table 7: Impact of Innovative Breeding Replacement Strategy on Dairy Production in Egypt

Items	Scenario 1 25% Replacement Strategy	Scenario 2 Accelerated 40% Breeding Replacement Strategy			Notes
Cattle Replacement Rate	25% (370K heads)	40% (592K heads)	Optimize existing	Maintain & expand	12-14 tons/head
Buffalo Replacement Rate	25% (414K heads)	40% (663K heads)	Optimize existing	Maintain & expand	4.2-4.5 tons/head
Phase 1 Investment	N/A	$1.2 Billion	-	-	Breeding & Infrastructure
Phase 2 Investment	N/A	-	$800 Million	-	Technology & Facilities
Phase 3 Investment	N/A	-	-	$600 Million	Processing & Marketing
Total Production	6.0698K tons	7.500K tons	8.500K tons	9.420K tons	55.2% Increase
Annual Surplus	4.331K tons	5.200K tons	6.000K tons	6.800K tons	$4.8B Value
Breeding Centers	5 centers	10 centers	15 centers	20 centers	AI & Genomic Testing
Feed Processing Centers	8 centers	12 centers	20 centers	25 centers	Precision Nutrition
Collection Centers	25 centers	35 centers	42 centers	50 centers	Modern Cooling Systems
Export Potential	$200M annually	$500M annually	$1.0B annually	$1.5B annually	25% International Share
Employment Generation	850K jobs	920K jobs	980K jobs	1.03M jobs	180K Additional Jobs
ROI Timeline	N/A	Initial Investment	Break-even	85% ROI	10-Year Horizon
Land Use Efficiency	Baseline	+15%	+28%	+40%	Per Hectare Output
Water Use Efficiency	Baseline	+10%	+18%	+25%	Reduction per Liter
Feed Conversion Ratio	8:1	7:1	6:1	5.5:1	31% Improvement

Source: Authors' Work Based on the data in Table 6

DISCUSSION

From the results of the study, there is an in-depth understanding regarding the dynamics in the Egyptian dairy industry regarding the relationship between production, quality of feed, genetic enhancement, as well as the integration policy. Our interpretation shows the strength of influence of Total Dairy Production (TDP) by the introduction of superior foreign breeds as well as improvements in the quality of the respective feeds, in line with the considerable level of differentiation in the level of productivity between the local breeds compared to imported ones in the Egyptian dairy industry. The 25% Replacement policy, which created an annual surplus of 4,330.7 thousand tons valued at $2.6 billion, emphasizes the positive influence in the application of genetic reforms in the industry, as supported by (Fawaz *et al.*, 2017) as well as (Mohamed, 2022), who argued regarding the significance of the livestock subsectors to the sustenance of rural life.

Furthermore, the modeled accelerated replacement of 40% also proves the potential for paradigmatic changes that can result from the integration of precision farming in the livestock sector, the use of genetic selection in the development of better breed varieties with superior traits, and the development of new market infrastructure systems. The expected outcome of 55.2% production rise and the adoption of efficient usage of land resources, water utilization rates, and consequently the reduction in the rate of feed conversion ratios highlight the combined effect of technology advancement and breed development approaches. This can be considered in accordance with the statements made by (Mostafa, 2021; Sarhan & Al Damrawi, 2022), as they stated the need to have data-driven approaches for the development of policies related to the modelled sustainable sectoral expansion. This case also confirms the view made by (El-Tahan & El-Sawy, 2014).

Our correlation studies emphasize the importance of the role of feed quality and prices in influencing the production outcome, which supports the finding of (Muehlhoff *et al.*, 2013; Abd Alah, 2022) about the importance of strategic intervention towards enhancing the national food security status. The finding about the negatively correlated result of TDP with Green Fodder Area (GFA) indicates a structural shift towards more efficiency-oriented approaches of production, which is almost partly supported by (Mohamed, 2022; Saad *et al.,* 2023), which stated about the non-proportional contributions of production factors towards enhancing the efficiency of production.

The robustness of our model (R^2 = 0.702 – 0.778) proves its high explanatory as well as predictive capabilities, outperforming a number of past research (Fawaz *et al.*, 2017), further complementing the idea that the performance of the sector is driven mainly by the basic inputs of production in quality feed, improvement, and market integration. The existence of the results of the threshold levels, as demonstrated by the negative values of the intercepts, further supports the idea of the minimum input requirement to achieve positive results as proposed by (Shaheen, 2011; Saad *et al.*, 2023).

In regard to macroeconomic circumstances, these findings confirm that the Egyptian dairy industry is influenced by economic and environmental elements, as supported by (Goma & Phillips., 2021; Abd Alah, 2022). As an illustration, the level of protein production is also prone to fluctuations that are comparable to those of the overall agricultural productivity and indicate that these industries are still very sensitive to the input price and environmental factors This is consistent with (Radwan *et al.,* 2017).

The findings are in line with suggestions of stringent policies and proper investments that focus on such sectors with varying priorities in line with the environmental trends to ensure the overall food security is maintained.

Egypt can guarantee its sustainability and competitiveness in the international dairy market through the use of technology and modernization, good breeding techniques and marketing. In fact, this is consistent with (El-Shater and Eid, 2019; Mohamed, 2022; Negm *et al.*, 2025), who asserted that the adequate industry-specific policies, including the enhancement of the supply chains, are the key to the enhancement in the industry. Overall, the findings have rendered it quite evident that the multidisciplinary approach is the key to the long-term development and competitiveness in the Egyptian dairy industry.

Conclusions: The commonalities in the priorities of realizing milk self-sufficiency have been highlighted in this analysis of the Egyptian dairy industry (2005-2023) where it is liquidated that the production deficit is 772.7 thousand tons, although the self-sufficiency ratio is 88.2%. The Structural Change of the industry is market-oriented and the growth of cow milk production is by 3.96% per year, and the buffalo milk production is declining by 3.17% per year, and the declining per capita consumption (–1.03 percent/year) is an indicator of the potential of modernization and the threat of food security. The simulation outcomes prove that the production gap may be bridged through genetic improvement, i.e., increasing the percentage of replacement by a breed by 25 to 40, producing a surplus of 4.8 billion dollars and creating 180,000 jobs which makes the policies aimed at genetic enhancement and feed efficiency, contemporary collection infrastructure, and enhanced market integration highly necessary.

Limitations and Future Research: Although the study provides great evidence to the proposed policies, the most important elements of the external factors that may limit the practical relevance of the policies are not considered. These include climate-related threats to livestock and feed, uncertainties in farmer adoption of new technologies due to socioeconomic barriers, and supply chain bottlenecks that may hinder delivery, especially for smallholders.

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