SUSTAVİANFEED

ALTERNATIVE ANIMAL FEEDS IN MEDITERRANEAN POULTRY BREEDS TO OBTAIN SUSTAINABLE PRODUCTS

Economic evaluation of the pilot activities

DELIVERABLE 3.6

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List of Abbrevations

BSFL	:	Black Soldier Fly Larvae
ALT	:	Alternative Diet
ALT+BSFL	:	Alternative Diet with Black Soldier Fly Larvae
CON	:	Control Diet
GPM	:	Gross Profit Margin
CBR	:	Cost-Benefit Ratio
RoI	:	Return on Investment
SP	:	Selling Price
CF	:	Cost of Feed
ADF	:	Augmented Dickey-Fuller Test
EU	:	European Union
WB	:	World Bank
WTP	:	Willingness-to-pay
ARMA	:	Autoregressive Moving Average
ARIMA	:	Autoregressive Integrated Moving Average
UB	:	Upper Bond
LB	:	Lower Bound

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Executive Summary

This study investigates the potential of local by-products and black soldier fly larvae (BSFL) as sustainable protein sources in the Mediterranean region. An economic analysis was conducted to compare these alternatives with conventional soybean-based feeds, revealing the potential of BSFL and local by-products to improve cost-effectiveness and environmental sustainability. The study employed methodological approaches such as partial budgeting, cost-benefit analysis, and sensitivity analysis to evaluate these alternatives.

The results indicate that incorporating local by-products into feed formulations can lead to cost reductions in production and enhance food security by decreasing dependency on imported protein sources. Furthermore, the use of BSFL in converting organic waste into valuable resources aligns with circular economic principles, while the integration of local by-products supports regional economic stability. Sensitivity analyses highlight the impact of fluctuations in BSFL prices on profitability, emphasizing the importance of closely monitoring market dynamics. The findings suggest that the adoption of local protein sources and BSFL can offer sustainable cost benefits, particularly for small-scale producers.

In conclusion, this deliverable offers valuable insights for long-term strategic planning in the poultry sector, emphasizing the benefits of economic viability. The integration of local by-products and BSFL represents a promising pathway toward more resilient and sustainable agricultural practices in the Mediterranean region.

1. Introduction

The poultry industry is a crucial sector in global food production, providing affordable animal protein to meet the demands of a growing population. A core requirement in poultry production is securing a high-quality, reliable protein source in feed, traditionally fulfilled by soybean meal due to its excellent amino acid profile and digestibility. Soybean meals have been the preferred protein source in poultry diets, essential for supporting growth rates, productivity, and health in poultry (Park et al., 2002). However, with the rapid growth of the poultry industry, the increasing demand for soybean meals has highlighted substantial environmental and economic challenges. These concerns have spurred research into alternative protein sources to meet feed requirements without compromising sustainability or economic viability (Belhadj Slimen et al., 2023).

The environmental impact of soybean production is significant. Soybean cultivation requires extensive land use and is linked to deforestation, biodiversity loss, and high-water consumption, especially in major producing regions like South America. The environmental costs associated with large-scale soybean farming contribute to greenhouse gas emissions, resource depletion, and land degradation, raising questions about its long-term sustainability as a feed ingredient in animal production (Barrera et al., 2024). Furthermore, the high demand for soybean meals affects the overall ecosystem, impacting soil health and contributing to land use pressures. In addition to the environmental footprint of cultivation, the transportation of soybeans to global markets further provokes greenhouse gas emissions, particularly due to the reliance on long-distance shipping and heavy logistics operations. This adds another layer of environmental cost, emphasizing the need for more localized and sustainable feed alternatives. These combined concerns necessitate an urgent shift towards feed alternatives that can reduce the poultry industry's environmental footprint and promote more sustainable production systems.

In addition to environmental issues, the economic impact of relying on soybean meals is substantial. The poultry industry's dependence on soybean meals creates exposure to global market fluctuations, which influence feed costs and producer profitability. Price volatility can be triggered by factors such as climate change, rising global demand, and competition for agricultural land, impacting feed costs in the poultry sector ((Jerzak & Śmiglak-Krajewska, 2020). As soybean prices increase, feed becomes a rather costly input, challenging small-scale and large-scale producers alike and threatening the stability of poultry production systems in both developed and developing countries. The reliance on imported soybean meals also poses supply chain risks, particularly for regions that do not produce soybeans domestically, which contributes to food insecurity and further raises production (Jerzak & Śmiglak-Krajewska, 2020; Sun et al., 2018; Wang et al., 2023)

The Mediterranean region illustrates these challenges severely, with its projected population of 560 million by 2030 increasing demand for food, especially protein-rich diets like poultry. This growth, particularly within low- and middle-income countries, drives a dietary shift towards greater consumption of meat, fruits, and vegetables, intensifying strain on already limited resources. Furthermore, the Mediterranean's vulnerability to climate change—through desertification, droughts, floods, and extreme heat, especially in North African countries—amplifies the urgency of transitioning to a sustainable agri-food sector (IPCC, 2023).

Considering these environmental and economic pressures, the search for sustainable, alternative protein sources has intensified. Researchers and industry stakeholders are exploring diverse options, from algae and plant-based proteins to agri-industrial by-products and insect-based feeds, to meet the growing demands of animal production sustainably. Plant-base proteins such as field bean, triticale, fava beans, peas, and agri-industrial by-products such as pea protein, sunflower meal, canola meal, corn gluten meal, dried distillers grains with solubles (DDGS), wheat middlings can be alternative to soybean (Ávila et al., 2020; De Morais Oliveira et al., 2016; El-Deek et al., 2020; Kirn et al., 2024; Mushtaq et al., 2007). These alternative protein sources can replace 10 to 30% soybean in broiler and laying hen diets without any negative effect on performance and product quality. However, there is missing information on whether this replacement is economical or not.

On the other hand, Black Soldier Fly (BSFL) larvae, a species of insect known for its ability to convert organic waste into high-quality protein, offers a promising alternative to traditional protein sources (Schiavone et al., 2017). BSFL (*Hermetia illucens*) can be reared on various types of organic waste, from agricultural by-products to food industry residues, thus supporting circular economy principles. By recycling organic waste into valuable protein, BSFL production reduces the environmental impact of feed production, offering a dual benefit by simultaneously addressing waste disposal issues (Hilo et al., 2024; Matheka et al., 2022; Nana et al., 2019). The ability to cultivate BSFL locally further enhances their appeal, as it can reduce transportation costs, minimize import dependencies, and strengthen regional food security, particularly in areas where feed supply chains are vulnerable to external disruptions (Chaix-Bar et al., 2023; Purnamasari et al., 2022; Shit, 2021)

In terms of nutritional value, BSFL offer an amino acid profile like soybean meals, with high levels of fatty acids and protein, and support growth rates and productivity when integrated into feed (Barrera et al., 2023). Partial replacement of soybean meal with 10-25% of BSFL improved growth performance and feed efficiency (Bejaei & Cheng, 2023; Facey et al., 2023; Fruci et al., 2023) of broiler chickens and egg yolk color and shell quality of laying hens (Mwaniki et al., 2018). However, the 50% or full substitution of soybean meal with BSFL has yielded negative results by reducing growth rate, feed intake, and feed efficiency, as well as increased mortality rates (Chobanova et al., 2023; Facey et al., 2023). These findings highlight the need for balanced dietary formulations and indicate that partial replacement is a more effective approach for maintaining performance and product quality (Murawska et al., 2021; Patterson et al., 2021).

Economically, BSFL shows considerable promise as a cost-effective feed ingredient. Studies demonstrate that BSFL production can be scaled effectively and locally, potentially lowering the cost of protein in poultry feed. In regions where soybean imports contribute significantly to production costs, BSFL presents a local alternative with the potential for long-term cost savings. For instance, a study conducted in Uganda estimated that replacing conventional ingredients with insect-based feed could yield net economic benefits of USD 0.73 billion over 20 years, with a benefit-cost ratio of 28:1 and an internal rate of return of 138%, highlighting insect-based feed as a profitable investment (Abro et al., 2022).

The commercial poultry production mostly depends on commercial hybrids which are selected for their high egg or meat production. However, using the limited number of commercial breeds may reduce genetic variability. Native (local) chicken breeds, which are characterized by their resistance and adaptability to the environment, also play an important role in sustainable poultry production as genetic resources and improving the socio-economic status of smallholder producers and rural communities (Franzoni et al., 2021). Adopting local breeds for sustainable production could be key to boosting the productivity of small-scale chicken farms. Considering the high costs and price fluctuations of corn and soybean meals and decreased genetic diversity of chickens, poultry production can be limiting for poultry producers and small farmers, affecting their profitability and sustainability. The SUSTAvianFEED project exemplifies these efforts, targeting sustainable poultry feeding with local feedstuffs, bakery and agri-industry by-products and BSFL as a protein alternative. Through pilot studies in Spain, Italy, Tunisia, and Turkey, SUSTAvianFEED project evaluates the impact of local feedstuffs and BSFL in local meat- and egg-type chicken diets on performance, product quality, animal health and welfare, as well as their potential to provide economic and environmental benefits.

This deliverable focuses specifically on assessing the economic viability of incorporating local ingredients and BSFL as sustainable alternative protein sources in local and commercial egg- and meat type chicken's diets within the SUSTAvianFEED project. By conducting a comprehensive economic evaluation, including partial budgeting, cost-benefit analysis, and price forecasting, this deliverable seeks to demonstrate the potential economic benefits and cost-effectiveness of diets with increased amount of local ingredients, including a BSFL-supplemented alternative compared to traditional soybean-based diets for broiler production in the Mediterranean region.

2. Objective

The objective of Deliverable 3.6 is to evaluate the economic implications of the proposed production system for farmers, with a particular focus on small producers in each pilot region. This evaluation entails a comparison of the proposed sustainable poultry feed diet with existing conventional diets, and provides an overall picture, along with opportunities and recommendations for different actors in the supply chain.

3. Materials and Methods

All pilot studies were conducted in accordance with the local Animal Experiments Ethics Committee. All birds in the pilot studies were raised under standard management conditions. Details of the animal material, housing conditions, and experimental diets of the pilot studies can be found in Deliverable 3.2. The materials and methods used in the pilot studies were briefly explained in the present deliverable.

3.1. Experimental facilities, housing conditions, diets, and measurements

UMU: The experiments were carried out at the experimental farm of the University of Murcia. The hens were obtained from a commercial farm (Granja Santa Isabel, Córdoba, Spain). 17-week-old Isazul laying hens (n=120 hens) were randomly assigned to one of three dietary treatment groups, with five replicates per treatment. The dietary treatments:

-Control treatment (CON): A standard diet composed of soybean meals, corn, and wheat.

-Alternative feed (ALT): A diet where soybean meal and corn were partially replaced with locally sourced plant-based alternatives, including pea meal, corn dried distillers' grains (DDGs), and a higher percentage of sunflower meal.

-ALT+BSFL treatment: The same alternative feed as the ALT group but supplemented with 5% whole dehydrated black soldier fly larvae (BSFL). The larvae supplementation was calculated weekly based on the dry matter intake from the previous week.

The initial weight was measured at the beginning of the trial (6 weeks), the hens were reweighed after 6 weeks the adaptation period, and at 28, 32, and 38 weeks of age. Egg production was recorded daily. Feed consumption and egg weight were recorded weekly.

UNITO: The experiments were carried out at the experimental poultry facilities of the University of Turin. 39-day-old Bianca di Saluzzo birds (n=144 chicks) were divided into three groups, each consisting of 6 replications. Each group received a different dietary treatment:

- The control group (CON) was fed a standard commercial diet based on traditional ingredients, including soybean meals.

- The first alternative group (ALT) received a diet where soybean meals were completely replaced with alternative ingredients, such as corn meal, field bean, pea protein, barley, sunflower meal, corn gluten.

- The second alternative group (ALT+BSFL) was given a diet that replaced soybean meal with alternative ingredients, along with 5% of the expected daily dry matter intake supplemented by dehydrated black soldier fly larvae (BSFL).

Body weights of birds and feed consumption were measured on the day of the hatch, d 39, 60, 81, 102, 123, 147, 174 and 175 (slaughter age). At 147 and 174 days of age, 12 birds from each dietary treatment were slaughtered to obtain carcass weights.

ISA-CM: For the fattening trial, slow-growing breed (SASSO) T44 male broiler chicks (n=180 chicks) were used (15 pen replicates x 12 birds/pen replication). The fattening experimental period started at 37 and ended at 86 days of age.

For the laying hens trial, 30-week-old Lohmann White hens (n=150 hens) were used (15 pen replicates × 10 hens per pen). The egg trial ended after a duration of 10 weeks. The birds were randomly divided into three groups and fed one of the three experimental diets formulated taking into account the requirements of meat-type chickens and laying hens. Briefly,

1) a standard corn-soybean meal-based diet (control diet CON),

2) an alternative diet (ALT) containing local ingredients or by-products as partial substitutes for corn and soybean meals. Alternative ingredients used in feed formulas were triticale, canola meal, faba beans.

3) an alternative diet + BSFL (ALT + BSFL) containing local ingredients or by-products and dried full-fat BSFL. BSFL were adjusted to account for 5% of the estimated daily feed intake either for fattening or laying hens trials.

During the meat-type chickens trial, feed intake was controlled weekly. Initial and final body weight in the grower and finisher periods were recorded. On day 86, 30 birds (10 birds/treatment) were slaughtered to obtain carcass weight.

In the egg-type chicken experiment, the live body weight of the chickens was recorded at the beginning and end of the experiment. Feed consumption, egg production (number of laid egg and egg mass) were daily registered. The experimental period lasted for 10 weeks.

EGE: Day-old mixed-sex chicks obtained from a Local (Anadolu-T dam line) and commercial broiler breeder strain (Cobb500) were used (n=245 chicks/strain). The chicks from each strain were randomly divided into three groups and fed one of three diets. There were 6 replicated pens/diets. The diets were;

- The first group was fed a typical soybean-corn diet (CON).
- The second group was fed an alternative diet in which soybeans were partly replaced (ALT) (SPR diet) with local agri-industrial byproducts, consisting of high-protein sunflower meals, brewers dried grain, and wheat middlings.
- The third group was fed a diet supplemented with dried BSF (5%) larvae meal to the ALT diet (ALT+BSFL).

Body weights of Anadolu-T birds were measured on the day of the hatch, d 10, 25, and 55 (slaughter age) while body weight of Cobb broilers was measured on the d of the hatch, 10,25 and 40 (slaughter age). Feed consumption was measured on the same day. At slaughter age, 18 birds from each strain were slaughtered to obtain carcass weights.

3.2. Methodology used for Economic Analysis

The economic sustainability of implementing experimental diets including alternative local protein sources with or without BSFL in the poultry industry were evaluated from the perspective of the economic outcomes for poultry farms.

Various economic models, such as partial budgeting and cost-benefit analysis, are widely employed to evaluate the anticipated effects of new strategies in animal production on business income and to guide future production strategies (Harrison, 1996; Jerlström et al., 2022; Rushton, 2008; Tandoğan & Çiçek, 2014). This project aims to assess the economic viability of alternative diets, for which partial budgeting represents the most suitable analytical approach. This method calculates the costs and revenues associated with changes in production, illustrating the resulting net change in producer income (Anonymous, 2018; Eleveld, 1987; Horton, 1982; Rabin et al., 2007). This approach operates on the premise that any minor organizational change in a farm business may lead to one or more of the following: reduction or elimination of specific costs, reduction or elimination of certain returns, generation of additional costs, or generation of additional returns (Dalsted & Gutierrez, 2010).

In partial budgeting, only the resources directly affected by the change are considered; resources that remain constant are excluded. This method is frequently used to evaluate the economic impact of shifts in farm management practices, product modifications, or new technology adoption (Allen, 2006; Cox et al., 2009; Engle & Brown, 1999; Tamirat & Pedersen, 2019). The method is widely preferred in animal husbandry economics, with applications across dairy farming (Del Real et al., 2007; Overton, 2005; Swinkels et al., 2005) and poultry production (Verspecht et al., 2011).

The method involves comparing total costs and benefits, estimated by calculating additional and reduced costs and returns, as shown in Table 9 (Rabin et al., 2007). The budget consists of two columns and four sections—additional returns, reduced returns, additional costs, and reduced costs—where additional costs and reduced returns comprise the cost section, while additional returns and reduced costs constitute the benefits section. Together, these components reflect the net effects of the proposed change on the business (Rabin et al., 2007).

Table 1. Partial Budgeting

Costs	Benefits
Additional Costs (A)	**Reduced Costs (D)**
(costs incurred by the new application)	(costs eliminated with the new application)
Reduced Returns (B)	**Additional Returns (E)**
(returns abandoned by the new application)	(returns generated by the new application)
Total Costs (C=A+B)	**Total Benefits (F=D+E)**
G. Net Change in Profit (F - C)	
H. Benefit / Cost Ratio (F ÷ C)	

Source: (Rabin et al., 2007).

In addition to partial budgeting, this project incorporates cost-benefit (CB) analysis to comprehensively assess the economic sustainability of experimental diets, including local feeds and an insect-supplemented alternative, in poultry production. Cost-benefit analysis is a widely applied tool in agricultural and animal production economics, particularly in evaluating the economic feasibility of new practices and technologies (Boardman et al., 2011). This method enables a thorough assessment of the net economic value by comparing projected costs and benefits over time. Its relevance is further heightened when outcomes include both financial and non-financial benefits, providing a holistic view of potential gains or losses.

The economic implications of substituting soybean meals with local ingredients and BSFL were also evaluated using cost-benefit analysis. Key criteria such as gross profit margin (GPM), cost-benefit ratio (CBR), and return on investment (RoI) are calculated to evaluate the economic viability of alternative diets. The costs of feed consumed were determined by evaluating the prices of ingredients and considering the quantities of each item used in the diets. The GPM was calculated using the following formula GPM= total selling price of carcass (SP) or unit egg - cost of feed consumed (CF) (in Euro). The utilization of CBR within the framework of cost-benefit analysis was employed to succinctly assess the economic worth of substituting soybean meals with local ingredients and BSFL. The CBR was determined by dividing SP by the CF. A CBR value above 1 indicates that the benefits derived from production have surpassed the associated production costs, whereas a value below 1 suggests the opposite. RoI is a metric used to evaluate the profitability of an investment by comparing the gain or loss achieved to the amount of money initially invested. RoI was calculated by the formula RoI=(GPM/CF) x100. The greater the value of RoI, the more favorable the financial gains of the project being evaluated (Onsongo et al., 2018).

Partial budgeting and CB analysis provide complementary insights into the feasibility of insect-based feed in poultry production. While partial budgeting examines immediate changes, CB analysis incorporates both short- and long-term impacts, ensuring robust economic analysis to inform decision-making.

To achieve the SUSTAVIANFEED project's objectives of reducing poultry feed production costs by at least 6% and total production costs by at least 4%, sensitivity analysis was conducted alongside cost-benefit analysis. This approach examined the effects of price fluctuations in feed ingredients (e.g., BSFL and soybean) and outputs (e.g., chicken meat and eggs), offering deeper insights into achieving cost advantages.

Sensitivity analysis is an essential tool in cost-benefit analysis to assess the impact of uncertainty in key input variables on project outcomes (Linton, 2024). This analysis helps decision-makers better understand the reliability of the results and identify which variables have the most significant influence on the outcomes, enabling more informed decision-making (Więckowski & Sałabun, 2023).

Sensitivity analysis is typically conducted in several steps (Anonymous, 2006). The first step involves identifying the key variables to be analyzed. In the cost-benefit analysis conducted, the variables that most influenced the outcomes were identified as BSFL price, prices of conventional ingredients (soybean, corn), and sales prices of poultry meat and eggs.

In the next step, a minimum and maximum value range was determined for each key variable. For instance, for BSFL prices, a range slightly below and above the current market price can be used. In this study, however, a different approach was used to determine the variable ranges. A forecasting model was employed to predict possible changes in the primary variables (BSFL price, prices of conventional ingredients, poultry meat, and egg prices) over the next five years. This model used historical data to provide projections on how prices might evolve in the future.

The reliability of the results of an economic analysis largely depends on the quality of the information used in it. Therefore, in this study, primary data from pilot experiments were used in the partial budget and cost benefit analysis. These cover technical (zootechnical) information, particularly information on feed consumption and yields, market prices of feed ingredients and final products (poultry eggs and meat).

Table 2 presents an organized depiction of the key variables and data sources incorporated into the time series and grey modelling analyses for this study. It details the information on the data for key variables such as broiler and egg selling prices, along with prices of significant feed components: BSFL, soybean, soybean meal, corn, and fish meal. The data spans varied periods, with long-standing commodities like broiler and soybean prices dating back to 1979, providing a substantial historical foundation. By contrast, data for BSFL prices only begins in 2016, reflecting the recent emergence of insect-based feed as a research area. Data sources include the World Bank and the EU Agri-Food Data Portal. Broiler prices were derived from world prices obtained from the World Bank (WB). Egg prices were based on prices from Spain within the European Union (EU). For Tunisia, local egg prices were considered to better reflect local conditions. Feed ingredient prices were also based on world prices obtained from the WB.

Table 2 Variables and Databases used in the Time Series and Grey Modelling Analysis

Variables	Period	Source
Broiler wholesale price (€ per kg)	1979-2023	World Bank Commodity Price Data (The Pink Sheet)
Egg selling price (€/egg) (barn, for Spain) Egg selling price (€/egg) (Tunisia)	1998-2024	EU, Agri-Food Data Portal
BSFL Prices (€/kg)	2016-2023	Entomo
Soybean prices (€/kg)	1979-2023	World Bank Commodity Price Data (The Pink Sheet)
Soybean meal prices (€/kg)	1979-2023	World Bank Commodity Price Data (The Pink Sheet)
Corn prices (€/kg)	1979-2023	World Bank Commodity Price Data (The Pink Sheet)
Fish meal (€/kg)	1979-2023	World Bank Commodity Price Data (The Pink Sheet)

Sensitivity analysis was conducted to evaluate the potential impacts of price fluctuations on the financial viability of diets developed for broiler and laying hens. Five specific scenarios were developed to reflect realistic market conditions and assess the profitability of the proposed diets. These scenarios focused on variations in BSFL, broiler, and egg prices, as well as the prices of conventional ingredients used in feed formulations.

The scenarios developed for the sensitivity analysis:

1. Base case: average prices for BSFL, soybean, soybean meal, soybean oil, corn and outputs (broiler and egg)
2. Optimistic scenario: lower bound BSFL prices, average prices for soybeans, soybean meals, soybean oil, corn, and outputs (broiler and egg)
3. Worst scenario: upper bound BSFL prices, average prices for soybeans, soybean meals, soybean oil, corn, and outputs (broiler and egg)
4. BSFL average price, upper bound soybeans, soybean meal, soybean oil, corn prices, average price for outputs (broiler and egg)
5. BSFL average price, soybeans, soybean meal, soybean oil, corn average price, willingness-to-pay (WTP) price for outputs (broiler and egg)

Price analysis in the poultry industry, particularly for broiler and egg prices, commonly employs a variety of methods to understand price dynamics. While techniques like regression analysis, supply and demand modelling, cost-plus pricing, and comparative market analysis offer valuable insights, this study focuses on time series analysis for several key reasons.

Time-series analysis is frequently used to examine historical price trends and identify seasonal or cyclical fluctuations in broiler and egg prices. This method is particularly relevant due to the readily available data on these prices over extended periods, allowing for reliable analysis. Additionally, chicken and egg prices are known to exhibit seasonal fluctuations and cyclical movements influenced by factors like consumer demand, production costs, and weather patterns. Univariate time series analysis effectively identifies these patterns to forecast future price movements without the complexity of considering multiple variables.

However, to analyze BSFL prices, a different approach is necessary. As BSFL production is a relatively new sector with limited historical price data, this study utilizes grey model forecasting. This method is well-suited for making predictions from limited datasets, accounting for uncertainty and incomplete information to provide valuable insights into future BSFL price trends. The Grey model is a forecasting method capable of working with limited and incomplete datasets. It is particularly effective for making reliable predictions with short time series. Based on Grey system theory, this model handles uncertainties by mathematically supplementing incomplete information for analysis. The most commonly used version, GM(1,1), employs first-order differential equations to predict trends in time series data. The model first smooths the raw data using an accumulated generating operation (AGO) and then predicts future values through differential equations. The accuracy of predictions is assessed by optimizing model parameters and conducting error analyses. The Grey model is widely used in fields such as agriculture, economics, and engineering for short-term forecasting.

4. Results and Discussion

4.1. Results of Partial Budgeting Analysis

Interest in poultry production has shifted from traditional feed compositions to alternative formulations because of its potential to enhance sustainability and cost-effectiveness. A partial budgeting analysis was, therefore, carried out to investigate the economic outcomes of replacing a control diet with two alternative diets, Alternative 1 (ALT) and Alternative 2 (ALT + BSFL), for broiler production in Italy, Tunisia, and Türkiye and egg production in Spain and Tunisia.

4.1.1. Broiler Production

The partial budgeting analysis, examining the economic implications of shifting from the control diet (CON) to Alternative 1 (ALT) for broiler production in **UNITO pilot**, presents a structured breakdown of added incomes, added costs, reduced incomes, and reduced costs per bird. The analysis offers insights into the financial viability of this shift, considering various feed components and income changes.

The economic implications of adopting Alternative 1 (ALT) for Bianca Saluzzo broilers in UNITO were examined to provide a comparative perspective on the financial feasibility of dietary transitions across different regions and breeds. The transition to ALT did not generate any added income. However, the shift introduced significant additional feed costs, amounting to €2.9751 per bird. The major contributors to these costs were corn gluten (€1.1394), field beans (€0.6843), pea protein (€0.6188), and sunflower meal (€0.3188). Other ingredients, such as barley (€0.1154) and L-lysine (€0.0982), also added to the overall feed cost, although to a lesser extent. Cost savings from the transition totaled €2.3585 per bird, primarily driven by reduced reliance on soybean meal (€1.6942) and corn (€0.5507). However, the shift resulted in a reduction in the selling price per carcass by €0.2323. The overall economic effect of the shift to ALT was a net income loss of €-0.8489 per bird (Table 3).

Table 3. Partial Budget Analysis: Economic Impact of Feed Ingredient Changes in Broiler Production (shift from CON to ALT (€/per bird) (UNITO Pilot Bianca Saluzzo)

Added income due to change		***Added costs due to change***	
Increase in total selling price per carcass	0.0000	Corn gluten	1.1394
		Barley	0.1154
		Sunflower meal 37	0.3188
		Pea protein	0.6188
		Field ben	0.6843
		Calcium carbonate	0.0002
		L-lysine	0.0982
Total Increase	**0.0000**	**Total Increase**	**2.9751**

Reduced costs due to change		*Reduced income due to change*	
Corn	0.5507	Decrease in total selling price per carcass	0.2323
Soybean oil	0.0779		
Soybean meal	1.6942		
Dicalcium phosphate (dcp - % 18 p)	0.0030		
Vitamin + mineral premix (poultry)	0.0026		
Sodium chloride	0.0000		
Sodium bicarbonate	0.0002		
Methionine dl (mash - % 99)	0.0300		
Total Decrease	**2.3585**	**Total Decrease**	**0.2323**
Increase in Net Income	***2.3585***	***Decreases in Net Income***	***3.2074***
CHANGE in NET INCOME	***-0.8489***		

Expanding the analysis to ALT+BSFL for Bianca Saluzzo broilers in UNITO provides further insights into the financial impacts of adopting innovative feed formulations. The transition to ALT+BSFL did not yield any increase in the selling price per carcass. However, the dietary shift introduced substantial additional feed costs, totaling €4.7369 per bird. The major cost contributors included BSFL (€1.7408), corn gluten (€1.1474), field bean (€0.6891), and pea protein (€0.6231). Sunflower meal (€0.3210) and barley (€0.1162) also contributed significantly. The transition achieved cost reductions of €2.3446 per bird, primarily through reduced use of soybean meal (€1.6942), corn (€0.5403), and soybean oil (€0.0760). Despite these savings, the transition resulted in a decrease in the selling price per carcass by €0.2347. The overall economic effect of the shift to ALT+BSFL was a net income loss of €-2.6269 per bird (Table 4). This significant financial loss was driven by the exceptionally high costs of BSFL and other alternative feed ingredients.

Table 4. Partial Budget Analysis: Economic Impact of Feed Ingredient Changes in Broiler Production (shift from CON to ALT+BSFL (€/per bird) (UNITO Pilot Bianca Saluzzo)

Added income due to change		*Added costs due to change*	
Increase in total selling price per carcass	0.0000	Corn gluten	1.1474
		Barley	0.1162
		Sunflower meal 37	0.3210
		Pea protein	0.6231
		Field ben	0.6891
		BSF Larvae	1.7408
		Calcium carbonate	0.0003
		L-lysine	0.0989
Total Increase	**0.0000**	**Total Increase**	**4.7369**
Reduced costs due to change		***Reduced income due to change***	
Corn	0.5403	Decrease in total selling price per carcass	0.2347
Soybean oil	0.0760		
Soybean meal	1.6942		
Dicalcium phosphate (dcp - % 18 p)	0.0022		

Vitamin + mineral premix (poultry)	0.0019		
Sodium chloride	0.0000		
Sodium bicarbonate	0.0001		
Methionine dl (mash - % 99)	0.0298		
Total Decrease	**2.3446**	**Total Decrease**	**0.2347**
Increase in Net Income	***2.3446***	***Decreases in Net Income***	***4.9715***
CHANGE in NET INCOME	***-2.6269***		

The dietary change (from ALT to ALT+BSFL) introduced significant additional costs, amounting to €1.7757 per bird. The greatest contribution to overall costs was BSFL, amounting to €1.7408. The transition did not lead to any significant reductions in feed costs. Furthermore, the selling price per carcass decreased slightly by €0.0024. The net economic impact of transitioning from ALT to ALT+BSFL was a net income loss of €-1.7781 per bird (Table 5). This substantial loss was driven predominantly by the high costs associated with BSFL.

Table 5. Partial Budget Analysis: Economic Impact of Feed Ingredient Changes in Broiler Production (shift from ALT to ALT+BSFL (€/per bird) (UNITO Pilot Bianca Saluzzo)

Added income due to change		***Added costs due to change***	
Increase in total selling price per carcass		Corn	0.0103
		Soybean oil	0.0019
		Soybean meal	0.0000
		Corn gluten	0.0080
		Barley	0.0008
		Sunflower meal 37	0.0022
		Pea protein	0.0043
		Field ben	0.0048
		BSF Larvae	1.7408
		Calcium carbonate	0.0001
		Dicalcium Phosphate (DCP - % 18 P)	0.0008
		Vitamin + Mineral Premix (Poultry)	0.0007
		Sodium chloride	0.0000
		Sodium bicarbonate	0.0000
		L-lysine	0.0007
		Methionine DL (Mash - % 99)	0.0001
Total Increase	**0.0000**	**Total Increase**	**1.7757**
Reduced costs due to change		***Reduced income due to change***	
		Decrease in total selling price per carcass	0.0024
Total Decrease	**0.0000**	**Total Decrease**	**0.0024**
Increase in Net Income	***0.0000***	***Decreases in Net Income***	***1.7781***
CHANGE in NET INCOME	***-1.7781***		

The analysis now looks at **ISA-CM**. It examines the economic effects of changing from a control diet to ALT for broiler production. The transition to ALT in ISA-CM did not lead to an increase in the selling price per carcass. However, the dietary shift introduced additional feed costs amounting to €0.6162 per bird. The primary contributors to these increased costs were triticale (€0.2533), faba beans (€0.1429), and canola (€0.1238). Substantial cost savings were achieved through the reductions amounting to €0.7681 per bird**.** Key savings came from replacing corn (€0.4760) and soybean meal (€0.2808). Despite these savings, there is a slight decrease in the total selling price per carcass (€0.0161). The transition to ALT for meat chickens in ISA-CM resulted in a net income gain of €0.1358 per bird (Table 6).

Table 6. Partial Budget Analysis: Economic Impact of Feed Ingredient Changes in Broiler Production (shift from CON to ALT (€/per bird)) (ISA-CM Pilot meat type chicken)

Added income due to change		***Added costs due to change***	
Increase in total selling price per carcass	0.0000	Soybean oil	0.0946
		Triticale	0.2533
		Canola	0.1238
		Faba beans	0.1429
		Pure Methionine	0.0011
		Lysine (HCl- %)	0.0005
Total Increase	**0.0000**	**Total Increase**	**0.6162**
Reduced costs due to change		***Reduced income due to change***	
Corn	0.4760	Decrease in total selling price per carcass	0.0161
Soybean	0.2808		
Limestone (caco3)	0.0000		
Dicalcium phosphate (2h2o)	0.0096		
Salt (Nacl)	0.0000		
Premix	0.0017		
Total Decrease	**0.7681**	**Total Decrease**	**0.0161**
Increase in Net Income	***0.7681***	***Decreases in Net Income***	***0.6323***
CHANGE in NET INCOME	***0.1358***		

Switching to ALT + BSFL alternative feed resulted in a change of €0.0422 in the total selling price of the birds. This transition also resulted in an increase of €2.0736 in the total cost. €1,3056 of this increase is due to the use of BSFL. Other feed items that contributed significantly were triticale (€0.4484), faba beans (€0.1701), and canola (€0.1156). The transition achieved cost reductions of €1.24526 per bird, primarily through reduced use of soybean (€0.4879) and corn (€0.7358). The net economic impact of transitioning from CON to ALT + BSFL was a net income loss of €-0.7862 per bird (Table 7).

Table 7. Partial Budget Analysis: Economic Impact of Feed Ingredient Changes in Broiler Production (shift from CON to ALT + BSFL (€/per bird)) (ISA-CM Pilot meat type chicken)

Added income due to change		***Added costs due to change***	
Increase in total selling price per carcass	0.0422	Soybean oil	0.0326
		Triticale	0.4484
		Canola	0.1156
		Faba beans	0.1701
		BSF Larvae	1.3056
		Pure Methionine	0.0002
		Lysine (HCl- %)	0.0010
Total Increase	**0.0422**	**Total Increase**	**2.0736**
Reduced costs due to change		***Reduced income due to change***	
Corn	0.7358	Decrease in total selling price per carcass	0.0000
Soybean	0.4879		
Limestone (CaCO3)	0.0000		
Dicalcium Phosphate (2H2O)	0.0141		
Salt (NaCl)	0.0001		
Premix	0.0072		
Total Decrease	**1.2452**	**Total Decrease**	**0.0000**
Increase in Net Income	***1.2874***	***Decreases in Net Income***	***2.0736***
CHANGE in NET INCOME	***-0.7862***		

The transition to ALT + BSFL resulted in a modest increase in the selling price per carcass, contributing €0.0583 to added income. However, the dietary change introduced significant additional costs, totaling €1.5284 per bird. The most substantial cost driver was BSFL, accounting for €1.3056 of the total increase. Other significant contributors included triticale (€0.1952) and faba beans (€0.0272). The dietary shift achieved cost savings of €0.5427 per bird, primarily through the reduced use of traditional feed components such as corn (€0.2599), soybean meal (€0.2071), and soybean oil (€0.0619 There was no reduction in the total selling price. The net financial impact of transitioning from ALT to ALT + BSFL was a net income loss of €-0.9275 per bird. This loss was driven by the substantial increase in feed costs, particularly due to BSFL (Table 8).

Table 8. Partial Budget Analysis: Economic Impact of Feed Ingredient Changes in Broiler Production (shift from ALT to ALT + BSFL (€/per bird)) (ISA-CM Pilot meat type chicken)

Added income due to change		***Added costs due to change***	
Increase in total selling price per carcass	0.0583	Triticale	0.1952
		Faba beans	0.0272
		BSF Larvae	1.3056
		Lysine (HCl- %)	0.0005
Total Increase	**0.0583**	**Total Increase**	**1.5284**
Reduced costs due to change		***Reduced income due to change***	

corn	0.2599	Decrease in total selling price per carcass	0.0000
Soybean	0.2071		
Soybean oil	0.0619		
Canola	0.0082		
Lime Stone ($CaCO_3$)	0.0000		
Dicalcium Phosphat ($2H_2O$)	0.0046		
Salt (NaCl)	0.0001		
Pure Methionine	0.0009		
Total Decrease	**0.5427**	**Total Decrease**	**0.0000**
Increase in Net Income	***0.6010***	***Decreases in Net Income***	***1.5284***
CHANGE in NET INCOME	***-0.9275***		

Following the results of UNITO and ISA-CM, the economic implications of adopting local ingredients and BSFL were examined for two breeds in **EGE pilot**. In the project, two distinct broiler breeds were examined: Anadolu-T, a hybrid breed adapted to local conditions and specific to Türkiye, and COBB, a commercially widely used broiler breed.

For the slow growing breed Anadolu-T, the shift to ALT yields an increase in the total selling price per carcass, amounting to €0.0572. This is mainly due to a minor increase in carcass weight per bird with ALT local diet. Throughout the basic partial budgeting and cost benefit analysis, no change in unit price of output has been assumed. On the cost side, the shift in diet incurs an additional cost of €0.4082 per bird, with sunflower oil (€0.1674) and sunflower meal (€0.1170) contributing significantly. Minor contributions come from ingredients like brewer's dried grain (€0.0669), wheat middlings (€0.0468) and wheat (€0.0088). The new formulation also results in a cost reduction of €0.3772 per bird, largely attributed to the substitution of soybean meal (€0.2464) and corn (€0.1308). The analysis identifies no loss in total selling price or revenue from this dietary shift. The net change in income is marginally positive, with an overall gain of €0.0261 per bird. This value is derived by balancing the increases in income and the reductions in costs against increases in costs and potential income losses (Table 9).

Table 9. Partial Budget Analysis: Economic Impact of Feed Ingredient Changes in Broiler Production (shift from CON to ALT (€/per bird) (EGE Pilot-Anadolu-T)

Added income due to change		***Added costs due to change***	
		Wheat	0.0088
Increase in total selling price per carcass	0.0572	Sunflower oil	0.1674
		Sunflower Meal 37	0.1170
		Brewer’s Dried Grain	0.0669
		Wheat Middlings	0.0468
		Lime Stone (Mash)	0.0000
		Dicalcium Phosphat (DCP - % 18 P)	0.0004
		Vitamin + Mineral Premix (Poultry)	0.0004
		Salt (NaCl)	0.0000

		Rovabio (50 gr) + Natuphos E (100 gr) BASF	0.0001
		Lysine (HCL - % 98.5)	0.0003
		Methionine DL (Mash - % 99)	0.0001
		Threonine	0.0000
Total Increase	**0.0572**	**Total Increase**	**0.4082**
Reduced costs due to change		***Reduced income due to change***	
Corn	0.1308	Decrease in total selling price per carcass	0.0000
Soybean Meal	0.2464		
Total Decrease	**0.3772**	**Total Decrease**	**0.0000**
Increase in Net Income	***0.4343***	***Decreases in Net Income***	***0.4082***
CHANGE in NET INCOME	***0.0261***		

The economic results of ALT + BSFL are somewhat different and reflect the difficulties with the inclusion of BSFL into production. In contrast to ALT, for Anadolu-T breed, moving to ALT + BSFL did not bring any extra profits, as the transition introduced considerable additional costs, amounting to €1.1250 per bird. BSFL accounted for the most significant share with approximately €0.8961/bird, followed by sunflower meal at €0.1141, brewer's dried grain at €0.0654 and wheat middlings at €0.0458. Whereas ALT + BSFL also presented cost savings of € 0.5540 per bird, these savings came mainly from a reduced inclusion of soybean meal by € 0.4034 and corn by € 0.1121. However, these savings were not enough to offset the high added costs. Besides, the dietary shift caused no increase, but a small decrease in the total selling price, amounting to € -0.0382 per bird. Since a minor reduction was observed in the carcass weight per bird. The net economic effect of ALT + BSFL became negative: € -0.6093 per bird (Table 10). The result indicates an economic constraint on the use of BSFL at the current price for feeding the slow growing Anadolu-T breed.

Table 10. Partial Budget Analysis: Economic Impact of Feed Ingredient Changes in Broiler Production (shift from CON to ALT + BSFL (€/per bird)) (EGE Pilot-Anadolu-T)

Added income due to change		***Added costs due to change***	
Increase in total selling price per carcass	0.0000	Wheat	0.0028
		Sunflower Meal 37	0.1141
		Brewer's Dried Grain	0.0654
		Wheat Middlings	0.0458
		BSF Larvae	0.8961
		Lime Stone (Mash)	0.0000
		Dicalcium Phosphat (DCP - % 18 P)	0.0000
		Lysine (HCL - % 98.5)	0.0004
		Methionine DL (Mash - % 99)	0.0002
		Threonine	0.0001
Total Increase	**0.0000**	**Total Increase**	**1.1250**
Reduced costs due to change		***Reduced income due to change***	

Corn	0.1121	Decrease in total selling price per carcass	0.0382
Soybean Meal	0.4034		
Sunflower oil	0.0381		
Vitamin + Mineral Premix (Poultry)	0.0003		
Salt (NaCl)	0.0000		
Rovabio (50 gr) + Natuphos E (100 gr) BASF	0.0001		
Total Decrease	**0.5540**	**Total Decrease**	**0.0382**
Increase in Net Income	***0.5540***	***Decreases in Net Income***	***1.1633***
CHANGE in NET INCOME	***-0.6093***		

The shift from ALT to ALT + BSFL, in other words from the local diet to the local diet with BSFL supplementation, in growing Anadolu-T breed broilers does not give any rise in the total selling price of poultry per bird, but a decline by €0.0954. On the other hand, it generates considerable extra costs amounting to €0.9150 per bird. Of these, the use of BSFL continues to be the leading cost driver, accounting for €0.8961 per bird. Other minor contributors include corn, adding €0.0186, There is also a reduction of €0.3750 per bird in the costs with the shift, mainly from the reduced inclusion of soybean meals at a value of €0.1570 and sunflower oil at €0.2055. Smaller savings come from the changes in feed ingredients such as wheat at €0.0060 and sunflower meal at €0.0029. The shift from ALT to ALT + BSFL results in a net negative value of €-0.6354 per bird, driven by the high value of added costs due to BSFL and the loss in revenue because of the reduced total selling price per carcass (Table 11). The large magnitude of the loss gives evidence of the financial burden that might be brought in by the inclusion of BSFL in the local diet for Anadolu-T breed.

Table 11. Partial Budget Analysis: Economic Impact of Feed Ingredient Changes in Broiler Production (shift from ALT to ALT + BSFL (€/per bird)) (EGE Pilot-Anadolu-T)

Added income due to change		***Added costs due to change***	
Increase in total selling price per carcass	0.0000	Corn	0.0186
		BSF Larvae	0.8961
		Lysine (HCL - % 98.5)	0.0001
		Methionine DL (Mash - % 99)	0.0001
		Threonine	0.0001
Total Increase	**0.0000**	**Total Increase**	**0.9150**
Reduced costs due to change		***Reduced income due to change***	
Wheat	0.0060	Decrease in total selling price per carcass	0.0954
Soybean Meal	0.1570		
Sunflower oil	0.2055		
Sunflower Meal 37	0.0029		
Brewer’s Dried Grain	0.0015		
Wheat Middlings	0.0010		
Lime Stone (Mash)	0.0000		

Dicalcium Phosphate (DCP - % 18 P)	0.0004		
Vitamin + Mineral Premix (Poultry)	0.0006		
Salt (NaCl)	0.0000		
Rovabio (50 gr) + Natuphos E (100 gr) BASF	0.0001		
Total Decrease	**0.3750**	**Total Decrease**	**0.0954**
Increase in Net Income	***0.3750***	***Decreases in Net Income***	***1.0104***
CHANGE in NET INCOME	***-0.6354***		

Partial budgeting analysis was also conducted to evaluate the economic effects of dietary changes for COBB in EGE pilot, focusing on the shift from the CON diet to ALT. Transitioning to ALT for COBB resulted in a slight increase in the total selling price per carcass, adding €0.0576 to the net positive change. However, the shift also incurred additional feed costs of €0.2944 per bird. The major contributors to the increased costs were sunflower oil (€0.1214), sunflower meal (€0.0829), brewer's dried grain (€0.0476) and wheat middlings (€0.0333). Cost reductions were principally realized through reduced consumption of soybean meal (€0.1684) and corn (€0.0856), resulting in an overall decrease of €0.2540 per bird. When all these changes are considered as a whole, the shift from CON diet to ALT diet with increased amounts of local ingredients resulted in a net income increase of €0.0172 per bird for COBB (Table 12).

Table 12. Partial Budget Analysis: Economic Impact of Feed Ingredient Changes in Broiler Production (shift from CON to ALT (€/per bird)) (EGE Pilot-COBB)

Added income due to change		***Added costs due to change***	
Increase in total selling price per carcass	0.0576	Wheat	0.0073
		Sunflower oil	0.1214
		Sunflower Meal 37	0.0829
		Brewer’s Dried Grain	0.0476
		Wheat Middlings	0.0333
		Lime Stone (Mash)	0.0000
		Dicalcium Phosphate (DCP - % 18 P)	0.0006
		Vitamin + Mineral Premix (Poultry)	0.0005
		Salt (NaCl)	0.0000
		Rovabio (50 gr) + Natuphos E (100 gr) BASF	0.0001
		Lysine (HCL - % 98.5)	0.0005
		Methionine DL (Mash - % 99)	0.0001
		Threonine	0.0001
Total Increase	**0.0576**	**Total Increase**	**0.2944**
Reduced costs due to change		***Reduced income due to change***	
Corn	0.0856	Decrease in total selling price per carcass	0.0000
Soybean Meal	0.1684		
Total Decrease	**0.2540**	**Total Decrease**	**0.0000**

Increase in Net Income	***0.3116***	***Decreases in Net Income***	***0.2944***
CHANGE in NET INCOME	***0.0172***		

The transition from CON diet to ALT + BSFL for COBB in EGE pilot resulted in a significant increase in the total selling price per carcass, increasing income by €0.0990. However, this increase in income was accompanied by significant additional costs amounting to €0.8849 per bird. The largest cost contributor was BSFL at €0.6970. Other contributors were sunflower meal (€0.0854), brewers dried grains (€0.0491) and wheat middlings (€0.0344). The analysis also identified cost reductions totaling €0.3316 per bird, primarily due to reduced use of soybean meal (€0.2687) and corn (€0.0428). The switch from the CON diet to ALT + BSFL resulted in a net income loss of -0.4543 € per bird (Table 13). This negative result was mainly due to the high cost of BSFL, which outweighed both the additional income, and the cost reductions achieved.

Table 13. Partial Budget Analysis: Economic Impact of Feed Ingredient Changes in Broiler Production (shift from CON to ALT + BSFL (€/per bird)) (EGE Pilot-COBB)

Added income due to change		***Added costs due to change***	
Increase in total selling price per carcass	0.0990	Wheat	0.0134
		Sunflower Meal 37	0.0854
		Brewer's Dried Grain	0.0491
		Wheat Middlings	0.0344
		BSF Larvae	0.6970
		Lime Stone (Mash)	0.0000
		Dicalcium Phosphate (DCP - % 18 P)	0.0017
		Vitamin + Mineral Premix (Poultry)	0.0014
		Salt (NaCl)	0.0001
		Rovabio (50 gr) + Natuphos E (100 gr) BASF	0.0003
		Lysine (HCL - % 98.5)	0.0014
		Methionine DL (Mash - % 99)	0.0004
		Threonine	0.0002
Total Increase	**0.0990**	**Total Increase**	**0.8849**
Reduced costs due to change		***Reduced income due to change***	
Corn	0.0428	Decrease in total selling price per carcass	0.0000
Soybean Meal	0.2687		
Sunflower oil	0.0200		
Total Decrease	**0.3316**	**Total Decrease**	**0.0000**
Increase in Net Income	***0.4306***	***Decreases in Net Income***	***0.8849***
CHANGE in NET INCOME	***-0.4543***		

The transition from ALT to ALT + BSFL resulted in a slight increase in the total selling price per carcass, amounting to an additional €0.0414 in the income. However, this increase was surpassed by considerable additional costs amounting to €0.7547 per bird. The most substantial contributor to the additional costs was the use of BSFL, which accounted for €0.6970, a figure that far exceeds the combined costs of other feed components, including corn (€0.0428), wheat (€0.0061), and sunflower meal (€0.0025). The analysis identified cost reductions of €0.2418 per bird, primarily from reduced usage of soybean meal (€0.1004) and sunflower oil (€0.1414). Importantly, there were no reductions in income, as the total selling price per carcass remained stable or slightly increased. The net outcome of the transition was a net income loss of €-0.4715 per bird (Table 14). This negative impact was largely driven by the high cost of BSFL, which overshadowed the modest increases in income and the cost savings achieved through feed substitutions.

Table 14. Partial Budget Analysis: Economic Impact of Feed Ingredient Changes in Broiler Production (shift from ALT to ALT + BSFL (€/per bird)) (EGE Pilot-COBB)

Added income due to change		***Added costs due to change***	
Increase in total selling price per carcass	0.0414	Corn	0.0428
		Wheat	0.0061
		Sunflower Meal 37	0.0025
		Brewer's Dried Grain	0.0016
		Wheat Middlings	0.0011
		BSF Larvae	0.6970
		Lime Stone (Mash)	0.0000
		Dicalcium Phosphate (DCP - % 18 P)	0.0011
		Vitamin + Mineral Premix (Poultry)	0.0009
		Salt (NaCl)	0.0001
		Rovabio (50 gr) + Natuphos E (100 gr) BASF	0.0002
		Lysine (HCL - % 98.5)	0.0009
		Methionine DL (Mash - % 99)	0.0003
		Threonine	0.0002
Total Increase	**0.0414**	**Total Increase**	**0.7547**
Reduced costs due to change		***Reduced income due to change***	
Soybean Meal	0.1004	Decrease in total selling price per carcass	0.0000
Sunflower oil	0.1414		
Total Decrease	**0.2418**	**Total Decrease**	**0.0000**
Increase in Net Income	**0.2832**	**Decreases in Net Income**	**0.7547**
CHANGE in NET INCOME	***-0.4715***		

4.1.2. Egg Production

Following an in-depth examination of the dietary transitions associated with broiler production across geographical regions, this section shifts its focus to egg production. An analysis of partial budgeting outcomes for Isazul layer hens in UMU (Spain) and layers in ISA-CM (Tunisia) offer valuable insights into the economic implications of adopting alternative diets in the context of laying hens. This analysis serves to understand the similarities and distinct considerations pertaining to feed strategies in broiler and egg production systems.

The transition to ALT for layer hens in **UMU pilot** resulted in a significant increase in selling price per hen, generating €0.4504 in added income. However, this was accompanied by additional feed costs amounting to €0.9799 per hen. The primary contributors to these increased costs included corn DDGs (€0.4109), peas (€0.3018), and sunflower meal (28%) (€0.1575). Cost reductions totaled €0.9660 per hen, driven primarily by decreased use of high-cost traditional feed ingredients such as soybean meal (46%) (€0.4581), corn (13%) (€0.2810), and soybean hulls (€0.1311). The overall economic outcome of transitioning to ALT for Isazul layer hens was a net income gain of €0.4365 per hen (Table 15). This positive financial result reflects the effective balance between cost savings and income gains, even with the increased feed costs associated with ALT. The results demonstrate the economic viability of adopting ALT under favorable conditions.

Table 15. Partial Budget Analysis: Economic Impact of Feed Ingredient Changes in Egg Production (shift from CON to ALT (€/per hen)) (UMU pilot - Isazul)

Added income due to change		***Added costs due to change***	
Increase in total return of eggs per hen	0.4504	Wheat	0.0456
		Calcium carbonate	0.0014
		Corn DDGS	0.4109
		Sunflower meal (28%)	0.1575
		Peas	0.3018
		Soybean oıl	0.0081
		Barley	0.0245
		C.gallinas super v-330-phy	0.0011
		L-lysıne	0.0253
		Sodium bicarbonate	0.0032
		Abutox lq dry (antiox)	0.0001
		Hostazym x microgranulate 150	0.0002
Total Increase	**0.4504**	**Total Increase**	**0.9799**
Reduced costs due to change		***Reduced income due to change***	
Corn (13%)	0.2810	Decrease in total return of eggs per hen	0.0000
Soybean meal (46%)	0.4581		
Wheat middling	0.0643		
Soybean hulls	0.1311		
Monocalcıum phosphate	0.0283		
Salt	0.0006		
Dl-methionine	0.0027		
Total Decrease	**0.9660**	**Total Decrease**	**0.0000**
Increase in Net Income	***1.4164***	***Decreases in Net Income***	***0.9799***
CHANGE in NET INCOME	***0.4365***		

The transition to ALT + BSFL resulted in a substantial increase in the total selling price per hen, contributing €0.9527 in added income. However, this income gain was accompanied by significant additional feed costs, totaling €2.2583 per hen. The primary cost driver was BSFL, which accounted for €1.3283 of the total increase. Other notable contributors included corn DDGs (€0.4023), peas (€0.2954), and sunflower meal (28%) (€0.1519). Significant cost reductions were achieved, totaling €1.0319 per hen. These savings were primarily driven by decreased use of soybean meal (46%) (€0.4799) and corn (13%) (€0.3180). Additional reductions came from soybean hulls (€0.1311). The net financial outcome of transitioning to ALT + BSFL was a net income loss of €-0.2738 per hen (Table 16). This loss reflects the significant additional feed costs, primarily driven by BSFL.

Table 16. Partial Budget Analysis: Economic Impact of Feed Ingredient Changes in Egg Production (shift from CON to ALT + BSFL (€/per hen)) (UMU pilot- Isazul)

Added income due to change		***Added costs due to change***	
Increase in total return of eggs per hen	0.9527	Wheat	0.0300
		Calcıum carbonate	0.0007
		Corn DDGS	0.4023
		Sunflower meal (28%)	0.1519
		Peas	0.2954
		Barley	0.0221
		L-lysine	0.0247
		Sodium bicarbonate	0.0030
		BSF larvae	1.3283
Total Increase	**0.9527**	**Total Increase**	**2.2583**
Reduced costs due to change		***Reduced income due to change***	
Corn (13%)	0.3180	Decrease in total return of eggs per hen	0.0000
Soybean meal (46%)	0.4799		
Soybean oıl	0.0026		
Wheat middling	0.0644		
Soybean hulls	0.1311		
Monocalcium phosphate	0.0305		
C.gallinas super v-330-phy	0.0004		
Salt	0.0006		
Dl-methionine	0.0042		
Abutox lq dry (antiox)	0.0000		
Hostazym x microgranulate 150	0.0001		
Total Decrease	**1.0319**	**Total Decrease**	**0.0000**
Increase in Net Income	***1.9846***	***Decreases in Net Income***	***2.2583***
CHANGE in NET INCOME	***-0.2738***		

The shift to ALT + BSFL resulted in an increase in the total selling price per hen, generating €0.5024 in added income. However, this was offset by significant additional feed costs, totaling €1.3283 per hen. The primary contribution to these added costs was BSFL, which accounted for the entire increase. This heavy reliance on BSFL as a key protein source highlights the financial challenge of transitioning to ALT + BSFL from ALT. Cost reductions achieved through this transition amounted to €0.1156 per hen, primarily due to decreased use of ingredients such as corn (€0.0371), soybean meal (€0.0218), and wheat (€0.0156). The overall financial outcome of transitioning from ALT to ALT + BSFL for Isazul layer hens was a net income loss of €-0.7103 per hen (Table 17). This loss reflects the significant feed cost increase, primarily due to BSFL.

Table 17. Partial Budget Analysis: Economic Impact of Feed Ingredient Changes in Egg Production (shift from ALT to ALT + BSFL (€/per hen)) (UMU pilot- Isazul)

Added income due to change		***Added costs due to change***	
Increase in total return of eggs per hen	0.5024	BSF Larvae	1.3283
Total Increase	**0.5024**	**Total Increase**	**1.3283**
Reduced costs due to change		***Reduced income due to change***	
Corn (13%)	0.0371	Decrease in total return of eggs per hen	0.0000
Soybean meal (46%)	0.0218		
Wheat	0.0156		
Calcium carbonate	0.0008		
Corn DDGS	0.0086		
Sunflower meal (28%)	0.0056		
Peas	0.0063		
Soybean oıl	0.0107		
Barley	0.0024		
Wheat middling	0.0001		
Monocalcium phosphate	0.0023		
C.gallinas super v-330-phy	0.0015		
Salt	0.0001		
Dl-methionine	0.0015		
L-lysine	0.0007		
Sodium bicarbonate	0.0002		
Abutox lq dry (antiox)	0.0002		
Hostazym x microgranulate 150	0.0003		
Total Decrease	**0.1156**	**Total Decrease**	**0.0000**
Increase in Net Income	***0.6180***	***Decreases in Net Income***	***1.3283***
CHANGE in NET INCOME	***-0.7103***		

Following the analysis of egg production in UMU, this section shifts focus to **ISA-CM pilot** to examine the economic implications of transitioning to ALT for layer hens. The transition to ALT resulted in a modest increase in the selling price per hen, contributing €0.0385 in added income. However, the shift incurred significant additional feed costs, amounting to €1.1422 per hen. The primary cost drivers were triticale (€0.4977), faba beans (€0.3394), and canola (€0.1471). Soybean oil (€0.1561) also added substantially to the costs. Cost reductions achieved through the dietary shift amounted to €1.3333 per hen. These savings were primarily driven by reduced use of corn (€0.8767) and soybean (€0.4488). The overall net financial impact of transitioning from the CON diet to ALT for layer hens in ISA-CM was a positive net income change of €0.2297 per hen (Table 18). This outcome reflects the balance between substantial cost savings and the increased feed costs, with the added income contributing to the overall profitability of the transition.

Table 18. Partial Budget Analysis: Economic Impact of Feed Ingredient Changes in Egg Production (shift from CON to ALT (€/per hen)) (ISA-CM pilot- Layers)

Added income due to change		***Added costs due to change***	
Increase in total return of eggs per hen	0.0385	Triticale	0.4977

		Canola	0.1471
		Faba beans	0.3394
		Soybean Oil	0.1561
		Salt (NaCl)	0.0001
		Pure Methionine	0.0019
Total Increase	**0.0385**	**Total Increase**	**1.1422**
Reduced costs due to change		***Reduced income due to change***	
Corn	0.8767	Decrease in total return of eggs per hen	0.0000
Soybean	0.4488		
Lime Stone (CaCO3)	0.0000		
Dicalcium Phosphate (2H2O)	0.0074		
Premix	0.0003		
Total Decrease	**1.3333**	**Total Decrease**	**0.0000**
Increase in Net Income	***1.3718***	***Decreases in Net Income***	***1.1422***
CHANGE in NET INCOME	***0.2297***		

The transition to ALT + BSFL resulted in a moderate increase in the total selling price per hen, contributing €0.0964 in added income. However, this was offset by significant additional feed costs, totaling €2.9100 per hen. The most substantial contributor to these costs was BSFL, which accounted for €1.8505. Other notable costs included triticale (€0.4622), faba beans (€0.3152), and canola (€0.1366). Soybean oil (€0.1449) also added to the cost reductions achieved through the dietary shift amounted to €1.4867 per hen. These savings were primarily driven by the reduced use of corn (€0.9562) and soybean (€0.5102). The overall financial outcome of transitioning from the CON diet to ALT+ BSFL for layer hens in ISA-CM was a net income loss of €-1.3270 per hen (Table 19). This substantial loss reflects the high feed costs associated with BSFL.

Table 19. Partial Budget Analysis: Economic Impact of Feed Ingredient Changes in Egg Production (shift from CON to ALT+ BSFL (€/per hen)) (ISA-CM pilot- Layers)

Added income due to change		***Added costs due to change***	
Increase in total return of eggs per hen	0.0964	Triticale	0.4622
		Canola	0.1366
		Faba beans	0.3152
		Soybean Oil	0.1449
		BSF Larvae	1.8505
		Pure Methionine	0.0006
Total Increase	**0.0964**	**Total Increase**	**2.9100**
Reduced costs due to change		***Reduced income due to change***	
Corn	0.9562	Decrease in total return of eggs per hen	0.0000
Soybean	0.5102		
Lime Stone (CaCO3)	0.0012		
Dicalcium Phosphate (2H2O)	0.0137		
Salt (NaCl)	0.0000		
Premix	0.0054		
Total Decrease	**1.4867**	**Total Decrease**	**0.0000**
Increase in Net Income	***1.5830***	***Decreases in Net Income***	***2.9100***
CHANGE in NET INCOME	***-1.3270***		

The transition to ALT+ BSFL from ALT resulted in a modest increase in the selling price per hen, generating €0.0578 in added income. However, this income gain was overshadowed by significant additional feed costs, amounting to €1.8505 per hen. The largest cost contributor was BSFL, which accounted for the entirety of the additional costs. Cost reductions associated with the transition totaled €0.2360 per hen. The most substantial savings came from decreased use of corn (€0.0795) and soybean (€0.0614). Additional minor savings were achieved through reduced reliance on triticale (€0.0355), faba beans (€0.0242), and canola (€0.0105). Small reductions were also noted for ingredients such as soybean oil (€0.0111), limestone (€0.0011), and premix (€0.0050). The overall financial impact of transitioning from ALT to ALT+ BSFL for layer hens in Tunisia was a net income loss of €-1.5567 per hen (Table 20). This loss reflects the significant additional costs associated with BSFL.

Table 20. Partial Budget Analysis: Economic Impact of Feed Ingredient Changes in Egg Production (shift from ALT to ALT+ BSFL (€/per hen)) (ISA-CM pilot- Layers)

Added income due to change		***Added costs due to change***	
Increase in total return of eggs per hen	0.0578	BSF Larvae	1.8505
Total Increase	**0.0578**	**Total Increase**	**1.8505**
Reduced costs due to change		***Reduced income due to change***	
Corn	0.0795	Decrease in total return of eggs per hen	0.0000
Soybean	0.0614		
Triticale	0.0355		
Canola	0.0105		
Faba beans	0.0242		
Soybean Oil	0.0111		
Lime Stone (CaCO3)	0.0011		
Dicalcium Phosphate (2H2O)	0.0063		
Salt (NaCl)	0.0001		
Pure Methionine	0.0012		
Premix	0.0050		
Total Decrease	**0.2360**	**Total Decrease**	**0.0000**
Increase in Net Income	***0.2939***	***Decreases in Net Income***	***1.8505***
CHANGE in NET INCOME	***-1.5567***		

4.2. Cost Benefit Analysis

4.2.1. Broiler Production

In this section cost benefit analysis results of the pilot experiments are summarized (Tables 21 to 23). In particular, Gross Profit Margin (P), Cost Benefit Ratio (CBR) and Return on Investment (RoI) of each case study are analyzed per each of the pilot experiments.

In **UNITO pilot**, for slow growing breed Bianca Saluzo, the control diet yielded robust baseline results, with a cost of feed consumed per bird of 4.3484€, leading to a substantial gross profit margin of €14.5021 and a RoI of 333.97%. This establishes an economically favorable baseline. The transition to alternative diet 1 (ALT) demonstrates a shift in cost dynamics, with the cost of feed consumed per bird increasing to €4.9650 and the gross profit margin decreasing to €13.6532, resulting in a RoI of 275.04%. ALT+BSFL stands out in the UNITO pilot for its profitability potential, achieving a gross profit margin of €11.7975 per bird and a RoI of 173.03%, even though its cost of feed consumed per bird rises to €6.8192. These results suggest that, within UNITO's operational framework, the BSFL-based diet remains a viable option, balancing higher input costs with substantial economic returns. On the other hand, both gross profit margins, CBR and RoI are decreased with Alt-2 diet compared to control, given that the unit price for broilers grown using both diets were assumed to be equal.

ISA-CM pilot trial, under the control diet, demonstrates a stable baseline, with a cost of feed consumed per bird of €2.7379, a gross profit margin of €4.3135, and a RoI of 157.63%. These figures establish a moderate economic foundation. The introduction of ALT leads to a slight improvement in economic performance, with the cost of feed consumed per bird reduced to 2.5861€. This results in an increase in gross profit margin to €4.4492 and a RoI of 172.05%, highlighting the cost-effectiveness of this local diet formulation. In contrast, the implementation of ALT- diet with BSFL supplementation shows a cost of feed consumed per bird of €3.5663, yielding a gross profit margin of €3.5272 and a RoI of 98.92% (Table 21).

In the **EGE pilot** with the slow growing local breed, the control diet serves as a reference point, with a cost of feed consumed per bird of €2.3015, resulting in a gross profit margin of 2.3536€ and a RoI of 102.71%. These figures indicate a moderate level of profitability, with stable performance indicators. The introduction of ALT results in slight improvements in profitability. The cost of feed consumed per bird increases slightly to €2.3325, but the gross profit margin rises to €2.3797, leading to an RoI of 102.20%. These findings suggest that while ALT maintains profitability, the improvement is minimal, reflecting the trade-offs between feed costs and total selling price per carcass. In contrast, ALT+ BSFL introduces significant changes. The cost of feed consumed per bird increases to €2.8726, and the gross profit margin decreases to €1.7443, resulting in a RoI of 60.75%. These figures indicate that, for Anadolu-T breed, while BSFL feed incurs higher costs, the profitability decreases due to the elevated feed expenses.

The economic performance of EGE COBB under the Control diet demonstrates a low-cost structure, with a cost of feed consumed per bird of €1.7032. Based on this cost, the total selling price per carcass is calculated as €3.6944, with a gross profit margin of €1.9912. The CBR is 2.1747, while the RoI stands at 117.47%. The ALT formulation, despite a slight increase in feed costs, largely maintains its performance. The cost of feed consumed per bird rises to €1.7436, but the total selling price per carcass is €3.7520, and the gross profit margin is €2.0084. The CBR is 2.1569, and the RoI is 115.69%. This formulation shows a slight increase in costs compared to the Control diet but remains economically viable (Table 22). ALT+BSFL diet presents lower economic performance. The cost of feed consumed per bird increases to €2.2565, with total selling price per carcass at €3.7934. As a result, the gross profit margin is €1.5369, which is lower compared to the other diets. The CBR is 1.6839, and the RoI is 68.39%. These results indicate that ALT+BSFL diet delivers lower profitability, largely due to its higher feed costs (Table 23).

Table 21. Cost Benefit Analysis Results of Pilot Activities (Broiler Meat) (CON)

	EGE_AT	StdDev	EGE_CBB	StdDev	UNITO	StdDev	ISA-CM	StdDev
Cost of Feed (€/kg) (weighted average	0.4460		0.4519		0.5174		0.5049	
Cost of Feed Consumed (€/bird)	2.3015	0.13	1.7032	0.10	4.3484	0.15	2.7379	0.04
Selling price (€ per kg of carcass) (average	2.8304		2.2643		11.0000		3.5702	
Total selling price (€/bird) (S)	4.6551	0.07	3.6944	0.08	18.8505	0.85	7.0514	0.12
Gross Profit Margin (€/bird)	2.3536	0.11	1.9912	0.12	14.5021	0.87	4.3135	0.16
Cost Benefit Ratio (CBR=S/C)	2.0271	0.11	2.1747	0.13	4.3397	0.25	2.5763	0.08
Return on Investment (%)	102.71	10.56	117.47	12.71	333.97	25.33	157.63	8.05

Notes: EGE_AT: EGE pilot Anadolu-T; EGE_CBB: EGE pilot COBB

Table 22. Cost Benefit Analysis Results of Pilot Activities (Broiler Meat) (ALT)

	EGE_AT	StdDev	EGE_CBB	StdDev	UNITO	StdDev	ISA-CM	StdDev
Cost of Feed (€/kg) (weighted average	0.4474		0.4532		0.6066		0.4866	
Cost of Feed Consumed (€/bird)	2.3325	0.12	1.7436	0.09	4.9650	0.11	2.5861	0.02
Selling price (€ per kg of carcass) (average	2.8304		2.2643		11.0000		3.5702	

	EGE_AT	StdDev	EGE_CBB	StdDev	UNITO	StdDev	ISA-CM	StdDev
Total selling price (€/bird) (S)	4.7123	0.14	3.7520	0.07	18.6182	0.73	7.0353	0.17
Gross Profit Margin (P=S-C)	2.3797	0.04	2.0084	0.13	13.6532	0.69	4.4492	0.17
Cost Benefit Ratio (€/bird)	2.0220	0.04	2.1569	0.13	3.7504	0.14	2.7205	0.06
Return on Investment (%)	102.20	4.29	115.69	12.91	275.04	13.95	172.05	6.48

Notes: EGE_AT: EGE pilot Anadolu-T; EGE_CBB: EGE pilot COBB

Table 23. Cost Benefit Analysis Results of Pilot Activities (Broiler Meat) (ALT+BSFL)

	EGE_AT	StdDev	EGE_CBB	StdDev	UNITO	StdDev	ISA-CM	StdDev
Cost of Feed (€/kg) (weighted average	0.5610		0.5666		0.7858		0.6829	
Cost of Feed Consumed (€/bird)	2.8726	0.07	2.2565	0.09	6.8192	0.05	3.5663	0.04
Selling price (€ per kg of carcass) (average	2.8304		2.2643		11.0000		3.5702	
Total selling price (€/bird) (S)	4.6169	0.10	3.7934	0.09	18.6159	0.81	7.0936	0.18
Gross Profit Margin (€/bird)	1.7443	0.07	1.5369	0.16	11.7975	0.81	3.5272	0.18
Cost Benefit Ratio (CBR=S/C)	1.6075	0.03	1.6839	0.10	2.7303	0.12	1.9892	0.05
Return on Investment (%)	60.75	2.91	68.39	9.90	173.03	11.97	98.92	5.32

Notes: EGE_AT: EGE pilot Anadolu-T; EGE_CBB: EGE pilot COBB

A comparison of the pilot trials reveals notable differences in economic performance across the three pilots. Among them, UNITO pilot achieves the highest economic returns with the ALT+ BSFL, recording a gross profit margin of €11.7975 and a RoI of 173.03%. These returns are higher than the outcomes observed for BSFL supplemented diets in both EGE and ISA-CM. In contrast, EGE_COBB and ISA-CM demonstrate stronger and more consistent results with their ALT diets in which local ingredients were used. Further, ISA-CM reports a gross profit margin of €4.4492 and a RoI of 172.05% under ALT, showcasing improved returns compared to both its CON and ALT+ BSFL diets. For EGE COBB, ALT achieves a gross profit margin of €2.0084 and an ROI of 115.69%, demonstrating its viability as a local alternative by offering greater economic stability and profitability compared to the CON and BSFL diets.

4.2.2. Egg Production

In **UMU pilot** trial, the control diet demonstrated a cost of feed per kilogram of €0.4108 and a cost of feed per egg of €0.0700. The selling price per egg remains consistent across diets at €0.2600, resulting in a gross profit margin of €0.1900 per egg and a cost-benefit ratio (CBR) of 3.73. The return on investment (RoI) for this dietary plan is 273.16%. In the alternative diet, the cost per kilogram of feed is reduced to €0.4053, and the cost per egg also decreases to €0.0691. The gross profit margin per egg increases slightly to €0.1909, resulting in a higher CBR of 3.81 and a RoI of 281.48%. This indicates a slight improvement in respect to control diet. However, with the introduction of ALT+BSFL, the cost per kilogram of feed increases to €0.4813, while the cost per egg rises to €0.0776. This results in a reduction in the gross profit margin per egg to €0.1824, accompanied by a lower CBR of 3.35 and an RoI of 235.31% (Table 24).

The control diet for **ISA-CM** has a feed cost of €0.4603 per kilogram and a feed cost per egg of €0.0527, resulting in a gross profit margin of €0.0436 per egg. The CBR is calculated to be 1.83, with a RoI of 82.75%. In comparison, ALT demonstrates a reduction in feed cost, reaching €0.4050 per kilogram and a decreased feed cost per egg at €0.0445. This results in an elevated gross profit margin of €0.0519 per egg. The CBR and RoI demonstrate an improvement, reaching 2.17 and 116.67%, respectively. This indicates that the diet in question is more profitable than control. With the introduction of ALT+BSFL, the feed cost per kilogram increases to €0.4813, while the feed cost per egg rises to €0.0684. The gross profit margin per egg is reduced to €0.0279, with a CBR of 1.41 and a RoI of 41.07%. This indicates a diminished economic return with the BSFL diet in ISA-CM (Table 25).

A comparison of the trials reveals that ALT is the most economically viable option across both UMU and ISA-CM trials, with higher RoIs of 281.48% and 116.67%, respectively. The BSFL-based diet (ALT+BSFL) exhibits the highest cost per kilogram and the lowest profitability, indicating that its elevated feed expenses may constrain its near-term economic viability.

Table 24. Cost Benefit Analysis Results of UMU (Egg)

	Control	**StdDev**	**ALT**	**StdDev**	**ALT+ BSFL**	**StdDev**
Cost (price) of Feed (€/kg)	0.4108		0.4053		0.4813	
Cost of Feed Consumed per saleable egg (C) (€)	0.0700	0.01	0.0691	0.01	0.0776	0.00
Cost of Feed Consumed per hen (C) (€)	5.4849	0.16	5.4991	0.46	6.3930	0.34
Selling price of unit egg (€/egg)	0.2600		0.2600		0.2600	
Total return of eggs per hen (S) (€)	20.4908	1.98	20.9411	3.08	21.4435	1.58
Gross Profit Margin (per egg) (€)	0.1900	0.01	0.1909	0.01	0.1824	0.00
Cost Benefit Ratio (CBR=S/C) (€)	3.7316	0.28	3.8148	0.52	3.3531	0.14
Return on Investment (RoI=P/C*100)	273.16	27.74	281.48	52.38	235.31	13.59

Table 25. Cost Benefit Analysis Results of ISA-CM (Egg)

	Control	StdDev	ALT	StdDev	ALT+ BSFL	StdDev
Cost (price) of Feed (€/kg)	0.4603		0.4050		0.4813	
Cost of Feed Consumed per saleable egg (C) (€)	0.0527	0.00	0.0445	0.00	0.0684	0.00
Cost of Feed Consumed per hen (C) (€)	3.50	0.04	2.97	0.04	4.61	0.16
Selling price of unit egg (€/egg)	0.0964		0.0964		0.0964	
Total return of eggs per hen (S) (€)	6.3985	0.11	6.4371	0.17	6.4949	0.11
Gross Profit Margin (per egg) (€)	0.0436	0.00	0.0519	0.00	0.0279	0.00
Cost Benefit Ratio (CBR=S/C) (€)	1.8275	0.03	2.1667	0.05	1.4107	0.06
Return on Investment (RoI=P/C*100)	82.75	2.80	116.67	4.83	41.07	6.44

4.3. Sensitivity Analysis under Different Scenarios

Sensitivity analysis plays a crucial role in understanding the robustness and reliability of cost-benefit analysis results, particularly in the face of uncertainty surrounding key input variables. This section explores the outcomes of the sensitivity analysis conducted on the project, investigating how variations in BSFL prices, conventional ingredients prices, and broiler/egg prices could potentially impact the project's economic feasibility across different scenarios.

In this sensitivity analysis, five different scenarios were developed and for each scenario BSFL prices, prices of traditional ingredients and broiler/egg prices were estimated for the next five years. The objective of these scenarios is to reflect different market conditions and economic fluctuations, thereby providing a clearer picture of the impact of possible changes in the prices of key inputs on the economic results obtained using the poultry diets developed in the project. Initially, the results of the price projections are shared, and the assumptions of each scenario are detailed. Overall, this approach allows the impact of price fluctuations to be assessed and provides strategic insights for long-term decision-making.

4.3.1. Results of Time Series Analysis and Price Forecasting

The time series analysis, which supports these projections, follows several essential stages. First, a stationarity test is performed to determine if the data series has a consistent mean and variance over time, using Augmented Dickey-Fuller (ADF) test. If the series is found to be non-stationary, differencing technique is applied to stabilize it. Once stationarity is established, the structural dependencies within the series are analyzed through Autocorrelation Function (ACF) and Partial Autocorrelation Function (PACF) plots, which are crucial for identifying the autoregressive (AR) and moving average (MA) components in the ARIMA models. Following the selection and implementation of the model, residual analysis is conducted to validate its accuracy, confirming that error terms are random and stationary. Once validated, the model enables the generation of future forecasts with established confidence intervals. These methodological steps ensure that the time series analysis is comprehensive, accurate, and reliable, thereby supporting the sensitivity analysis with solid, data-driven projections and providing a strategic foundation for understanding the financial viability of the practices suggested in the project under various economic conditions.

Table 26 presents the results of the Augmented Dickey-Fuller (ADF) test, which examines the stationarity of time series data for broiler, egg, soybean, soybean meal, corn, and fish meal prices. Stationarity is a critical requirement for time series analysis, as non-stationary data can produce spurious results in regression models. At the level form, the ADF test statistics indicate that all variables are non-stationary. However, after taking the first differences, all variables show significant ADF test statistics rejecting the null hypothesis and confirming that they become stationary after differencing (Table 26).

Table 26. Unit Root Test Results for Price Series

	Level ADF	First Difference ADF
Broiler (World)	-0.441787	-5.697267(0.0000)
Egg (Spain)	-1.809149	-5.634979 (0.0000)
Egg (Tunisia)	1.381211	-4.708166 (0.0000)
Soybean	-3.077910	-6.190493 (0.0000)
Soybean meal	-2.351362	-6.523313 (0.0000)
Corn	-3.141275	-5.535811 (0.0000)
Soybean oil	-0.791221	-7.459110 (0.0000)

ADF - Augmented Dickey-Fuller Test: A statistical test used to determine whether a time series contains a unit root and is stationary. **Level ADF:** ADF method used to test the stationarity of a time series at its level. **First Difference ADF:** ADF method used to test the stationarity of a time series at its first difference.

Following the stationarity tests, time series analyses were conducted for each product to model price behavior and generate projections. After ensuring that the series were stationary, autocorrelation function (ACF) and partial autocorrelation function (PACF) analyses were performed. These analyses examine the degree of dependence on past observations and the autocorrelation structure, which are essential for identifying an appropriate autoregressive integrated moving average (ARIMA) model.

Broiler prices

Based on the ADF and ACF/PACF results (Graph 2, 3 in appendix), ARIMA(2,1,0) was selected as the optimal model for the series. Both the AR(1) and AR(2) components are significant, with coefficients of -0.323 and -0.416, respectively, and p-values of 0.0121 and 0.0088 (Table 27, Table 28, Graph 4 in appendix). This suggests a strong dependence on past prices through the first and second-order autoregressive components. The model demonstrates high overall accuracy, making it reliable for future price forecasts.

To verify model validity, residual analysis was conducted, yielding a Durbin-Watson statistic of 2.073 (Table 27). This statistic indicates that the residuals are independent and randomly distributed, confirming a good model fit (Graph 5 in appendix). These steps suggest that the ARIMA(2,1,0) model is a suitable and reliable model for understanding the variability in broiler prices over time and forecasting future trends.

Table 27. ARMA Maximum Likelihood Estimation Results for Broiler Prices (ARIMA(2,1,0))

Dependent Variable: D(LNN_CHICKEN)

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	0.050454	0.016293	3.096723	0.0036
@TREND	-0.001417	0.000558	-2.540823	0.0152
AR(1)	-0.323297	0.122854	-2.631546	0.0121
AR(2)	-0.415614	0.150651	-2.758783	0.0088
SIGMASQ	0.005415	0.001469	3.685660	0.0007
R-squared	0.247176	Mean dependent var		0.016540
Adjusted R-squared	0.169964	S.D. dependent var		0.085792
S.E. of regression	0.078162	Akaike info criterion		-2.143581
Sum squared resid	0.238263	Schwarz criterion		-1.940832
Log likelihood	52.15879	Hannan-Quinn criter.		-2.068392
F-statistic	3.201238	Durbin-Watson stat		2.073292
Prob(F-statistic)	0.022932			
Inverted AR Roots	-.16-.62i	-.16+.62i		

The model projects a downward trend in broiler prices between 2024 and 2028, providing an estimate and confidence intervals for each year (Table 28 and Figure 1). The broiler price, forecasted at €1.531/kg in 2024, is expected to decline to €1.415/kg by 2028.

Table 28. Broiler Price Predictions (2024-2028)

Years	Forecast (€/kg)	Lower bound (€/kg)	Upper bound (€/kg)
2024	1.5312	1.2891	1.8189
2025	1.5151	1.2313	1.8643
2026	1.4331	1.1526	1.7819
2027	1.4239	1.1081	1.8297
2028	1.4152	1.0609	1.8878

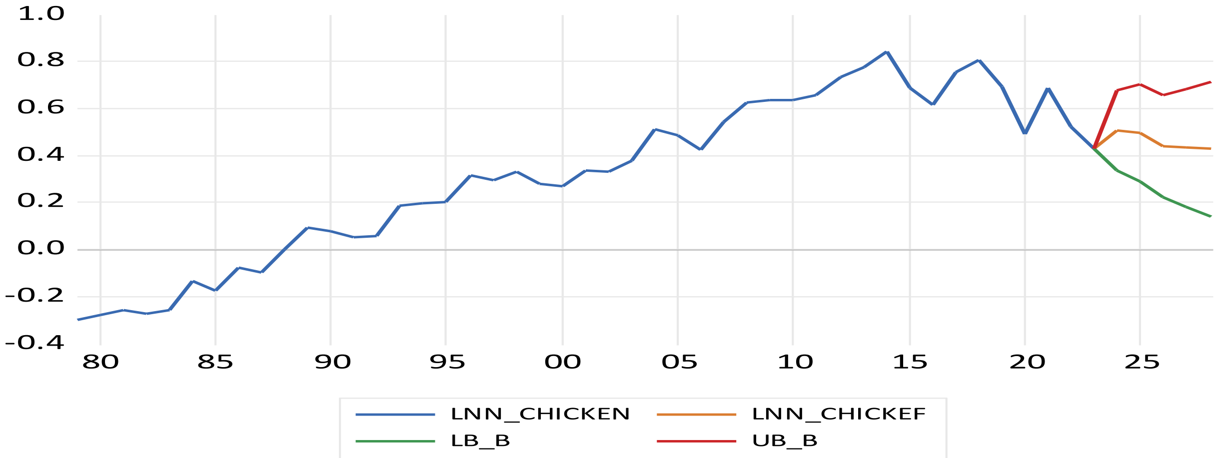

Figure 1. Historical and Forecasted Broiler Prices in logarithmic scale (€/kg)

Egg prices

The analysis of egg prices in Spain focused on assessing stationarity and modeling short-term price fluctuations. Augmented Dickey-Fuller (ADF) tests indicated that egg prices were non-stationary at level but became stationary after first differencing, confirming an integrated order of I(1) (Table 26). To capture short-term dynamics, an ARMA(0,1,5) model was selected based on diagnostic tests (Table 29). The model included a moving average component MA(5) with a coefficient of 0.8753, which was highly significant ($p < 0.001$), highlighting strong contribution of the fifth lagged error term on prediction of the current price value. The model's explanatory power ($R^2 = 48.6\%$) suggests it effectively captures short-term fluctuations in egg prices, making it a useful tool for forecasting and sensitivity analysis (Table 29).

Table 29. ARMA Maximum Likelihood Estimation Results for Spanish Egg Prices (ARIMA(0,1,5))

Dependent Variable: D(LN_EGG)

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	0.072783	0.066134	1.100535	0.2816
MA(5)	0.875328	0.051990	16.83654	0.0000

R-squared	0.485530	Mean dependent var	0.019975
Adjusted R-squared	0.464952	S.D. dependent var	0.249305
S.E. of regression	0.182359	Akaike info criterion	-0.494491
Sum squared resid	0.831371	Schwarz criterion	-0.398503
Log likelihood	8.675628	Hannan-Quinn criter.	-0.465949
F-statistic	23.59374	Durbin-Watson stat	2.191229
Prob(F-statistic)	0.000054		

Inverted MA Roots	79-.57i	.79+.57i	-.30+.93i	-.30-.93i
	-.97			

The following table presents the forecasts for egg prices from 2024 to 2028, along with the lower and upper bounds of these forecasts. According to the data, there is an anticipated annual increase in egg prices. The price of €217.30/100 kg in 2024 is projected to rise to €440.49/100 kg by 2028 (Table 30 and Figure 2).

Table 30. Spanish Egg Price Predictions (2024-2028)

Years	Forecast (€/100 kg)	Lower bound (€/100 kg)	Upper bound (€/100 kg)
2024	217.2955	149.2568	316.3496
2025	221.2949	128.3594	381.5184
2026	249.1201	126.3302	491.2583
2027	351.0126	158.2247	778.7024
2028	440.4936	177.5212	1093.0224

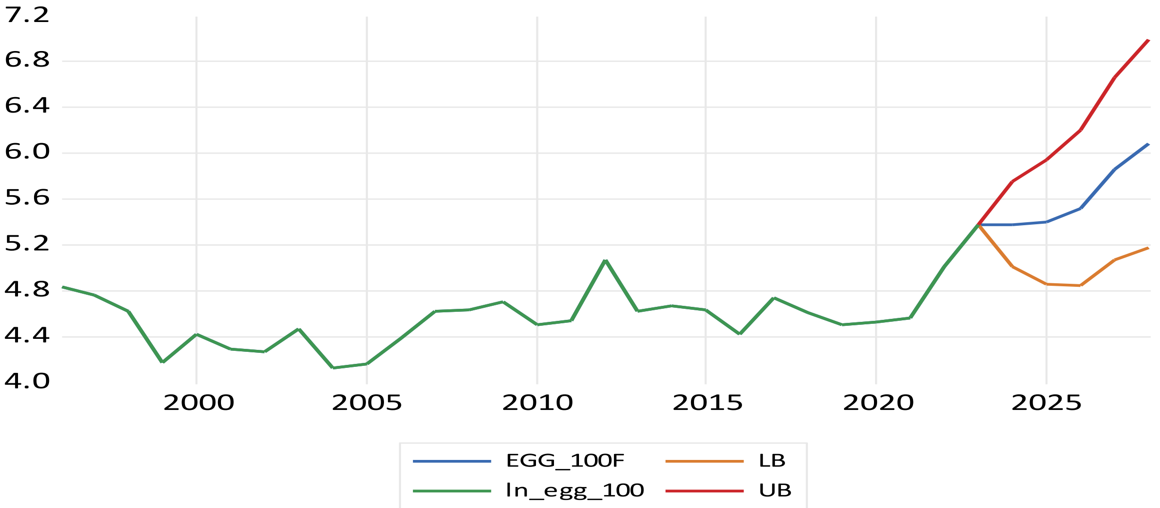

Figure 2. Historical and Forecasted Spanish Egg Prices in logarithmic scale (€/100kg)

The following findings are based on a time series analysis conducted to examine the dynamics of Tunisian egg prices. The results cover the application of the ARMA model using data from the 1998-2023 period. Autocorrelation and partial autocorrelation analyses were performed to determine the significance of lagged effects in the model. The findings indicate that the model provides meaningful and consistent results. Specifically, the AR(2) coefficient was found to be negative and statistically significant (p=0.0273) (Table 31).

Table 31. ARMA Maximum Likelihood Estimation Results for Tunisian Egg Prices (ARIMA(2,1,0))

Dependent Variable: D(LN_EGG)

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	0.052984	0.016922	3.131107	0.0047
AR(2)	-0.481785	0.204428	-2.356749	0.0273

R-squared	0.169785	Mean dependent var	0.053582
Adjusted R-squared	0.133689	S.D. dependent var	0.130422
S.E. of regression	0.121391	Akaike info criterion	-1.281853
Sum squared resid	0.338923	Schwarz criterion	-1.184343
Log likelihood	18.02316	Hannan-Quinn criter.	-1.254807
F-statistic	4.703664	Durbin-Watson stat	1.669073

Prob(F-statistic)	0.040686	
Inverted AR Roots	-.00+.69i	-.00-.69i

Forecasts for the 2024-2028 period were obtained using economic variables and time series analysis-based models. The projections estimate an average egg price of €0.0908 in 2024, gradually increasing to €0.1104 by 2028. Considering the lower and upper bounds of these forecasts, future price variability is expected to remain within a defined range (Table 32 and Figure 3).

Table 32. Tunisian Egg Price Predictions (2024-2028)

Years	Forecast (€/egg)	Lower bound (€/egg)	Upper bound (€/egg)
2024	0.0908	0.0701	0.1177
2025	0.0891	0.0607	0.1309
2026	0.0978	0.0659	0.1450
2027	0.1067	0.0704	0.1618
2028	0.1104	0.0688	0.1772

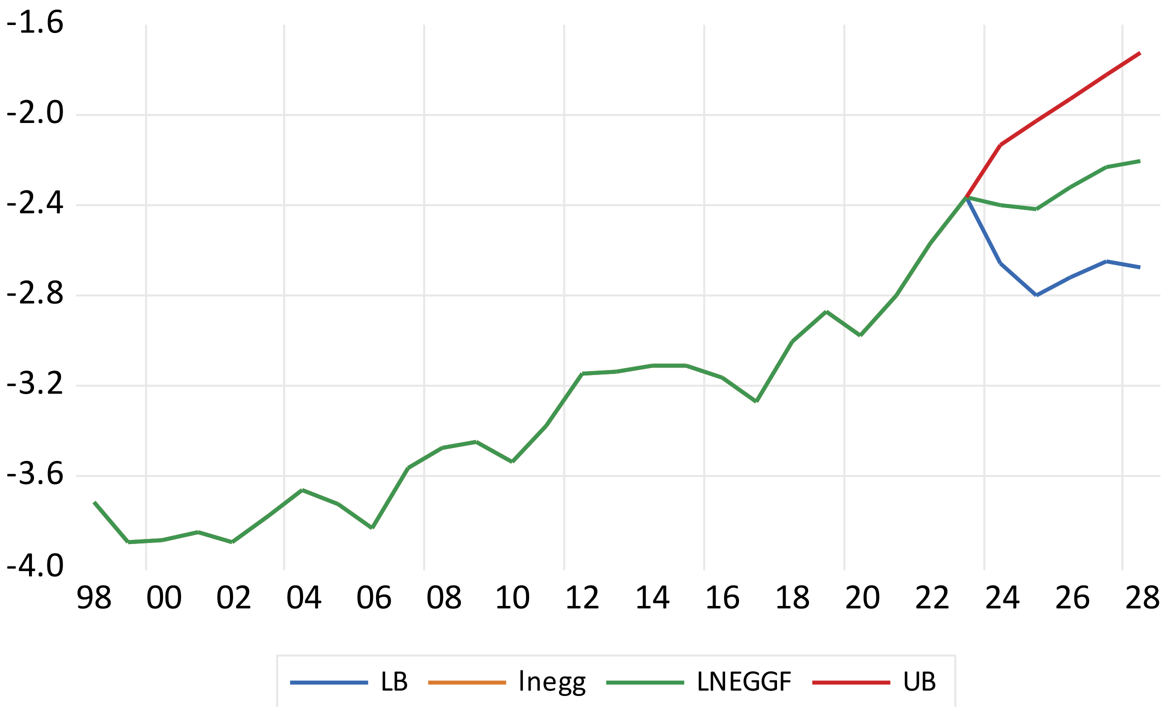

Figure 3. Historical and Forecasted Tunisian Egg Prices in logarithmic scale (€/egg)

BSFL prices

The Grey Modeling (GM(1,1)) analysis was conducted to forecast the prices of BSFL, in order to later assess their economic feasibility as a feed ingredient. The analysis utilized historical data to generate predictions and evaluate the model's accuracy. The results demonstrate that the fitted values closely align with the actual prices, indicating that the model effectively captures trends in BSFL price movements. The accuracy of the model is supported by statistical metrics, including a mean absolute percentage error (MAPE) of 2.86 percent and a root mean square error (RMSE) of 196.97. These values highlight the model's high reliability and predictive performance, suggesting its suitability for forecasting BSFL prices under different economic scenarios. The projections for future BSFL prices indicate a gradual decline over time. Predicted values for the next four years are as follows: 3239.59 €/ton, 2925.66 €/ton, 2642.14 €/ton, and 2386.11 €/ton, respectively (Table 33 and Figure 4).

Table 33. BSFL Price Predictions (2024-2028)

Years	Forecast (€/ton)	Lower bound (€/ton)	Upper bound (€/ton)
2024	3239.59	2683.05	3796.13
2025	2925.66	2138.59	3712.72
2026	2642.14	1678.18	3606.10
2027	2386.11	1273.02	3499.19

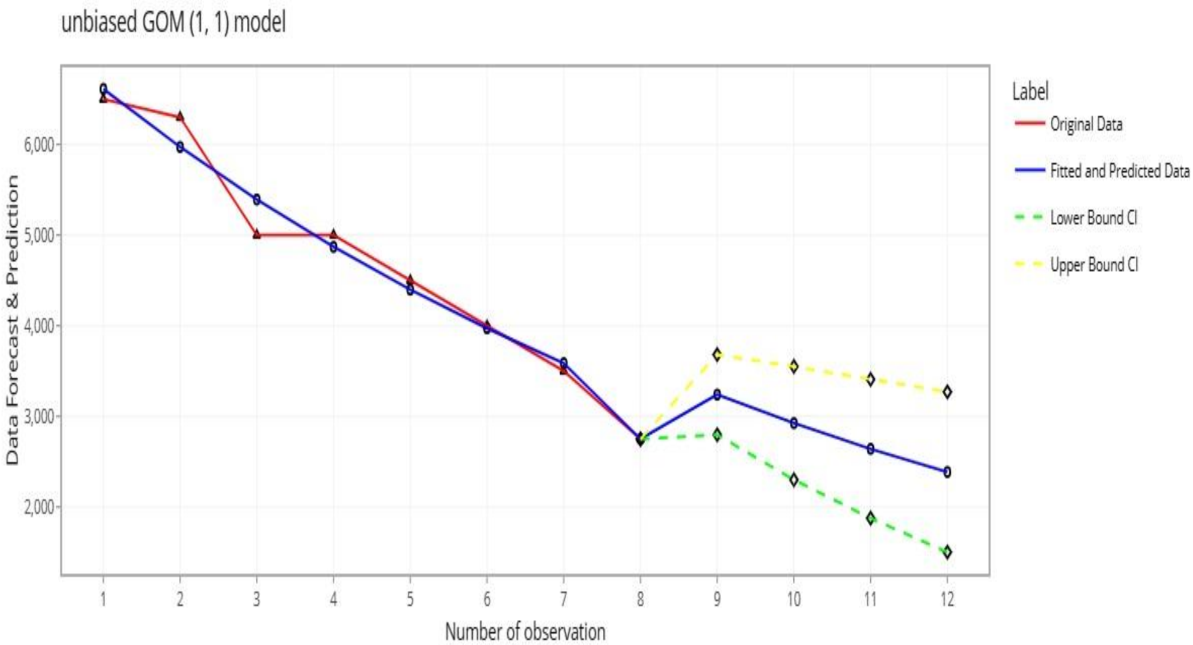

Figure 4. Historical and Forecasted BSFL Prices in logarithmic scale (€/ton)

Soybean prices

The analysis of soybean prices focused on developing a forecasting model to capture price trends and fluctuations. Autocorrelation (ACF) and partial autocorrelation (PACF) plots were examined to identify the most appropriate model structure (Graph 7, 8 in appendix). Based on these diagnostics, an ARIMA(2,1,0) model was selected as the best fit for soybean price forecasting (Table 34).

The model included autoregressive components AR(1) and AR(2) with coefficients of 0.2487 and -0.4073, respectively. The AR(2) coefficient was statistically significant with a p-value of 0.0099, indicating that second-order autoregressive effects play a critical role in explaining soybean price variations (Table 34).

Table 34. ARMA Maximum Likelihood Estimation Results for Soybean Prices (ARIMA(2,1,0))

Dependent Variable: : D(LN_SOYBEANS)				
Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	0.015630	0.019019	0.821771	0.4161
AR(1)	0.248665	0.133608	1.861155	0.0701
AR(2)	-0.407322	0.150410	-2.708085	0.0099
SIGMASQ	0.018263	0.004837	3.775838	0.0005
R-squared	0.197649	Mean dependent var		0.015845
Adjusted R-squared	0.137473	S.D. dependent var		0.152614
S.E. of regression	0.141736	Akaike info criterion		-0.974229
Sum squared resid	0.803561	Schwarz criterion		-0.812030
Log likelihood	25.43304	Hannan-Quinn criter.		-0.914078
F-statistic	3.284506	Durbin-Watson stat		1.955051
Prob(F-statistic)	0.030438			
Inverted AR Roots	12-.63i	12+.63i		

The soybean price predictions for the period 2024–2028 indicate a gradual upward trend, with forecasted prices reflecting moderate growth over the years. In 2024, the projected price is €513.68 per ton. The confidence interval for this estimate ranges widely, with a lower bound of €308.79 per ton and an upper bound of €1110.38 per ton in 2028 (Table 35 and Figure 5).

Table 35. Soybean Price Predictions (2024-2028)

Years	Forecast (€/ton)	Lower bound (€/ton)	Upper bound (€/ton)
2024	513.6824	387.6825	696.7744
2025	539.9520	341.0908	875.0225
2026	573.2238	336.8362	998.6383
2027	580.5287	327.1051	1054.7221
2028	578.7330	308.7891	1110.3834

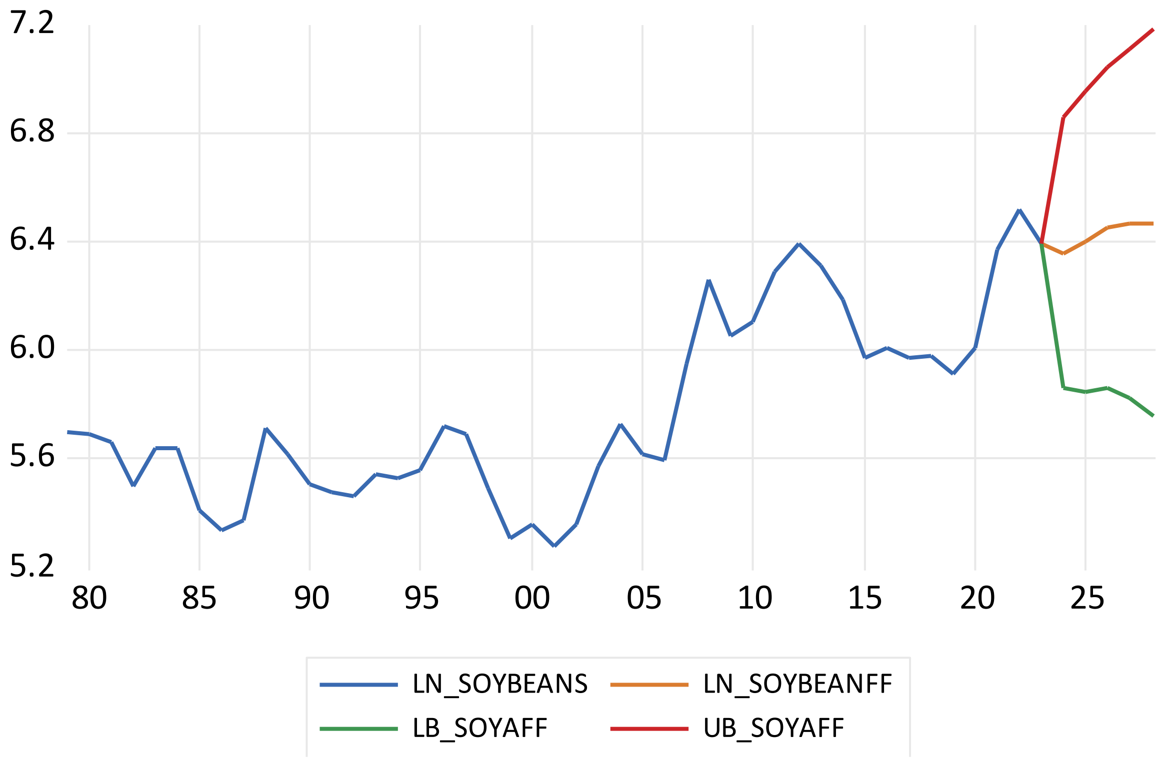

Figure 5. Historical and Forecasted Soybean Prices in logarithmic scale (€/ton)

Soybean meal prices

The soybean meal price analysis was conducted to forecast price trends and evaluate economic patterns. An autoregressive moving average (ARMA) model was selected based on the data characteristics, supported by autocorrelation function (ACF) and partial autocorrelation function (PACF) analyses (Graph 12, 13 in appendix). The analysis identified significant coefficients in the model, particularly the AR(2) term with a value of -0.7906 and a p-value of 0.0003, indicating that the second-order autoregressive component strongly influences price movements. This points out a similar pattern to that of soybean price series. Additionally, the MA(2) component, with a coefficient of 0.4853 and a p-value of 0.0975, showed marginal significance, suggesting some dependency on past shocks with two years lag (Table 36).

Table 36. ARMA Generalized Least Squares (Newton-Raphson) Estimation Results for Soybean Meal Prices (ARIMA(2,1,2))

Dependent Variable: : D(LN_SOYBEAN_MEAL)				
Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	0.018776	0.019497	0.963044	0.3412
AR(2)	-0.790634	0.201870	-3.916551	0.0003
MA(2)	0.485327	0.286231	1.695578	0.0975
R-squared	0.187863	Mean dependent var		0.018205

Adjusted R-squared	0.148247	S.D. dependent var	0.168028
S.E. of regression	0.155074	Akaike info criterion	-0.811288
Sum squared resid	0.985961	Schwarz criterion	-0.689639
Log likelihood	20.84833	Hannan-Quinn criter.	-0.766174
F-statistic	4.742050	Durbin-Watson stat	1.665995
Prob(F-statistic)	0.014041		

Inverted AR Roots	-.00+.89i	-.00-.89i
Inverted MA Roots	-.00+.70i	-.00-.70i

The soybean meal price predictions for 2024–2028 indicate a moderate upward trend with some fluctuations. The forecasted price begins at €496.73 per ton in 2024, with a confidence interval ranging from €366.43 to €689.35. Prices are projected to rise to €532.27 in 2025 and €553.19 in 2026. In 2027, the forecasted price slightly decreases to €541.69 per ton. By 2028, prices stabilize at €543.39 per ton, with a broader interval of €289.48–€1044.19 (Table 37 and Figure 6).

Table 37. Soybean Meal Price Predictions (2024-2028)

Years	Forecast (€/ton)	Lower bound (€/ton)	Upper bound (€/ton)
2024	496.7338	366.4260	689.3490
2025	532.2686	341.9360	848.1942
2026	553.1854	336.5547	930.8169
2027	541.6858	313.8850	956.9811
2028	543.3932	289.4845	1044.1941

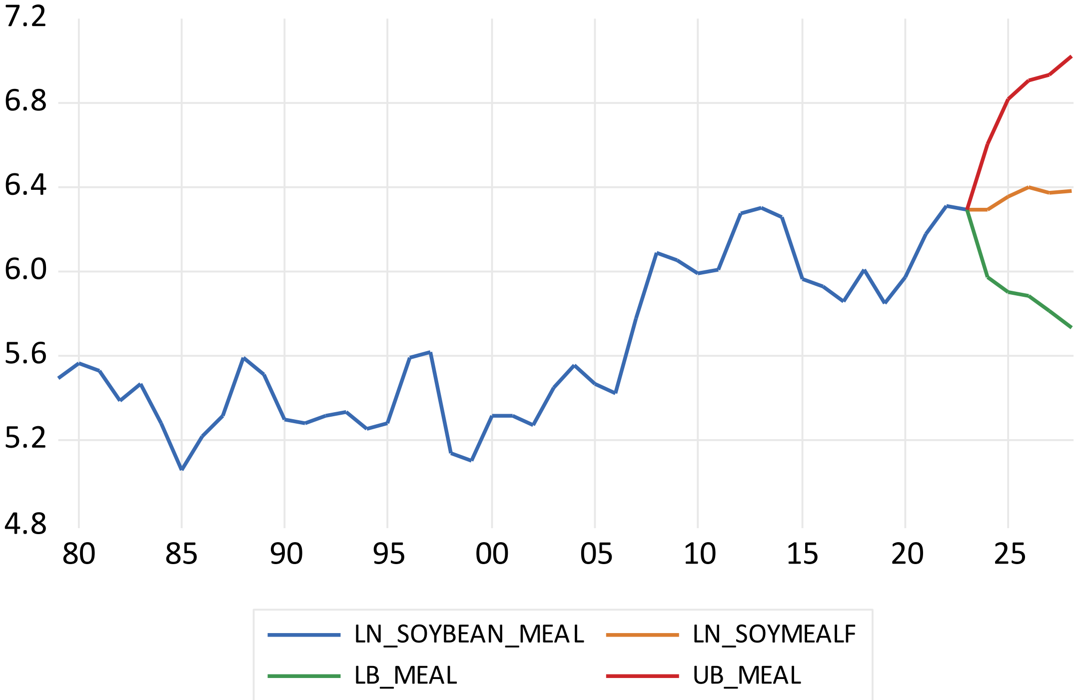

Figure 6. Historical and Forecasted Soybean Meal Prices (€/ton)

Corn prices

The corn price analysis utilized an ARMA model to capture price trends and dependencies effectively. ACF and PACF plots indicated gradual decay and significant spikes at lags 1 and 2, suggesting the presence of both autoregressive and moving average components. The AR(2) coefficient of -0.4146 (p = 0.0154) and the MA(9) coefficient of -0.5387 (p = 0.0345) were statistically significant (Table 38), highlighting the influence of past prices and shocks on current price movements.

Table 38. ARMA Generalized Least Squares (Newton-Raphson) Estimation Results for Soybean Meal Prices (ARIMA(2,1,9))

Dependent Variable: D(LN_CORN)

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	0.019684	0.011975	1.643724	0.1079
AR(2)	-0.414616	0.163957	-2.528811	0.0154
MA(9)	-0.538729	0.246314	-2.187160	0.0345
R-squared	0.200163	Mean dependent var		0.017785
Adjusted R-squared	0.161146	S.D. dependent var		0.191799
S.E. of regression	0.175667	Akaike info criterion		-0.496168
Sum squared resid	1.265214	Schwarz criterion		-0.374519
Log likelihood	13.91570	Hannan-Quinn criter.		-0.451055
F-statistic	5.130215	Durbin-Watson stat		1.651448
Prob(F-statistic)	0.010269			
Inverted AR Roots	-.00+.64i	-.00-.64i		
Inverted MA Roots	.93	.72-.60i	.72+.60i	16+.92i
	.16-.92i	-.47+.81i	-.47-.81i	-.88-.32i
	-.88+.32i			

The corn price predictions for 2024–2028 indicate a generally upward trend with some fluctuations. The forecasted price starts at €240.55 per ton in 2024. Prices are expected to rise to €290.12 in 2025 and €291.86 in 2026. By 2027, prices are projected to increase further to €300.32, followed by a slight decline to €292.82 in 2028 (Table 39 and Figure 7).

Table 39. Corn Price Predictions (2024-2028)

Years	Forecast (€/ton)	Lower bound (€/ton)	Upper bound (€/ton)
2024	240.5587	169.3883	349.7336
2025	290.1248	171.8422	501.4393
2026	291.8623	164.9225	528.7552
2027	300.3247	161.1241	573.0601
2028	292.8288	148.0687	592.8478

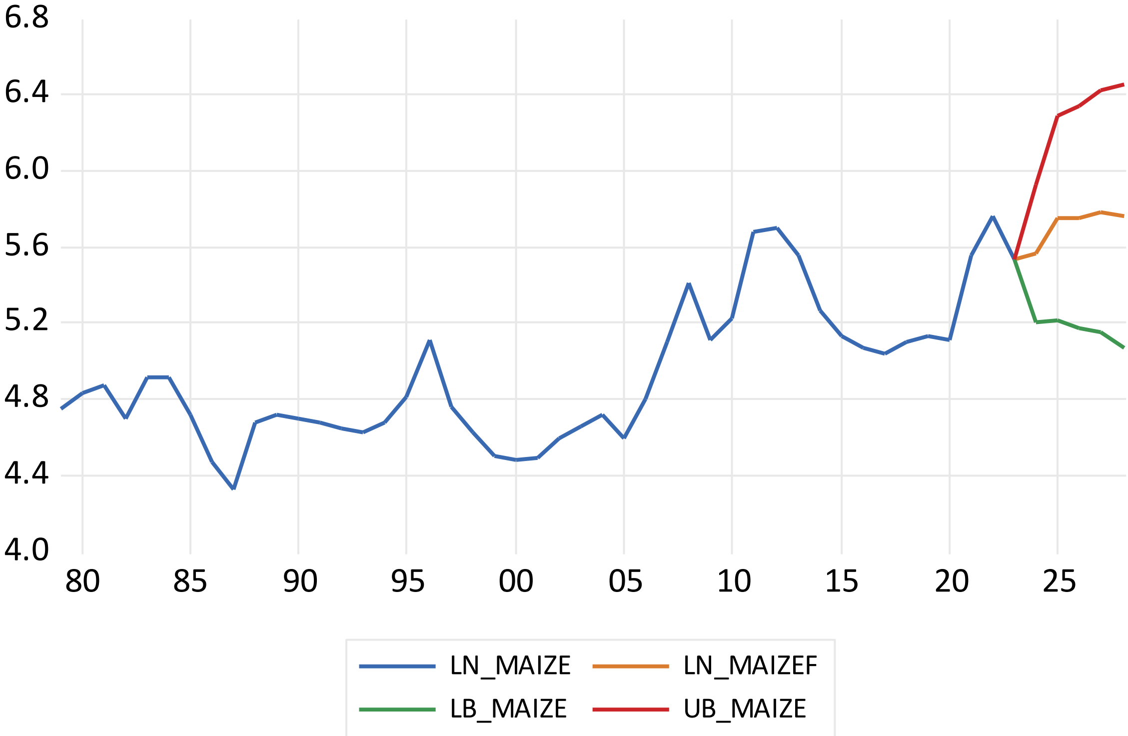

Figure 7. Historical and Forecasted Corn Prices in logarithmic scale (€/ton)

Soybean Oil prices

The model developed for forecasting soybean oil prices is the ARIMA(2,1,0) model. The Augmented Dickey-Fuller (ADF) test indicates that the series has a unit root (p=0.8113). However, it was found to become stationary after taking the first difference (p=0.0000). The ARIMA model results show that the AR(2) coefficient is negative and statistically significant (p=0.0013). The model's F-statistic (p=0.0021) supports its overall validity (Table 40).

Table 40. ARMA Generalized Least Squares (Newton-Raphson) Estimation Results for Soybean Oil Prices (ARIMA(2,1,0))

Dependent Variable: : D(LN_CORN)

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	0.016138	0.019897	0.811074	0.4220
AR(2)	-0.516326	0.149897	-3.444544	0.0013
SIGMASQ	0.035865	0.008266	4.338860	0.0001

R-squared	0.259826	Mean dependent var	0.011914
Adjusted R-squared	0.223720	S.D. dependent var	0.222671
S.E. of regression	0.196188	Akaike info criterion	-0.339647
Sum squared resid	1.578080	Schwarz criterion	-0.217998
Log likelihood	10.47223	Hannan-Quinn criter.	-0.294534
F-statistic	7.196180	Durbin-Watson stat	1.433058
Prob(F-statistic)	0.002096		

Inverted AR Roots	-.00+.72i	-.00-.72i

The forecasts are based on the ARIMA (2,1,0) model developed to predict future trends in soybean oil prices. Projections for the 2024-2028 period estimate that prices will start at an average of €961.81/ton in 2024 and are expected to reach €1163.03/ton by 2028. Considering the lower and upper bounds, prices in 2024 are expected to range between €645.82/ton and €1432.42/ton (Table 41 and Figure 8).

Table 41. Soybean Oil Price Predictions (2024-2028)

Years	Forecast (€/ton)	Lower bound (€/ton)	Upper bound (€/ton)
2024	961.8131	645.8183	1432.4222
2025	1211.0708	680.4512	2155.4724
2026	1287.4157	688.5261	2407.2256
2027	1171.3125	616.5628	2225.1980
2028	1163.0349	567.8448	2382.0748

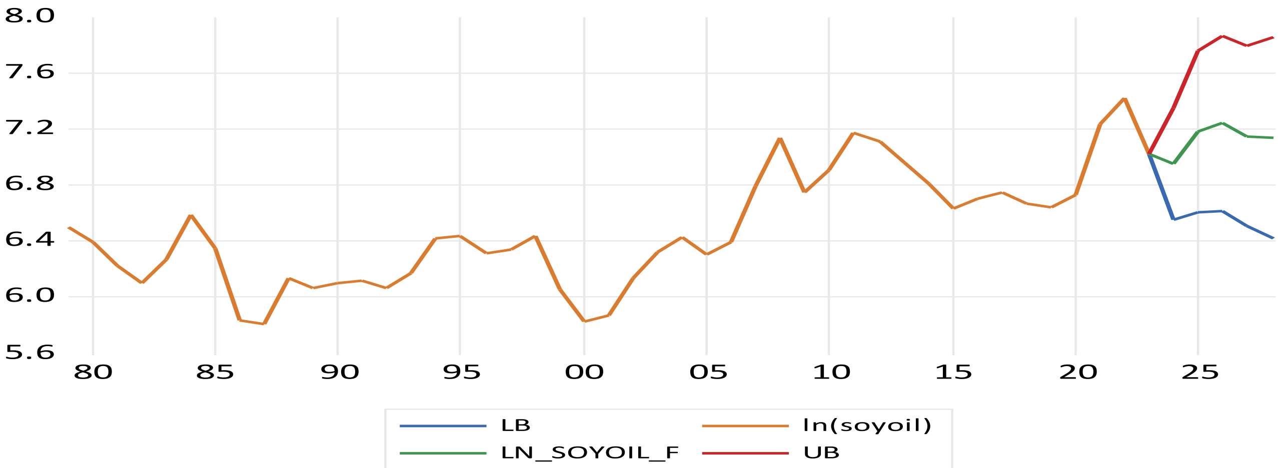

Figure 8. Historical and Forecasted Soybean Oil Prices in logarithmic scale (€/ton)

4.3.2. Results of sensitivity analysis

Investment decisions in the project were evaluated by assessing the sensitivity in terms of profitability of the of the proposed alternative feed formulations under varying economic conditions. These conditions include fluctuations in key variables such as feed ingredients prices, BSFL prices, broiler and egg prices. Sensitivity analysis was conducted to examine the impact of pessimistic (worst-case) to optimistic (best-case) scenarios on these prices , considering five distinct cases: (1) a base case with average prices for BSFL, soybean, soybean meal, corn, and outputs (broiler and egg); (2) an optimistic scenario with lower bound BSFL prices and average prices for other variables; (3) a worst-case scenario with high BSFL prices and average prices for the rest; (4) BSFL average prices combined with upper bound soybean meal and corn prices and average prices for outputs; and (5) BSFL and soybean meal, corn average prices with willingness-to-pay (WTP) prices for outputs. These scenarios were primarily applied to data obtained from UNITO, ISA-CM and EGE trials for broiler. For the egg example, data from the UMU and ISA-CM trials were evaluated. The first four scenarios have been applied to all country trials. The 5th scenario is based on consumers' willingness to pay, as calculated from surveys. These surveys were conducted for broilers in the EGE and UNITO cases and for eggs in the UMU and ISA-CM cases.

The **UNITO** sensitivity analysis findings provide comprehensive insights into the economic outcomes of alternative feeding diets under different scenarios. In the baseline scenario, ALT+BSFL demonstrates lower gross profit margins (13.67-12.19(€/bird)), cost-benefit ratios (3.12-2.88), and returns on investment (212.47%-187.72%) compared to CON and ALT. However, a slight recovery is observed in the optimistic scenario, with a 13.91(€/bird) gross profit margin, a 3.25 CBR, and a 224.70% RoI, whereas the pessimistic scenario reveals more significant risks, showing a 13.43 (€/bird) gross profit margin, a 3.01 CBR, and a 201.13% RoI. During the period 2024-2027, the ALT+BSFL maintains certain level of profitability even in the worst-case scenario (Figure 9, Figure 10 and Figure 11). These results highlight the need for a cautious approach when considering the economic feasibility of alternative feeding strategies.

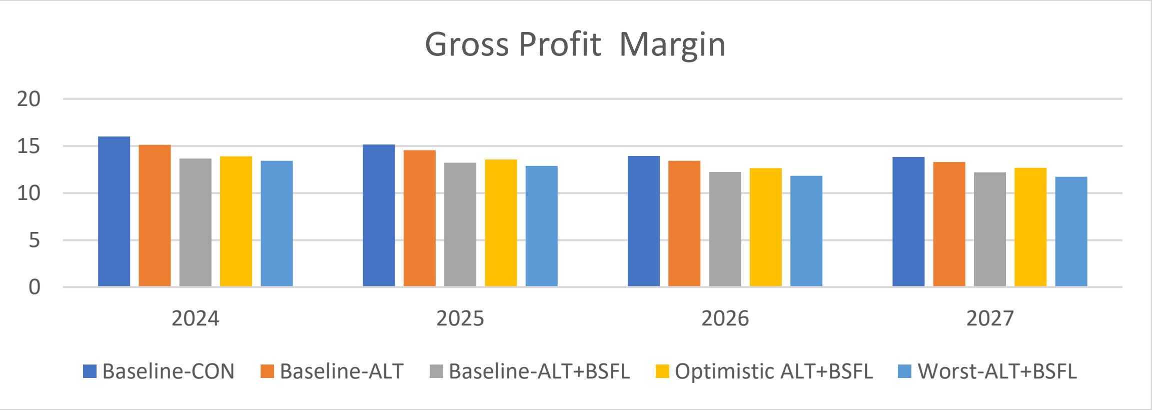

Figure 9. Projected Gross Profit Margins Under Different Scenarios (2024–2027) (UNITO-Broiler)

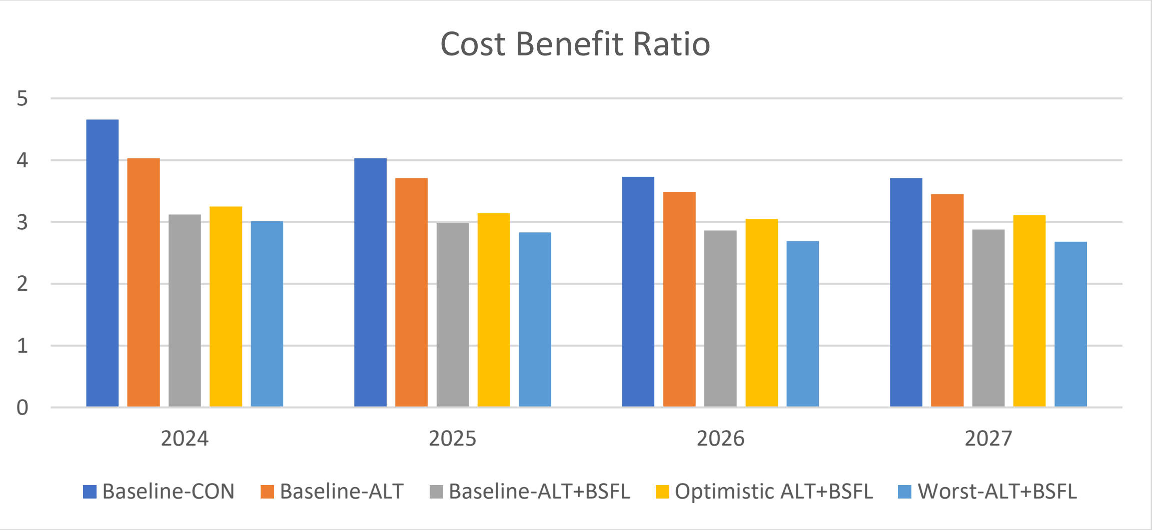

Figure 10. Projected Cost Benefit Ratio Under Different Scenarios (2024–2027) (UNITO-Broiler)

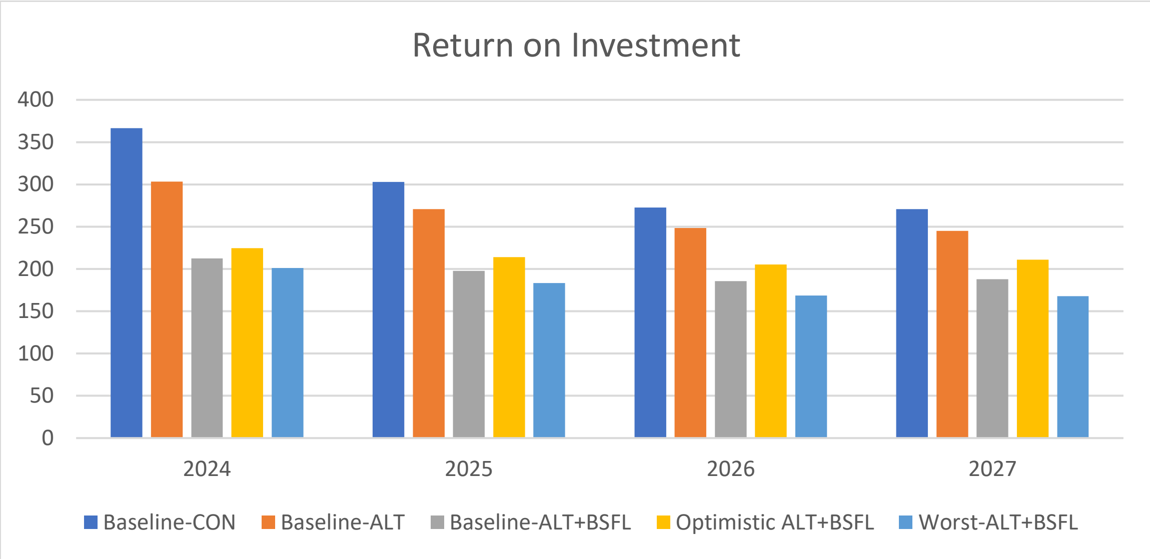

Figure 11. Projected RoI Under Different Scenarios (2024–2027) (UNITO-Broiler)

According to the results of the 4th scenario, during the 2024-2027 period, the ALT+BSFL diet demonstrated lower gross profit margins (12.87-10.22 (€/bird)), cost-benefit ratios (2.78-2.21), and returns on investment (178.21%-120.80%) compared to traditional (CON) and alternative (ALT) diet. However, the ALT diet showed better performance in both gross profit margins (14.46-11.32 (€/bird)) and returns on investment (257.41%-153.45%). While ALT+BSFL exhibited lower returns on investment, it holds potential in terms of long-term economic sustainability (Table 42).

Table 42. Projected Economic Performance of Alternative Diets for Scenario 4 (2024–2027) (UNITO-Broiler)

	Gross Profit Margin (€/bird)			Cost Benefit Ratio			Return on Investment (%)		
	CON	ALT	ALT+BSFL	CON	ALT	ALT+BSFL	CON	ALT	ALT+BSFL
2024	14.29	14.46	12.87	3.36	3.57	2.78	236.01	257.41	178.21
2025	12.00	12.98	11.66	2.48	2.88	2.42	147.70	187.81	141.59
2026	10.32	11.67	10.46	2.18	2.63	2.25	118.31	163.21	125.36
2027	9.79	11.32	10.22	2.07	2.53	2.21	107.31	153.45	120.80

The findings of the **ISA-CM trials** evaluate the economic performance of different diets under different scenarios (base, optimistic and worst). Under the baseline scenario, Conventional diet (Baseline-CON) demonstrated its highest performance in 2024 with a GPM of 4.86 (€/bird), but exhibited a gradual decline in subsequent years, reaching 3.82 (€/bird) in 2027. Similarly, alternative feeding diet under baseline (Baseline-ALT) exhibited a promising initial GPM performance, achieving 5.00 (€/bird) in 2024. And, as time progressed, the GPM performance of this alternative feeding diet also exhibited a downward trend, declining to 4.11 (€/bird) in 2027. Yet, these figures imply that, given the current price trends, Baseline-ALT presents a competitive alternative to the conventional diet in terms of economic sustainability. Under the baseline scenario ALT+BSFL diet (Baseline ALT+BSFL) demonstrated reasonable performance with a GPM of 4.54 (€/bird) in 2024, but this declined to 3.96 (€/bird) by 2027. These figures imply that, in terms of GPM, ALT+BSFL diet may outperform the conventional diet by the year 2027. At the same time, ALT diet represents the highest level of economic performance in both years. The optimistic scenario emerges as the case that best demonstrates the economic potential of BSFL supplemented diet (Optimistic ALT+BSFL). After an initial strong start of a GPM of 4.69 (€/bird) in 2024, the Optimistic ALT+BSFL demonstrates a relatively stable downward trend, declining to only 4.26 (€/bird) by 2027. This result suggests that, under the optimistic scenario, BSFL supplemented diet could become a competitive and sustainable alternative to both of other diets, underscoring the importance of cost control in ensuring economic feasibility. Conversely, under the pessimistic scenario ALT+BSFL diet (Worst ALT+BSFL) demonstrated the poorest performance across all years. Beginning at a GPM 4.40 (€/bird) in 2024, this diet demonstrated a decline to a GPM of 3.67 (€/bird) in 2027, indicating that achieving economic sustainability is at risk if cost management is not effectively executed in BSFL production (Figure 12).

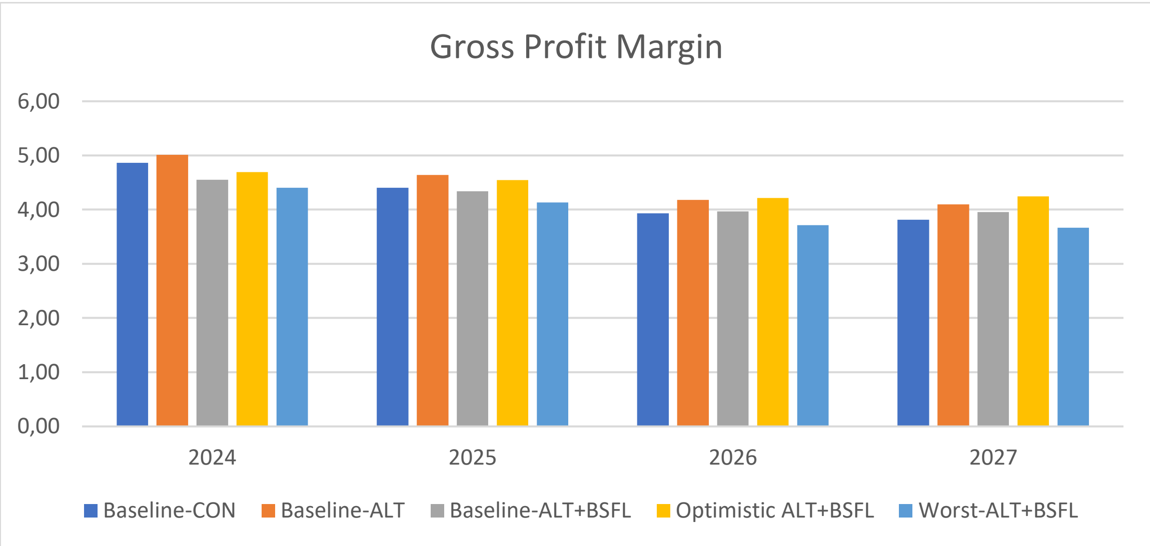

Figure 12. Projected Gross Profit Margins Under Different Scenarios (2024–2027) (ISA-CM-Broiler)

Under the baseline scenario, conventional diet (Baseline-CON) has demonstrated a robust cost-benefit ratio, establishing a solid foundation in terms of cost-effectiveness. The alternative diet (Baseline-ALT) initially demonstrated the most favorable performance and exhibited considerable promise. However, a more balanced cost-benefit ratio was observed for the ALT+BSFL diet under the optimistic scenario (Optimistic ALT+BSFL). This option seems to be the most favorable one particularly in the long run. Conversely, the ALT+BSFL diet under the pessimistic scenario exhibited the least favorable outcomes (Figure 13).

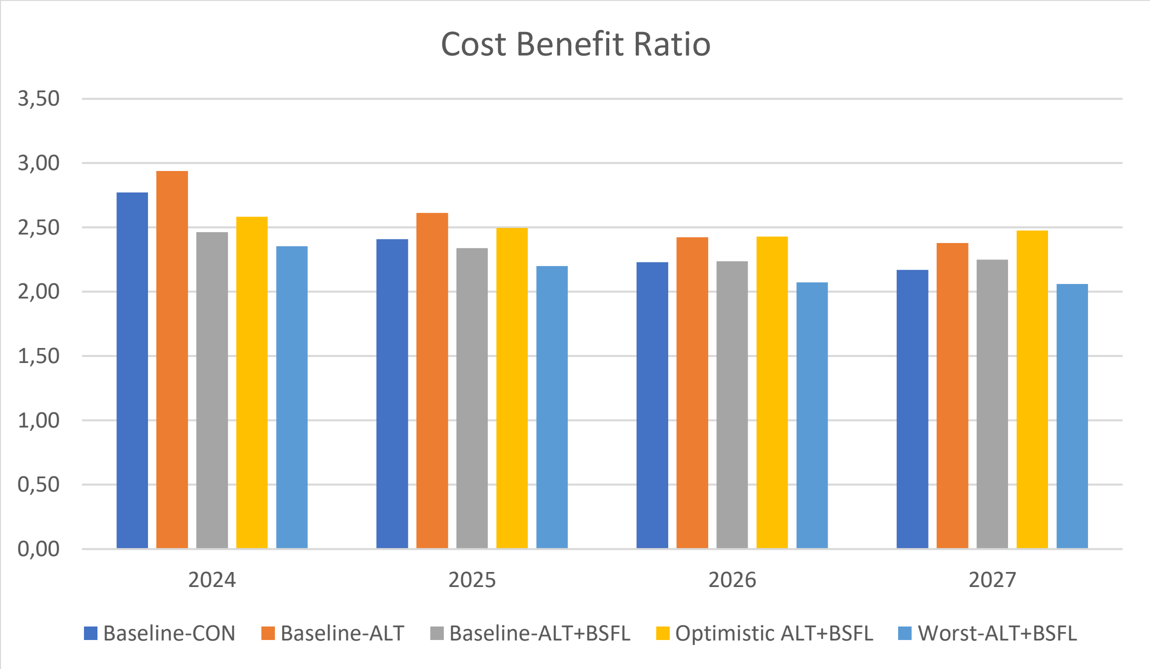

Figure 13. Projected Cost Benefit Ratio Under Different Scenarios (2024–2027) (ISA-CM-Broiler)

With respect to RoI, as well, conventional and alternative diets have been shown to provide more reliable and higher returns. However, the BSFL supplemented diet has the potential to be a competitive alternative if cost management and efficiency optimization are achieved. Specifically, under the optimistic scenario, the ALT+BSFL diet has exhibited consistent performance superiority over all other formulations, and for all the profit criteria, making it a compelling option if cost benefits can be attained (Figure 14).

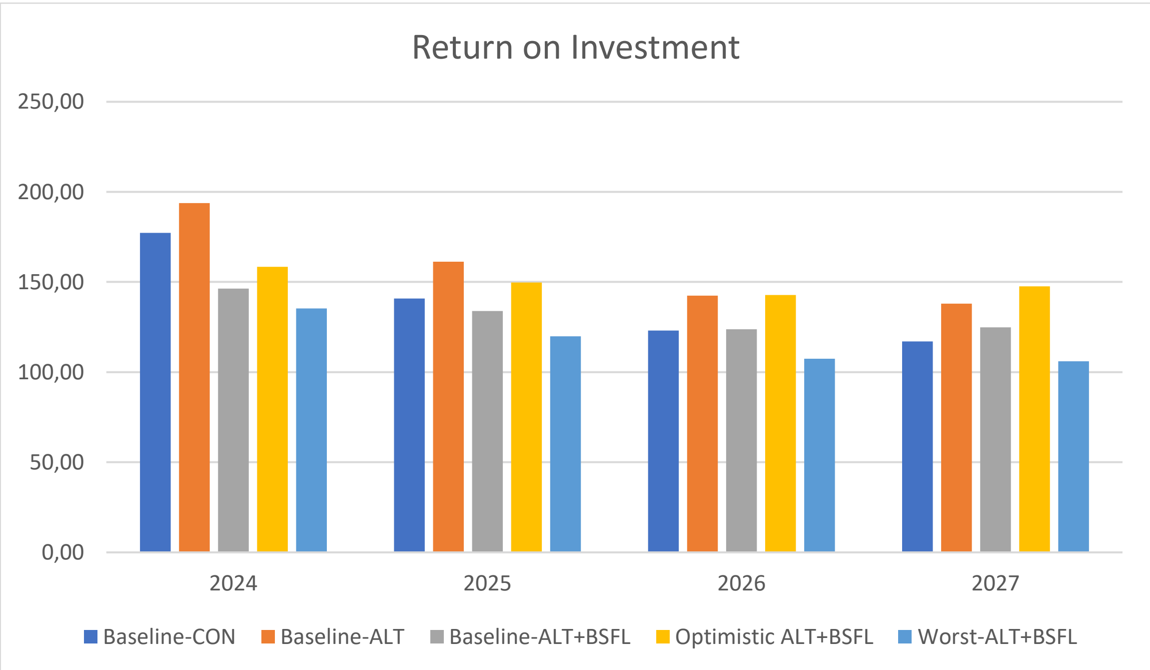

Figure 14. Projected RoI Under Different Scenarios (2024–2027) (ISA-CM-Broiler)

This table is obtained by applying the scenario 4 (average price of BSFL, upper bound soybean, soybean meal, corn prices, and average price of outputs [broilers]) to the ISA-CM trial results. It is evident that both ALT and ALT+BSFL yield superior profit margins, more favorable cost-benefit ratios, and higher returns on investment when compared to the control group. ALT demonstrates the highest performance, particularly in 2024, while in the long term (2025-2027), ALT+BSFL offers a balanced and sustainable advantage for all the criteria (Table 43). These findings imply that feeds containing BSFL could emerge as an economically viable alternative.

Table 43. Projected Economic Performance of Alternative Diets for Scenario 4 (2024–2027) (ISA-CM-Broiler)

	Gross Profit Margin(€/bird)			Cost Benefit Ratio			Return on Investment (%)		
	CON	ALT	ALT+BSFL	CON	ALT	ALT+BSFL	CON	ALT	ALT+BSFL
2024	3.57	4.10	3.88	1.88	2.17	2.03	88.25	116.94	102.84
2025	2.31	3.15	3.36	1.44	1.72	1.80	44.25	72.16	79.94
2026	1.54	2.42	2.69	1.28	1.51	1.60	27.61	51.48	59.96
2027	1.06	2.06	2.48	1.18	1.41	1.53	17.75	41.26	53.49

Figures 15, 16 and 17 present the results of this analysis for EGE for Anadolu-T, highlighting potential variations in profitability driven by changes in the key parameters. Figure 15 compares the effect of different diets on future GPMs under baseline, optimistic and pessimistic BSFL price predictions, evaluating the economic potential of alternative feeding strategies for EGE trial (**Anadolu T**). Under the baseline scenario, the control group (Baseline-CON) and the alternative local feed formulation (Baseline-ALT) generally offer higher and more stable profit margins, while the BSFL supplemented diet (Baseline-ALT+BSFL) show lower performance. The situation is even worsened for the diet containing BSFL under the worst BSFL price projection. However, the optimistic BSFL scenario supports the idea that alternative diets could become a competitive option in the long run, if costs are kept under control.

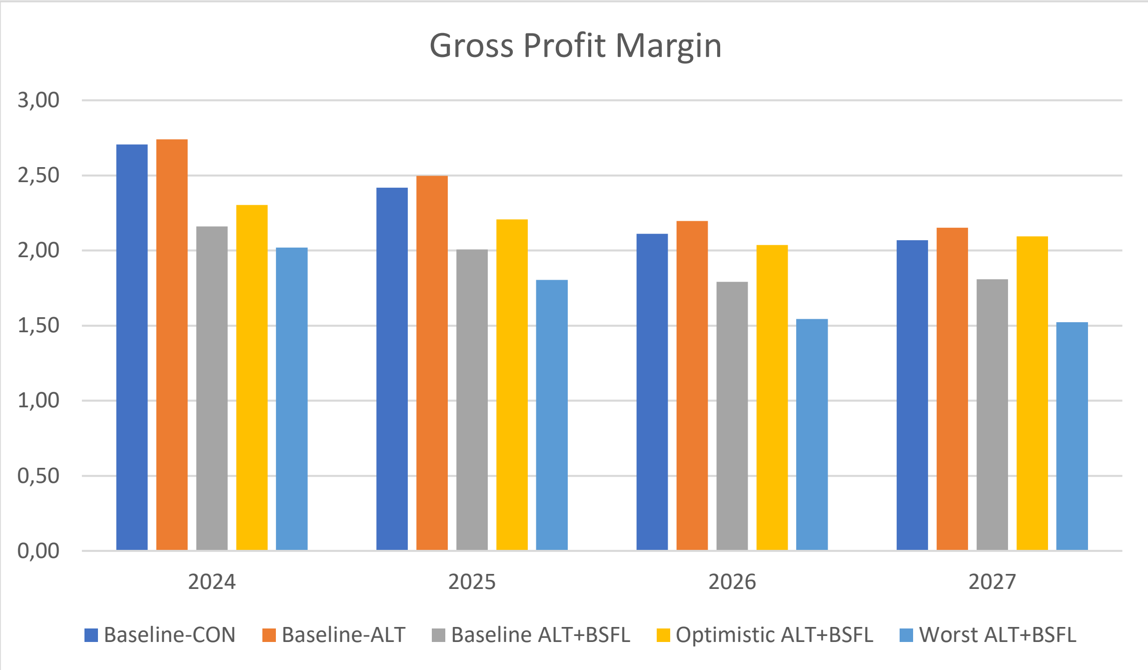

Figure 15. Projected Gross Profit Margins Under Different Scenarios (2024–2027) (EGE-Anadolu-T)

Figure 16 compares cost-benefit ratios across different Alternative Diets from 2024 to 2027 for EGE trials (Anadolu T). Under the baseline scenario, the control group (Baseline-CON) and the alternative local feed formulation (Baseline-ALT) consistently demonstrated the highest cost-benefit ratios throughout the years. Scenarios incorporating BSFL, particularly under pessimistic conditions (Worst ALT+BSFL), showed lower ratios. However, the optimistic scenario (Optimistic ALT+BSFL) suggests that BSFL could be a viable option in about three years if cost advantages are maintained in BSFL production.

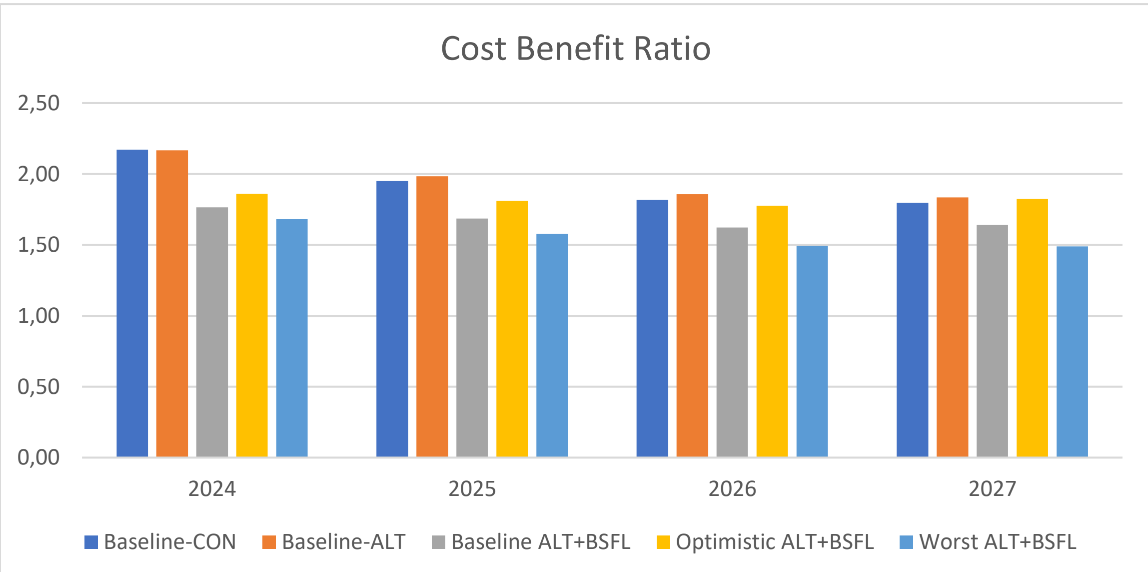

Figure 16. Projected Cost Benefit Ratio Under Different Scenarios (2024–2027) (EGE-Anadolu-T)

Figure 17 shows the impact of different alternative diets on RoI from 2024 to 2027. Under the baseline scenario, both the control group (Baseline-CON) and the alternative local feed formulation (Baseline-ALT) consistently provided the highest returns on investment each year. Scenarios incorporating BSFL, particularly under pessimistic conditions (Worst ALT+BSFL), exhibited lower returns. However, under the optimistic scenario, RoI estimations as well, support the idea that BSFL-supplemented feeds could become a competitive alternative in the medium to longer run.

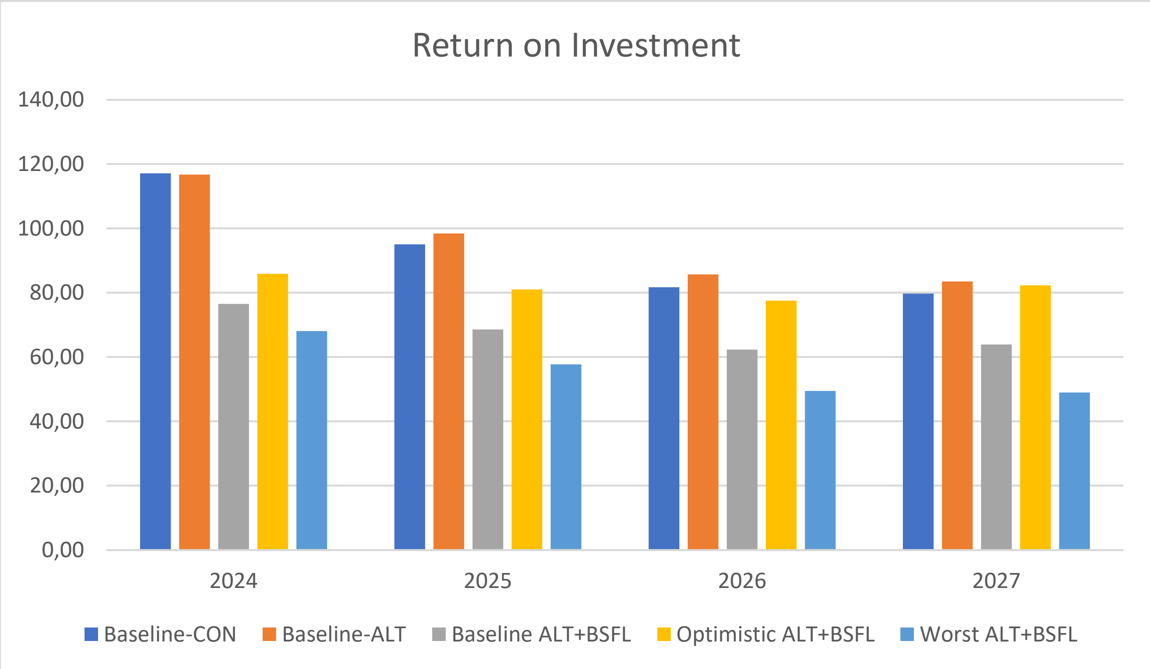

Figure 17. Projected RoI Under Different Scenarios (2024–2027) (EGE-Anadolu-T)

Table 44 examines the economic performance of feed strategies over the years based on Scenario 4. In this scenario the effects of BSFL average prices combined with upper bound soybean meal and corn prices and average prices for outputs are evaluated. Throughout the analysis period, the alternative local feed (ALT) strategy has demonstrated stable and the highest performance across all indicators. While the control group (CON) remained competitive in the short term, the BSFL-inclusive alternative feed (ALT+BSFL) has shown more promising results starting from the third year. Given that, under a probable upper bound soybean and corn prices scenario, all the profitability criteria (GPM, CBR and RoI) exhibit a declining trend over time, it is recommended to develop poultry diets including increased amount of local ingredients and also BSFL, which both helps with combatting the deteriorating profitability results. During such a development course for alternative diets, it will be crucial to optimize costs and improve processes to ensure sustainability.

Table 44. Projected Economic Performance of Alternative diets for Scenario 4 (2024–2027) (EGE-Anadolu-T)

	Gross Profit Margin (€/bird)			Cost Benefit Ratio			Return on Investment (%)		
	CON	ALT	ALT+BSFL	CON	ALT	ALT+BSFL	CON	ALT	ALT+BSFL
2024	1.59	2.22	1.69	1.68	1.77	1.51	68.46	77.45	51.29
2025	1.03	1.54	1.13	1.32	1.44	1.30	31.90	44.08	29.64
2026	0.68	1.09	0.79	1.18	1.30	1.20	17.71	29.93	20.26
2027	0.56	0.90	0.66	1.11	1.24	1.17	11.42	23.64	16.73

Table 45 provides insights into the economic performance of different feed diets under Scenario 5, covering projections from 2024 to 2027. In this scenario, the effect of consumers' willingness to pay for BSFL based broiler products, based on the results of the SUSTAvianFEED project consumer survey carried out in İzmir province, and the expected average prices of feed ingredients on economic profitability over time were evaluated. Based on the survey results, those consumers who are willing to buy chicken meat grown using the ALT+BSFL diet were identified to be willing to pay a price premium of 40.57% and for ALT is 37.27%. Accordingly, the ALT+BSFL diet is initially characterized by higher GPMs (4.18(€/bird)) and RoIs (148.17%). It is notable that, under the Scenario 5, ALT+BSFL maintains its competitive advantage relative to CON and ALT, for all the profitability criteria and for all the years. In case of a positive price margin, BSFL presents a promising solution for developing sustainable alternative feed resources over the long term. It is important to note that, for such positive price margin, respecting the environmental sustainability in the BSFL production and communicating advantages of using BSFL supplemented poultry diet through informative product labels would be necessary.

Table 45. Projected Economic Performance of Alternative Diets for Scenario 5 (2024–2027) (EGE-Anadolu-T)

	Gross Profit Margin (€/bird)			Cost Benefit Ratio			Return on Investment (%)		
	CON	ALT	ALT+BSFL	CON	ALT	ALT+BSFL	CON	ALT	ALT+BSFL
2024	2.71	4.64	4.18	2.17	2.98	2.48	117.14	197.59	148.17
2025	2.42	4.37	4.01	1.95	2.72	2.37	95.10	172.46	136.98
2026	2.11	3.97	3.68	1.82	2.55	2.28	81.75	154.90	128.13
2027	2.07	3.92	3.69	1.80	2.52	2.31	79.72	151.95	130.50

The results of the Ege trials for COBB highlight the economic advantages of local feed formulations and the cost impact of BSFL. The results of the Ege trials for COBB provide a comprehensive evaluation of the economic performance of various feed formulations, highlighting key insights into gross profit margins, cost-benefit ratios, and return on investment (Figure 18, Figure 19, Figure 20). The Baseline-CON and Baseline-ALT scenarios consistently demonstrate strong economic advantages, with similar gross profit margins and cost-benefit ratios across all years. Notably, the ALT formulation generally offers slightly higher margins and ratios, suggesting that locally sourced feeds may provide an economically advantageous alternative to conventional formulations. In terms of RoI, Baseline-CON slightly outperforms

Baseline-ALT in most years, except for 2025, where Baseline-ALT marginally surpasses Baseline-CON, further indicating the financial viability of both conventional and local feed formulations. In contrast, the Baseline ALT+BSFL scenario consistently exhibits lower economic performance across all metrics due to the high costs of BSFL, which significantly limit its economic viability under current market conditions. Although the Optimistic ALT+BSFL scenario performs better than other BSFL-inclusive scenarios, reflecting potential cost savings and profitability under favorable conditions, it still lags the Baseline-CON and Baseline-ALT scenarios. The Worst ALT+BSFL scenario, on the other hand, delivers the lowest values in gross profit margins, cost-benefit ratios, and RoI, underscoring the financial risks and challenges associated with unfavorable market conditions for BSFL.

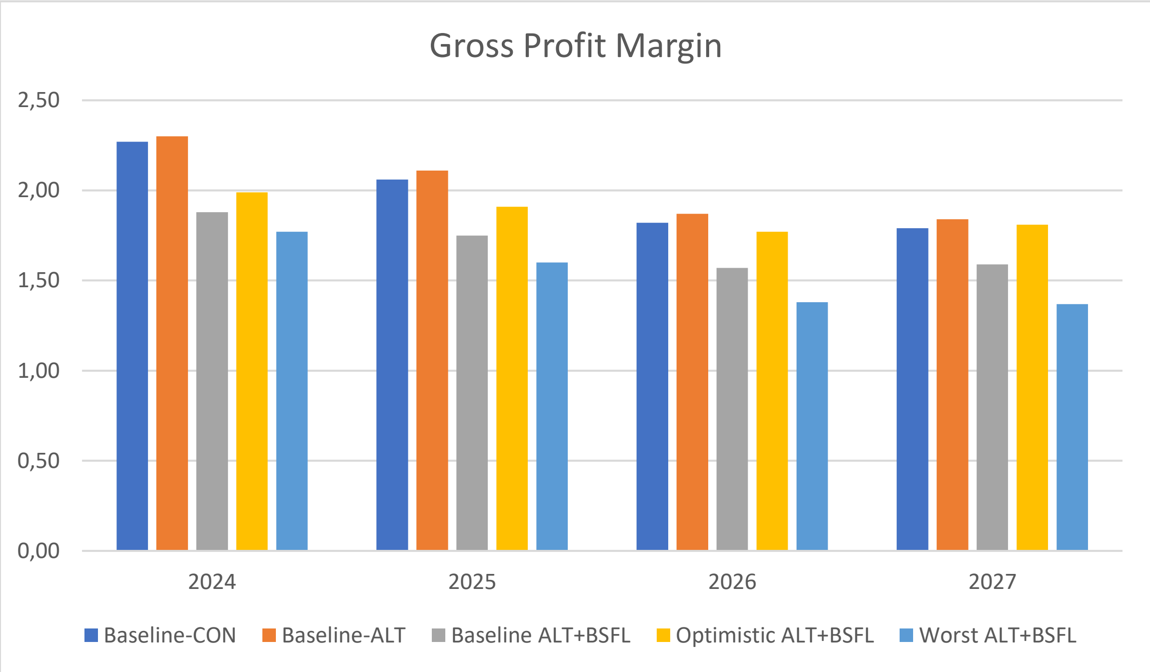

Figure 18. Projected Gross Profit Margins Under Different Scenarios (2024–2027) (EGE-Cobb)

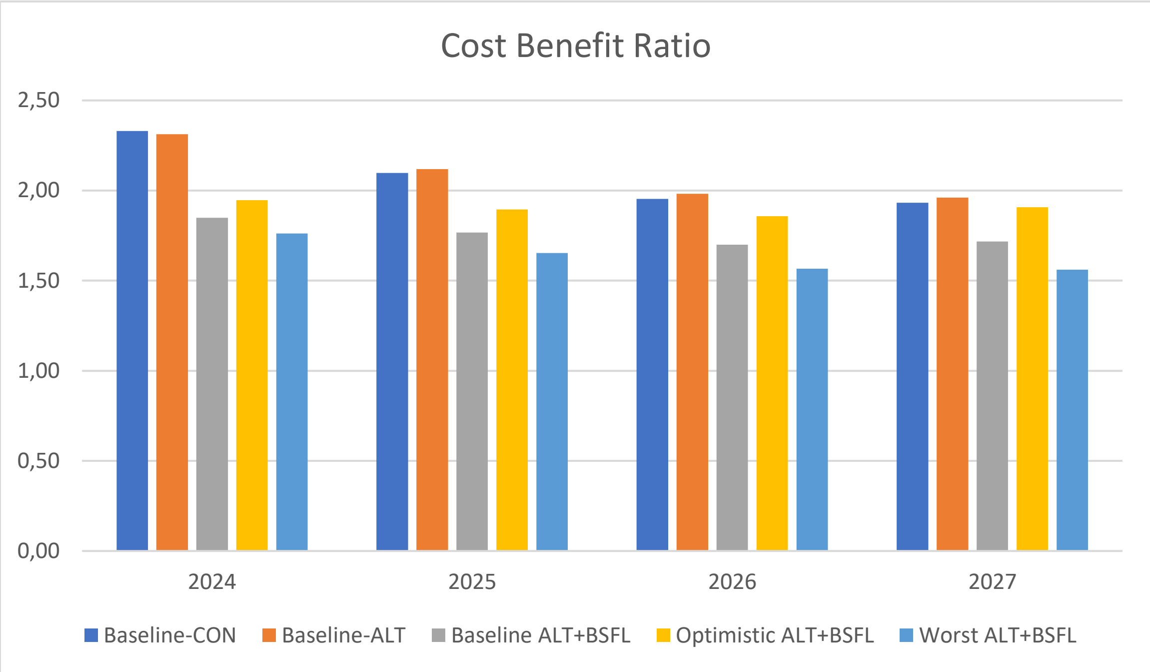

Figure 19. Projected Cost Benefit Ratio Under Different Scenarios (2024–2027) (EGE-Cobb)

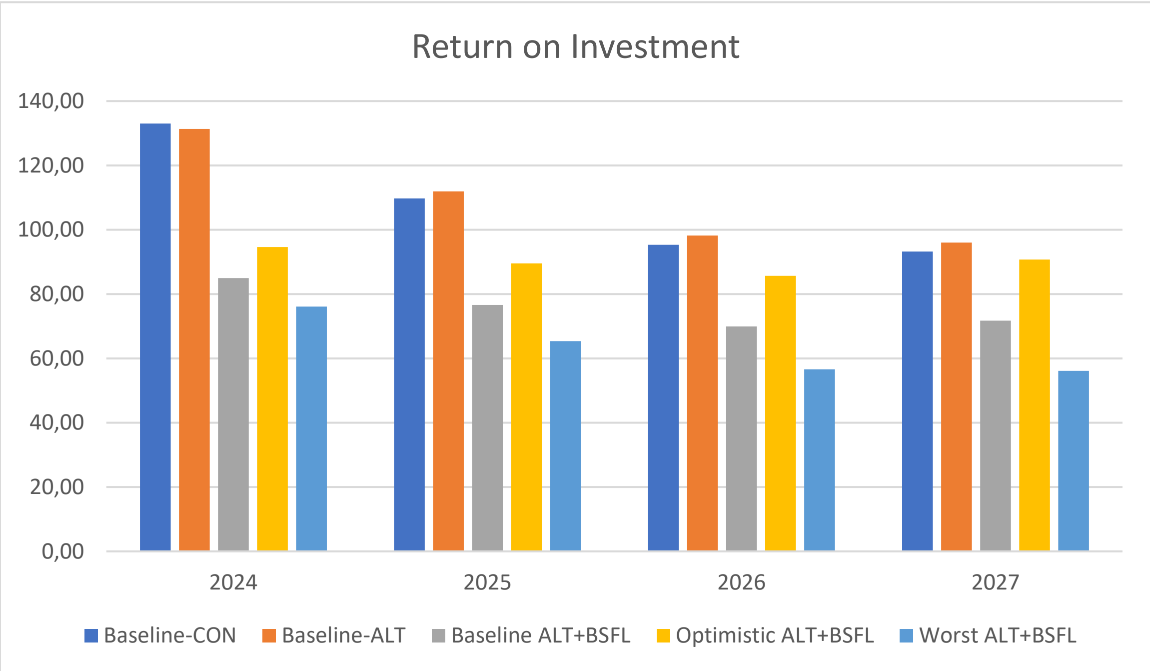

Figure 20. Projected RoI Under Different Scenarios (2024–2027) (EGE-Cobb)

The projected economic performance of alternative diets for Scenario 4 (2024–2027) highlights the clear economic advantage of locally sourced alternative feeds (ALT) over conventional diets (CON) and BSFL-inclusive feeds (ALT+BSFL). Across all metrics—Gross Profit Margin (GPM), Cost-Benefit Ratio (CBR), and Return on Investment (RoI)—ALT consistently outperforms both CON and ALT+BSFL. In contrast, while CON delivers moderate and stable results, ALT+BSFL consistently lags behind with significantly lower GPM (1.50

(€/bird)), CBR (1.58), and RoI (58.31%) in 2024. Over time, all diets experience a decline in economic performance, but ALT maintains its leading position (Table 46).

Table 46. Projected Economic Performance of Alternative diets for Scenario 4 (2024–2027) (EGE-Cobb)

	Gross Profit Margin (€/bird)			Cost Benefit Ratio			Return on Investment (%)		
	CON	ALT	ALT+BSFL	CON	ALT	ALT+BSFL	CON	ALT	ALT+BSFL
2024	1.78	1.90	1.50	1.81	1.89	1.58	81.15	89.19	58.31
2025	1.16	1.40	1.06	1.42	1.54	1.36	42.21	53.74	35.66
2026	0.78	1.05	0.78	1.27	1.39	1.26	26.90	38.55	25.73
2027	0.62	0.90	0.68	1.20	1.32	1.22	20.21	31.91	22.07

Scenario 5 evaluates the economic performance of alternative diets considering consumer willingness to pay premiums: 40.57% for ALT+BSFL and 37.27% for ALT. As reflected in the Table 47, ALT diet consistently deliver the highest gross profit margins, cost-benefit ratios, and return on investment across all years. For example, in 2024, ALT achieves a GPM of 3.81 (€/bird), a CBR of 3.18, and an RoI of 217.55%, indicating substantial financial returns driven by consumer preference for sustainable alternatives. ALT+BSFL diets also perform well, with a GPM of 3.54 (€/bird) and an RoI of 159.97% in 2024, showing their potential when supported by premium pricing. While conventional diets (CON) provide stable but lower economic returns, with a GPM of 2.27 (€/bird) and RoI of 133.04% in 2024, the gap widens significantly in favor of ALT and ALT+BSFL over time.

Table 47. Projected Economic Performance of Alternative Diets for Scenario 5 (2024–2027) (EGE-Cobb)

	Gross Profit Margin (€/bird)			Cost Benefit Ratio			Return on Investment (%)		
	CON	ALT	ALT+BSFL	CON	ALT	ALT+BSFL	CON	ALT	ALT+BSFL
2024	2.27	3.81	3.54	2.33	3.18	2.60	133.04	217.55	159.97
2025	2.06	3.61	3.40	2.10	2.91	2.48	109.73	190.92	148.28
2026	1.82	3.29	3.13	1.95	2.72	2.39	95.34	172.07	138.86
2027	1.79	3.24	3.13	1.93	2.69	2.41	93.25	169.04	141.39

To examine the situation for eggs, the economic results of the trials of UMU and ISA-CM were analyzed. For **UMU**, the data presented in the following graphs (Figure 21, Figure 22 and Figure 23) comparatively assesses the economic performance of different scenarios in terms of GPMs, CBRs and RoIs. The control and alternative local diet (ALT) generally outperform the ALT+BSFL. Nevertheless, the BSFL supplemented diet shows promising results, especially in optimistic forecasts. While the cost-effectiveness of BSFL is initially limited, a significant upward trend emerges by 2027. This suggests that BSFL produced in a cost-effective way has potential for sustainable alternative diets in laying hens and can be a competitive alternative in the long run.

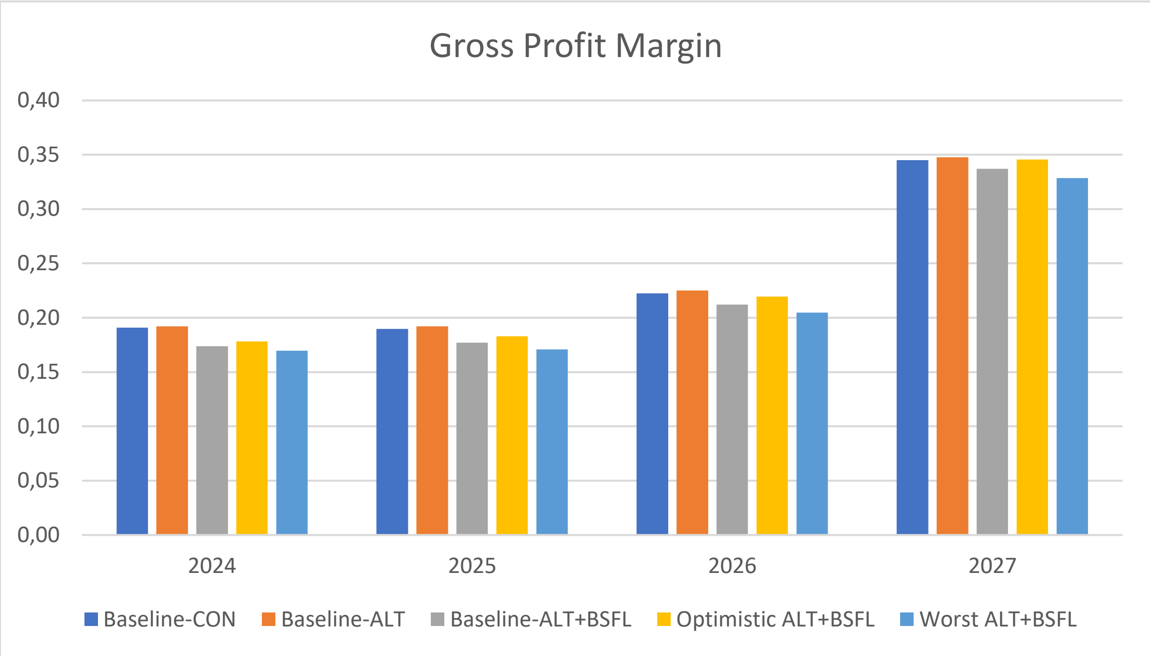

Figure 21. Projected Gross Profit Margins Under Different Scenarios (2024–2027) (UMU-egg)

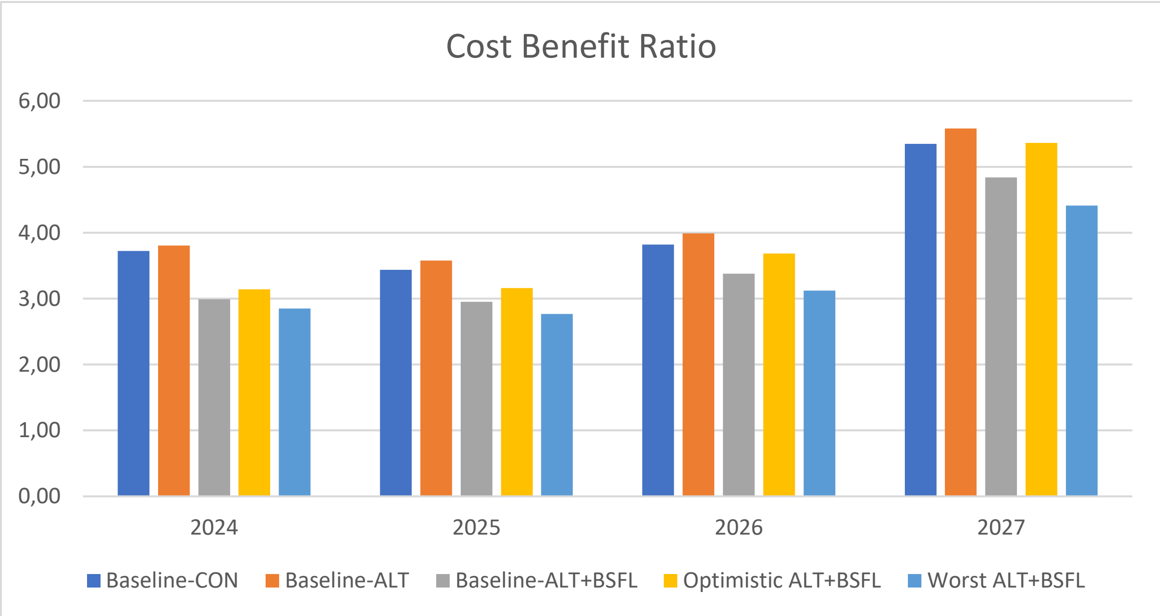

Figure 22. Projected Cost Benefit Ratio Under Different Scenarios (2024–2027) (UMU-egg)

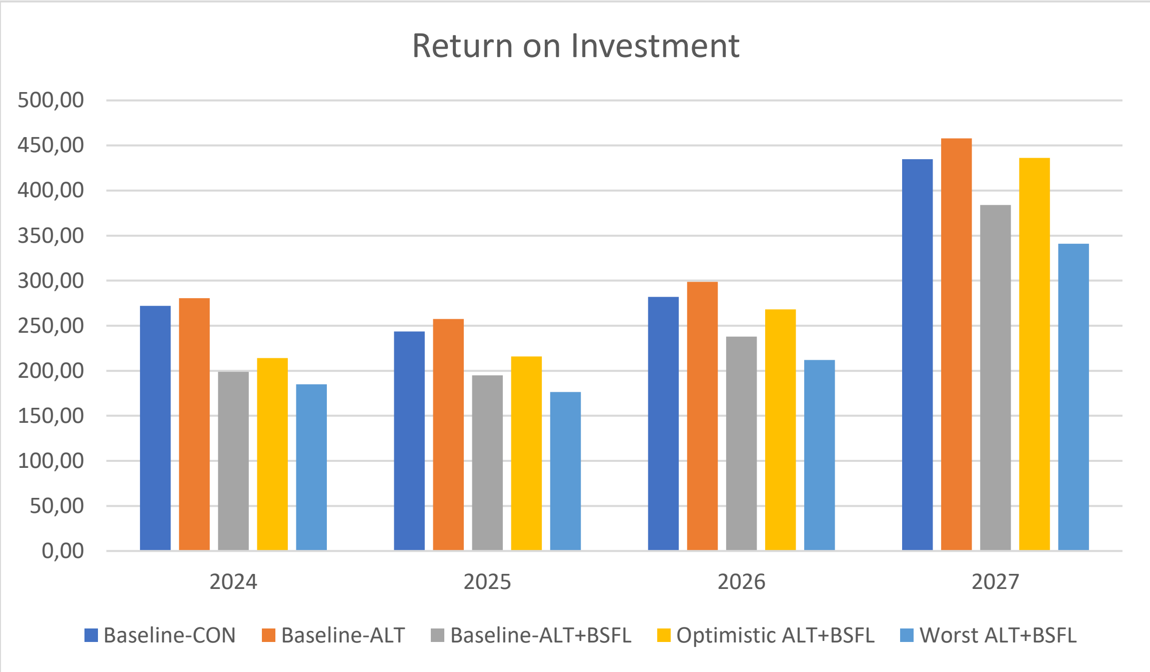

Figure 23. Projected RoI Under Different Scenarios (2024–2027) (UMU-egg)

The projections in Table 48 evaluate the economic performance of different diets under Scenario 4. In terms of GPM, all diets demonstrate consistent growth over time. This is despite increasing feed prices, and actually, due to prices of eggs increasing faster than those of feed ingredients. While the BSFL-supplemented local alternative formulation (ALT+BSFL) initially exhibits lower performance compared to conventional and local alternative diets, in 2026 and 2027, it shows potential for improving cost-effectiveness up to the level of the conventional diet. As in the case of GPM, the alternative local feed formulation (ALT) also delivers the highest values for CBR and RoI across all years, reaching a level of 4.27 and 327.23% for these indicators respectively in 2027. In terms CBR and RoI, although BSFL initially performs at lower levels, it rises up to a GPM of 0.32 (€/egg) and a RoI of 290.01% by 2027, achieving a competitive position especially compared to the conventional diet. This indicates that the use of BSFL could also be a valuable option for long-term economic sustainability.

Table 48. Projected Economic Performance of Alternative Diets for Scenario 4 (2024–2027) (UMU-Egg)

	Gross Profit Margin (€/egg)			Cost Benefit Ratio			Return on Investment (%)		
	CON	ALT	ALT+BSFL	CON	ALT	ALT+BSFL	CON	ALT	ALT+BSFL
2024	0.17	0.18	0.16	2.94	3.15	2.61	194.34	214.71	160.50
2025	0.17	0.18	0.16	2.68	2.93	2.53	168.24	192.92	153.29
2026	0.20	0.21	0.20	2.86	3.16	2.81	186.34	215.66	180.99
2027	0.32	0.33	0.32	3.86	4.27	3.90	285.71	327.23	290.01

In Scenario 5, consumer willingness-to-pay data obtained from survey results was used, revealing that consumers were willing to pay 11.12% more for eggs produced using BSFL-based feed. This percentage was reflected in the current egg prices to create Scenario 5, providing a foundation for analyzing the economic potential of BSFL-based feed formulations. As shown in Table 49, BSFL demonstrates steady growth across all performance metrics. Gross profit margins improve from 0.20 (€/egg) in 2024 to 0.38 (€/egg) in 2027, reflecting an increasing alignment with traditional feed formulations. The cost-benefit ratio also shows notable gains, rising to 5.35 in 2027. Return on investment follows a similar trend, reaching 434.69% in 2027, highlighting the formulation's profitability and competitiveness in the market presented in this scenario.

Table 49. Projected Economic Performance of Alternative Diets for Scenario 5 (2024–2027) (UMU-Egg)

	Gross Profit Margin (€/egg)			Cost Benefit Ratio			Return on Investment (%)		
	CON	ALT	ALT+BSFL	CON	ALT	ALT+BSFL	CON	ALT	ALT+BSFL
2024	0.19	0.19	0.20	3.72	3.81	3.32	272.07	280.69	231.97
2025	0.19	0.19	0.21	3.42	3.55	3.26	241.75	255.43	225.87
2026	0.22	0.22	0.24	3.80	3.96	3.73	279.92	296.41	273.15
2027	0.34	0.35	0.38	5.32	5.55	5.35	431.71	454.73	434.69

The findings of the **ISA-CM trials** reveal how GPMs in egg production change under different scenario analyses. Under the baseline scenario analyzed for the 2024–2027 period, a certain level of stability in GPMs was observed for all the diets (CON, ALT, and ALT+BSFL). Notably, the optimistic and the pessimistic BSFL price scenarios as well were considered for the ALT+BSFL diet. While GPMs for the ALT+BSFL diet ranged between 0.03 (€/egg) and 0.04 (€/egg) in 2024 and 2025, they showed an improving trend, reaching to the range of 0.04 (€/egg) to 0.06 (€/egg) in 2026 and 2027 (Figure 24). This suggests promising indications that BSFL can serve as a cost-effective and sustainable feed alternative. Furthermore, it highlights its potential to adapt to changing market conditions.

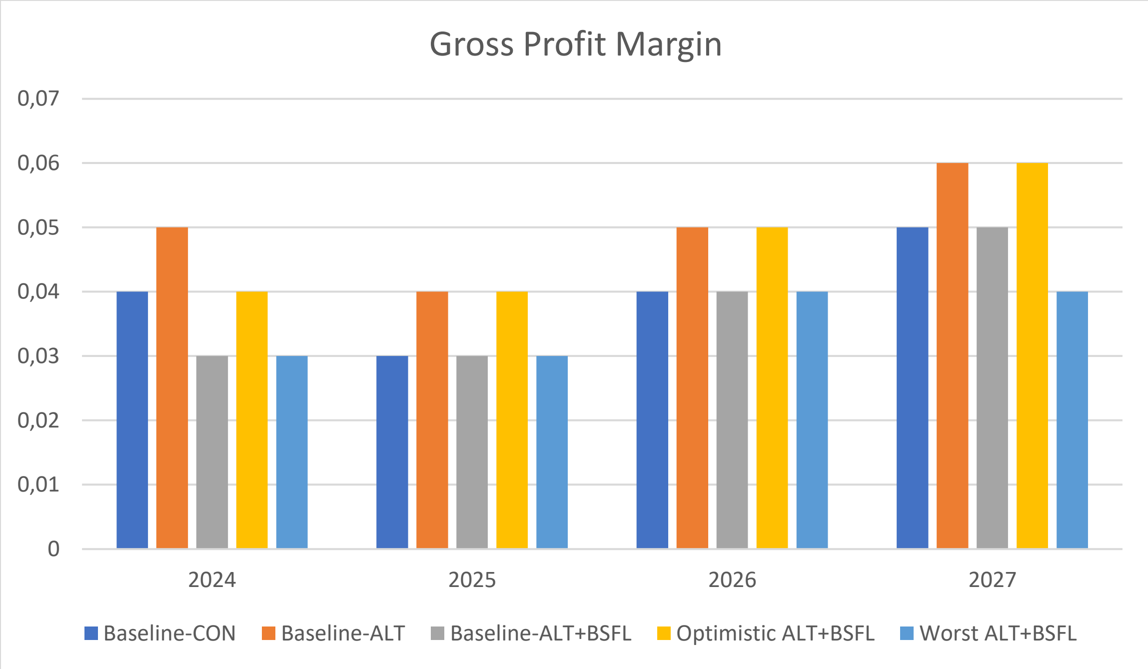

Figure 24. Projected Gross Profit Margins Under Different Scenarios (2024–2027) (ISA-CM-egg)

The findings of the ISA-CM trials include CBRs in egg production under different scenario analyses. For the 2024–2027 period, a certain level of stability in CBRs was observed across the baseline scenarios (CON, ALT, and ALT+BSFL). Again, both optimistic and pessimistic scenarios were analyzed for the ALT+BSFL diet. In 2024, CBRs estimated for ALT+BSFL ranged between 1.52 and 2.10, while in 2027, these ratios varied between 1.68 and 2.19 (Figure 25). This indicates that BSFL can be considered a sustainable and economically viable feed alternative over time.

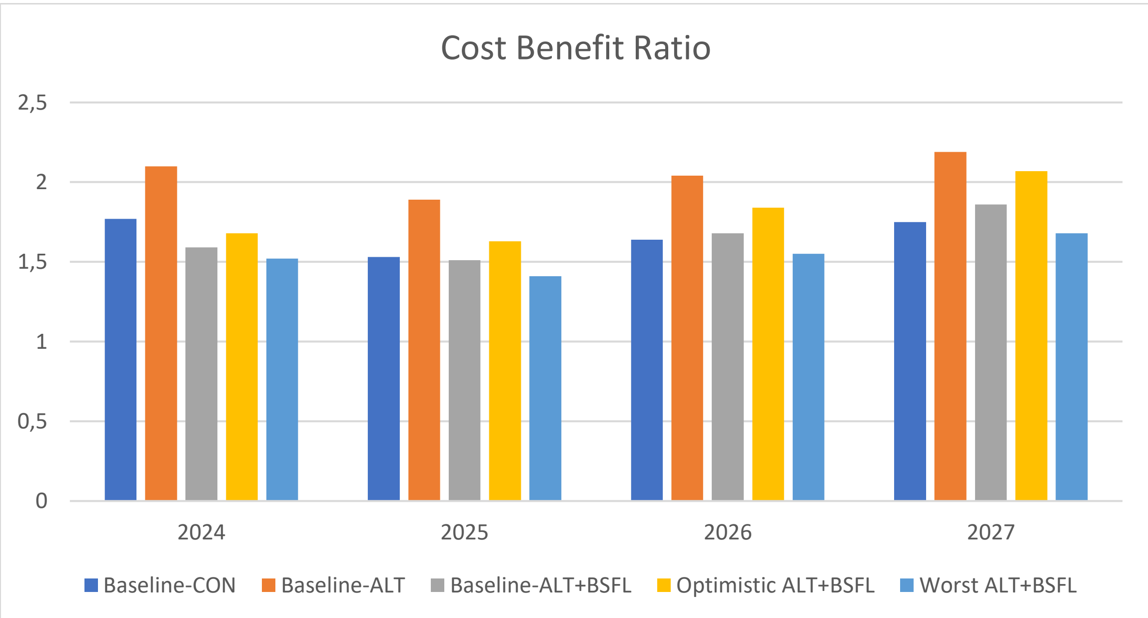

Figure 25. Projected Cost Benefit Ratio Under Different Scenarios (2024–2027) (ISA-CM-egg)

The analyses conducted within the scope of the ISA-CM trials highlight the impact of alternative feed strategies on RoI in egg production. Throughout the 2024–2027 period, the ALT+BSFL scenario presented results that reflected both opportunities and risks. While the ALT diet under the baseline scenario demonstrated high performance, with RoIs ranging between 110.18% and 118.92%, those of the ALT+BSFL diet under optimistic scenario ranged between 68.15% and 106.85% (Figure 26). These findings support the remarkable economic feasibility of the ALT diet over the next four years, as well as that of the ALT+BSFL diet within a longer period. Increasing profitability trends are notable for both diets.

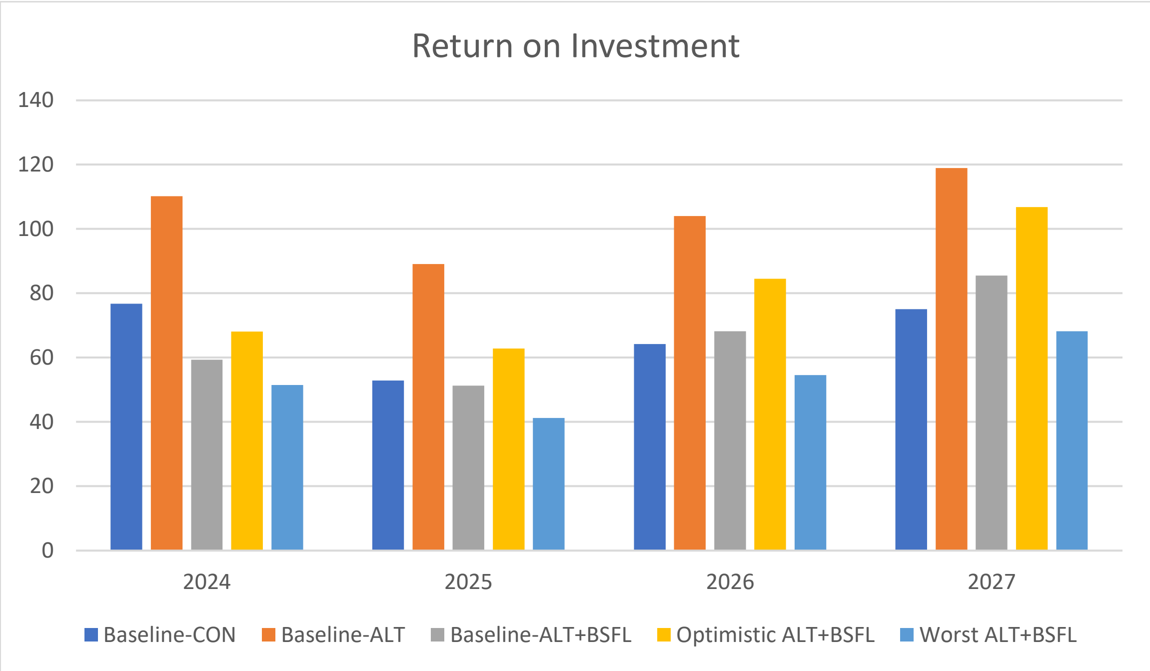

Figure 26. Projected RoI Under Different Scenarios (2024–2027) (ISA-CM-egg)

The findings of the ISA-CM trials present results based on Scenario 4 analyses regarding GPM, CBR, and RoI in egg production. Throughout the 2024–2027 period, alternative feed scenarios (ALT and ALT+BSFL) were compared with the conventional one (CON). The ALT diet generally demonstrated the highest performance, while the ALT+BSFL scenario provided stable and further improving outcomes. Under this scenario of increasing prices for conventional feed stuff, economic performance of the conventional poultry diet deteriorates to an unfeasible level (Table 50). These results reveal the need for the serious and urgent consideration of diets containing increased amounts of local ingredients as well as BSFL for economically sustainable egg production.

Table 50. Projected Economic Performance of Alternative Diets for Scenario 4 (2024–2027) (ISA-CM-Egg)

	Gross Profit Margin (€/egg)			Cost Benefit Ratio			Return on Investment (%)		
	CON	ALT	ALT+BSFL	CON	ALT	ALT+BSFL	CON	ALT	ALT+BSFL
2024	0.01	0.03	0.02	1.19	1.56	1.28	18.92	55.84	28.23
2025	-0.01	0.02	0.01	0.91	1.26	1.11	-9.19	26.07	10.62
2026	-0.01	0.02	0.02	0.94	1.31	1.18	-6.47	31.16	18.38
2027	-0.01	0.03	0.02	0.95	1.34	1.25	-5.30	34.50	24.60

The findings of the ISA-CM trials present Scenario 5 analyses on gross profit margin, cost-benefit ratio, and return on investment (RoI) in egg production. The results from 2024 to 2027 compare the baseline (CON) with alternative feed strategies (ALT and ALT+BSFL). ALT consistently outperforms the baseline, while ALT+BSFL demonstrates even higher performance across all indicators. For example, in 2024, gross profit margins range from 0.04 to 0.07, cost-benefit ratios from 1.77 to 2.19, and RoI reach 119.20% under ALT+BSFL. These results highlight BSFL's economic feasibility as a feed alternative, supporting its potential for profitability and sustainability (Table 51).

Table 51. Projected Economic Performance of Alternative Diets for Scenario 5 (2024–2027) (ISA-CM-Egg)

	Gross Profit Margin (€/egg)			Cost Benefit Ratio			Return on Investment (%)		
	CON	ALT	ALT+BSFL	CON	ALT	ALT+BSFL	CON	ALT	ALT+BSFL
2024	0.04	0.05	0.07	1.77	2.10	2.19	76.81	110.18	119.20
2025	0.03	0.04	0.07	1.53	1.89	2.08	52.89	89.07	108.02
2026	0.04	0.05	0.08	1.64	2.04	2.31	64.19	103.98	131.30
2027	0.05	0.06	0.09	1.75	2.19	2.55	75.10	118.92	155.13

Achievement of KPI4 of the Project

Percentage Changes in Costs with alternative sustainable diets

Given that one of the objectives of the SUSTAVIANFEED project was to achieve a minimum of 6% reduction in the poultry feed production cost and at least a 4% reduction in the total production cost throughout the entire value chain process (KPI4), a detailed analysis was carried out on the feed costs, including those under different scenarios considered in the economic analysis. Partial budgeting analysis and the cost-benefit analysis carried out for the economic analysis of the Project outputs permitted a throughout elaboration of the feed costs.

To measure the reduction in poultry feed production cost throughout the entire value chain process, "Cost of Feed Consumed (Euro/carcass kg)" was considered to be the most appropriate indicator for the broiler case. This is because this indicator directly relates to the production output (carcass weight), offering a comprehensive measure of feed efficiency relative to the final product. It reflects the overall cost efficiency of feed utilization across the value chain by linking feed costs to the weight of the final product (chicken meat).

When alternative sustainable diets used in the Project are compared with the control diet, with respect to the cost of feed consumed per kg of carcass weight, the following results are observed:

- In the case of the **UNITO pilot**, and under the baseline scenario, there is an increase and not a reduction for both cases of ALT and ALT+BSFL diets. While the use of ALT diet resulted in an increase of feed costs by 15.6% in 2023, this negative effect reduces throughout the years. Even so, a reduction in feed cost with ALT diet seems difficult in the short and medium term. Realization of a cost reduction target is even harder with the ALT+BSFL diet used by UNITO. The situation has been somewhat improved under the optimistic price trend scenario for BSFL. However, the Project goals of reduced feed and production costs have not seemed to be attainable with the sustainable alternative diets used in the UNITO pilot for broiler production, under the baseline and the optimistic scenarios (Table 52). Still, under scenario 4, in which upper bound price estimates were used for soybean and maize prices, both ALT and ALT+BSFL diets are found to be quite promising, both reaching the Project goals of cost savings (Table 53).
- In the case of **ISA-CM broiler pilot**, on the other hand, reductions of feed costs are identified from 5.33% to 8.87% for the ALT diet used. It is also observable that the cost saving is improved with the predicted feed ingredient prices under the baseline scenario. In the case of ALT diet used in ISA-CM broiler pilot, project cost reduction objectives are estimated to be achievable even by the year 2024. In the case of ALT+BSFL diet, the Project goal of 6% cost saving is not achievable during the prediction period, under the baseline scenario. On the other hand, this goal is attained by the year 2026, under the condition that the BSFL prices present an optimistic downward trend. Under this optimistic scenario, feed costs are reduced as twice of the goal of the Project, by 12,38% (Table 52). The savings are further improved under Scenario 4 (Table 53). These results reveal quite promising economic performance both for the ALT and ALT+BSFL diets developed under the ISA-CM broiler pilot.
- In the case of **EGE pilots**, ALT and ALT+BSFL diets did not provide a feed cost reduction of more than 2,25% for the prediction period, neither for the slow growing, nor for the fast-growing breeds. This is true both for the baseline and the optimistic scenarios (Table 52). On the other hand, under Scenario 4, the ALT diet of EGE pilot provides savings of up to 10% for the slow-growing and up to almost 9% for the fast-growing breeds (Table 53).

Overall, for the case of chicken meat production, although improvements in cost of feed consumed per unit of production is achieved over the predicted years; ISA-CM pilot diets both with and without BSFL were the ones that enabled the Project cost saving objectives of 6% reduction in feed costs and 4% reduction in production costs to be achieved.

Table 52. Cost of Feed Consumed per kg of carcass by years

	Control Baseline	ALT Baseline	Chng Con to ALT %	ALT+BSFL Baseline	Chng Con to ALT+BSFL %	ALT+BSFL Optimistic	Chng Con to ALT+BSF
			UNITO				
202	2.5375	2.9334	**15.60**	4.0294	**58.80**	4.0294	**58.80**
202	2.5499	2.9453	**15.51**	3.8020	**49.10**	3.6589	**43.49**
202	2.9201	3.1713	**8.60**	3.9465	**35.15**	3.7440	**28.22**
202	2.9853	3.1897	**6.85**	3.8921	**30.38**	3.6442	**22.07**
202	2.9822	3.2030	**7.40**	3.8396	**28.75**	3.5533	**19.15**
			ISA-CM – Br				
202	1.3862	1.3123	**-5.33**	1.7949	**29.48**	1.7949	**29.48**
202	1.3911	1.3119	**-5.69**	1.5652	**12.52**	1.4920	**7.26**
202	1.5838	1.4598	**-7.83**	1.6313	**3.00**	1.5279	**-3.53**
202	1.6180	1.4878	**-8.04**	1.6128	**-0.32**	1.4861	**-8.15**
202	1.6525	1.5060	**-8.87**	1.5941	**-3.53**	1.4479	**-12.38**
			EGE-ANADOLU T				
202	1.3994	1.4010	**0.12**	1.7611	**25.85**	1.7611	**25.85**
202	1.4106	1.4110	**0.03**	1.7315	**22.74**	1.6441	**16.55**
202	1.5535	1.5250	**-1.84**	1.7941	**15.49**	1.6706	**7.54**
202	1.5774	1.5418	**-2.25**	1.7628	**11.76**	1.6115	**2.17**
202	1.5849	1.5498	**-2.21**	1.7334	**9.37**	1.5587	**-1.65**
			EGE-COBB				
202	1.0439	1.0523	**0.80**	1.3469	**29.03**	1.3469	**29.03**
202	1.0519	1.0595	**0.71**	1.3243	**25.90**	1.2582	**19.61**
202	1.1565	1.1443	**-1.06**	1.3721	**18.64**	1.2785	**10.55**
202	1.1745	1.1573	**-1.46**	1.3490	**14.86**	1.2344	**5.10**
202	1.1796	1.1628	**-1.42**	1.3263	**12.44**	1.1939	**1.22**

Table 53. Cost of Feed Consumed per kg of carcass by years-Scenario 4

	Control Baseline €	ALT Baseline €	Chng Con to ALT %	ALT+BSFL Baseline €	Chng Con to ALT+BSFL %
			UNITO		
2023	2.5375	2.9334	**15.60**	4.0294	**58.80**
2024	3.5389	3.3336	**-5.80**	4.2704	**20.67**
2025	4.7500	4.0841	**-14.02**	4.8659	**2.44**
2026	5.0977	4.2241	**-17.14**	4.9339	**-3.21**
2027	5.3337	4.3585	**-18.28**	5.0034	**-6.19**
			ISA-CM – Br		
2023	1.3862	1.3123	**-5.33**	1.7949	**29.48**
2024	2.0486	1.7771	**-13.25**	1.9008	**-7.22**
2025	2.6453	2.2157	**-16.24**	2.1248	**-19.67**
2026	2.8285	2.3820	**-15.79**	2.2558	**-20.25**
2027	3.0456	2.5379	**-16.67**	2.3357	**-23.31**
			EGE-ANADOLU T		
2023	1.3994	1.4010	**0.12**	1.7611	**25.85**
2024	1.8183	1.7239	**-5.19**	2.0204	**11.12**
2025	2.2979	2.1008	**-8.58**	2.3331	**1.53**

	Control Baseline €	ALT Baseline €	Chng Con to ALT %	ALT+BSFL Baseline €	Chng Con to ALT+BSFL %
2026	2.4354	2.2035	**-9.52**	2.3790	**-2.32**
2027	2.5563	2.3005	**-10.01**	2.4350	**-4.74**
EGE-COBB					
2023	1.0439	1.0523	**0.80**	1.3469	**29.03**
2024	1.3532	1.2954	**-4.27**	1.5471	**14.33**
2025	1.7056	1.5774	**-7.52**	1.7863	**4.73**
2026	1.8079	1.6556	**-8.42**	1.8232	**0.84**
2027	1.8963	1.7277	**-8.89**	1.8657	**-1.61**

In the case of egg production, the cost of feed consumed per sealable egg was chosen as the main indicator for comparisons of feed costs.

When alternative sustainable diets used in the Project are compared with the control diet, with respect to the cost of feed consumed per sealable egg, the following results are obtained:

- In the case of **UMU pilot**, there are reductions in feed costs for the ALT diet. Even if realization of the cost reduction target of 6% is not estimated to be achievable for the next four years under the baseline scenario (Table 54); this target is well achieved under the Scenario 4, up to 8.93% in 2027 (Table 55). The ALT+BSFL diet used by UMU, on the other hand, does provide a feed cost reduction of the targeted size (6%), neither under the scenario 4.
- In the case of **ISA-CM egg pilot**, dramatic reductions of feed costs are identified for the ALT diet even for the baseline scenario (15 to 20 %). The cost savings are improved with the predicted feed ingredient prices. In the case of ALT+BSFL diet, the Project goal of cost saving is not achievable during the prediction period, under the baseline scenario. On the other hand, this goal is attained by the year 2025, under the condition that the BSFL prices present an optimistic downward trend. Under this optimistic scenario, feed costs are reduced by up to 15% (Table 54). The savings are further improved under Scenario 4 (Table 55). As in the case of ISA-CM's broiler pilot, these results reveal quite promising economic performance both for the ALT and ALT+BSFL diets developed under the ISA-CM's egg pilot.

Overall, for the case of egg production, while among the diets of the UMU pilot, ALT diet was able to reduce the feed costs up to 8,93%, under the Scenario 4; ISA-CM pilot diets were proved to be further potent to provide serious cost savings beyond those of the Project targets.

Table 54. Cost of Feed Consumed per saleable egg by years

	Control Baseline	ALT Baseline	Chng Con to ALT	ALT+BSFL Baseline	Chng Con to ALT+BSFL	ALT+BSFL Optimistic	Chng Con to ALT+BSFL
UMU							
Egg weight (gr)	63.53	63.69	**0.24**	64.44	**1.43**	64.44	**1.43**
Cost of Feed Consumed	**€**	**€**	%	**€**	%	**€**	%
2023	0.070	0.069	**-1.29**	0.0776	**10.86**	0.0776	**10.86**
2024	0.070	0.069	**-1.41**	0.0877	**24.15**	0.0834	**18.10**
2025	0.078	0.075	**-3.01**	0.0909	**16.18**	0.0849	**8.45**
2026	0.079	0.076	**-3.32**	0.0894	**12.78**	0.0820	**3.44**
2027	0.079	0.077	**-3.31**	0.0879	**10.16**	0.0794	**-0.56**
ISA-CM							
Egg weight (gr)	65.22	65.57	**0.53**	66.69	**2.25**	66.69	**2.25**
Cost of Feed Consumed	**€**	**€**	%	**€**	%	**€**	%
2023	0.052	0.044	**-15.56**	0.0684	**29.79**	0.0684	**29.79**
2024	0.052	0.044	**-15.86**	0.0588	**11.08**	0.0557	**5.30**
2025	0.060	0.048	**-19.12**	0.0608	**1.21**	0.0564	**-5.99**
2026	0.061	0.049	**-19.49**	0.0600	**-2.25**	0.0547	**-10.88**
2027	0.062	0.050	**-20.00**	0.0593	**-5.49**	0.0532	**-15.23**

Table 55. Cost of Feed Consumed per saleable egg years - Scenario 4

	Control Baseline	ALT Baseline	Chng Con to ALT	ALT+BSFL Baseline	Chng Con to ALT+BSFL
UMU					
Egg weight (gr)	63.53	63.69	**0.24**	64.44	**1.43**
Cost of Feed Consumed per saleable egg	**€**	**€**	**%**	**€**	**%**
2023	0.0700	0.0691	**-1.29**	0.0776	**10.86**
2024	0.0903	0.0852	**-5.65**	0.1017	**12.64**
2025	0.1009	0.0932	**-7.62**	0.1065	**5.57**
2026	0.1064	0.0974	**-8.49**	0.1081	**1.59**
2027	0.1113	0.1014	**-8.93**	0.1097	**-1.41**
ISA-CM					
Egg weight (gr)	65.22	65.57	**0.53**	66.69	**2.25**
Cost of Feed Consumed per saleable egg	**€**	**€**	**%**	**€**	**%**
2023	0.0527	0.0445	**-15.56**	0.0684	**29.79**
2024	0.0787	0.0600	**-23.67**	0.0731	**-7.12**
2025	0.1011	0.0728	**-27.95**	0.0831	**-17.79**
2026	0.1077	0.0768	**-28.68**	0.0852	**-20.88**
2027	0.1161	0.0818	**-29.58**	0.0884	**-23.89**

5. Conclusions

WP3.6 of the SUSTAvianFEED comprehensively evaluates the economic impacts of alternative protein sources and other ingredients for sustainable livestock production in the Mediterranean region. The use of black soldier fly larvae (BSFL) and locally sourced plant-based protein alternatives emerges as a promising substitute for traditional soybean-based feeds. The partial budgeting and cost-benefit analyses conducted in the study examined the economic feasibility of alternative feeds and demonstrated that BSFL-enriched diets can provide cost advantages, particularly for small-scale producers. The findings highlight significant outcomes in terms of both cost efficiency and environmental sustainability.

According to the results of the analysis, the use of BSFL-enriched feed has the potential to reduce input costs and enhance economic efficiency. This alternative approach appears to be a viable solution for alleviating financial pressure, especially for small-scale producers. However, price forecasts and sensitivity analyses indicate that fluctuations in BSFL prices could have a significant impact on profitability. This necessitates careful monitoring of future price trends and continuous evaluation of their effects on cost structures. Sensitivity analyses of alternative feed formulations revealed variability in cost-benefit ratios under different scenarios. Profit margins may narrow under unfavorable market conditions, while significant cost reductions and profitability increases are possible under optimistic scenarios.

The economic analyses highlight the variability in feed cost reductions across different pilots and diets. For instance, in the ISA-CM pilot for broilers, feed cost reductions between 5.33% and 8.87% were identified under the ALT diet, meeting the project targets even in the early prediction period. The optimistic price trend scenario for BSFL further enhanced the savings, doubling the cost reduction goal by 2026. Similarly, for egg production, the ISA-CM pilot revealed significant cost savings, exceeding the project targets with reductions up to 20% under the ALT diet. These findings indicate the feasibility of achieving KPI4, which aims for a 6% reduction in feed costs and a 4% reduction in production costs, depending on the diet and scenario.

Economic analyses evaluated not only direct cost and income changes but also long-term investment returns. Specifically, BSFL-enriched feeds were found to have the potential to strengthen regional production systems by reducing dependence on imported soybeans. Enhancing local production capacity is expected to support regional food security and reduce external dependency. Additionally, this approach could create new employment opportunities for local farmers and provide additional income for the agricultural economy.

The results of the deliverable 3.6 highlights the need to re-evaluate existing feed formulations in terms of sustainability and cost efficiency. While BSFL-enriched feed offers significant advantages over conventional methods, careful analysis of market conditions and price dynamics is necessary before implementation. Furthermore, policymakers and stakeholders in the agricultural sector are recommended to consider incentive programs and infrastructure investments to support these new feeding strategies.

In conclusion, this deliverable of SUSTAvianFEED analyzes the economic feasibility of black soldier fly larvae and locally sourced plant-based protein alternatives, providing an important roadmap for sustainable agriculture and livestock production in the Mediterranean region. The use of alternative protein sources offers both economic and environmental benefits while contributing to circular economic principles. Future research should focus on testing these findings in larger-scale applications and evaluating their long-term impacts to develop more sustainable and resilient production systems.

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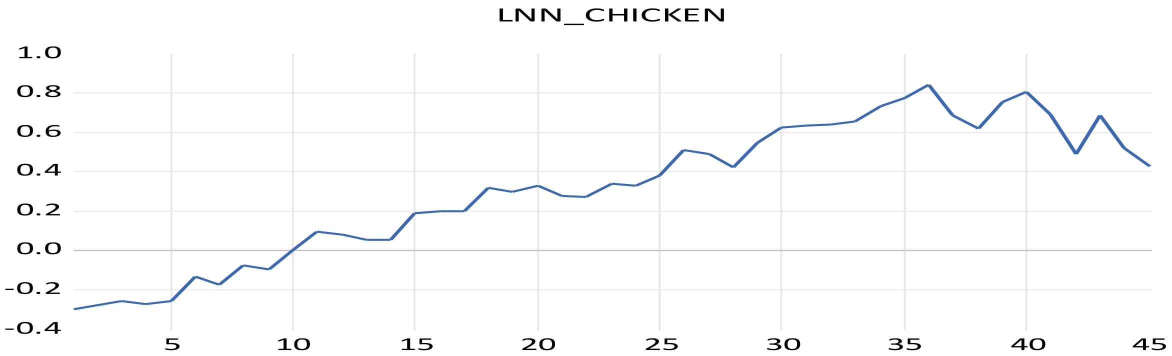
7. Appendix



Graph 1: Broiler Price Dynamics in Logarithmic Scale (€/kg)

Sample: 1 45
Included observations: 45

Autocorrelation Partial Correlation

	AC	PAC	Q-Stat	Prob
1	0.930	0.930	41.582	0.000
2	0.868	0.018	78.601	0.000
3	0.816	0.054	112.17	0.000
4	0.757	-0.082	141.73	0.000
5	0.676	-0.193	165.91	0.000
6	0.601	-0.035	185.47	0.000
7	0.528	-0.043	201.01	0.000
8	0.461	0.013	213.14	0.000
9	0.389	-0.053	222.02	0.000
10	0.318	-0.044	228.14	0.000
11	0.253	-0.024	232.12	0.000
12	0.191	-0.034	234.45	0.000
13	0.132	-0.015	235.60	0.000
14	0.072	-0.054	235.95	0.000
15	0.018	-0.017	235.98	0.000
16	-0.030	-0.016	236.04	0.000
17	-0.075	-0.023	236.46	0.000
18	-0.110	0.037	237.40	0.000
19	-0.149	-0.084	239.21	0.000
20	-0.180	0.009	241.95	0.000

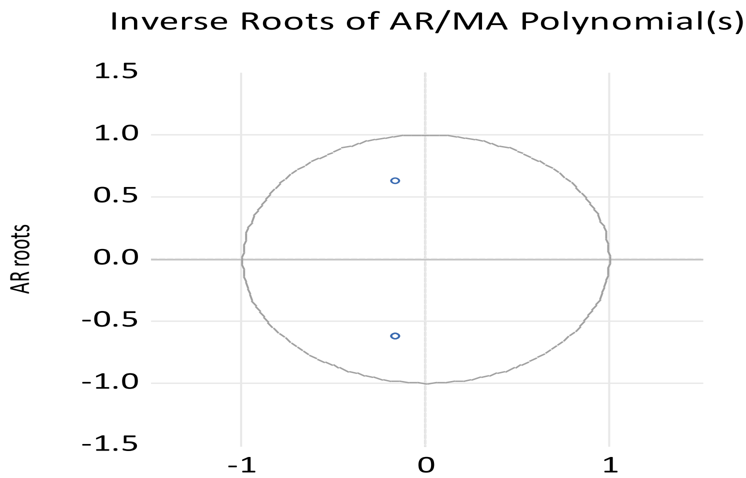
Graph 2: Autocorrelation and Partial Autocorrelation Analysis of Broiler Prices (Level)

Sample (adjusted): 2 45
Included observations: 44 after adjustments

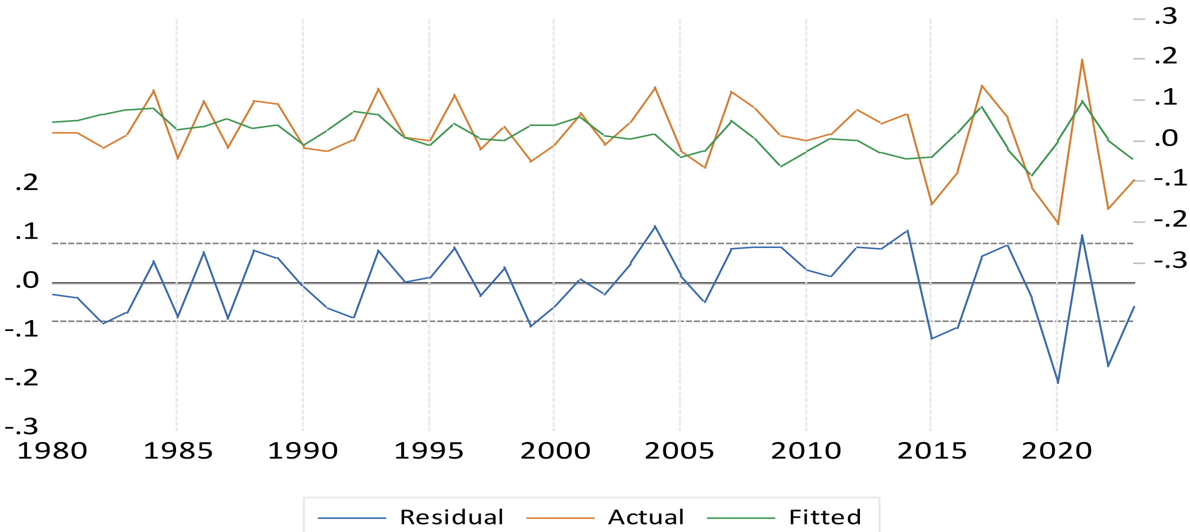
Autocorrelation Partial Correlation

	AC	PAC	Q-Stat	Prob
1	-0.153	-0.153	1.0965	0.295
2	-0.256	-0.286	4.2453	0.120
3	0.130	0.040	5.0760	0.166
4	0.252	0.236	8.2938	0.081
5	0.059	0.228	8.4719	0.132
6	-0.166	-0.005	9.9407	0.127
7	0.119	0.099	10.719	0.151
8	-0.035	-0.167	10.786	0.214
9	0.060	0.017	10.995	0.276
10	0.072	0.070	11.305	0.334
11	-0.112	-0.058	12.069	0.358
12	-0.106	-0.146	12.780	0.385
13	-0.028	-0.171	12.833	0.461
14	0.125	-0.031	13.878	0.459
15	-0.101	-0.021	14.591	0.481
16	-0.046	0.110	14.742	0.544
17	0.085	0.157	15.287	0.575
18	-0.019	0.050	15.314	0.640
19	-0.099	-0.112	16.111	0.650
20	0.086	0.051	16.739	0.670

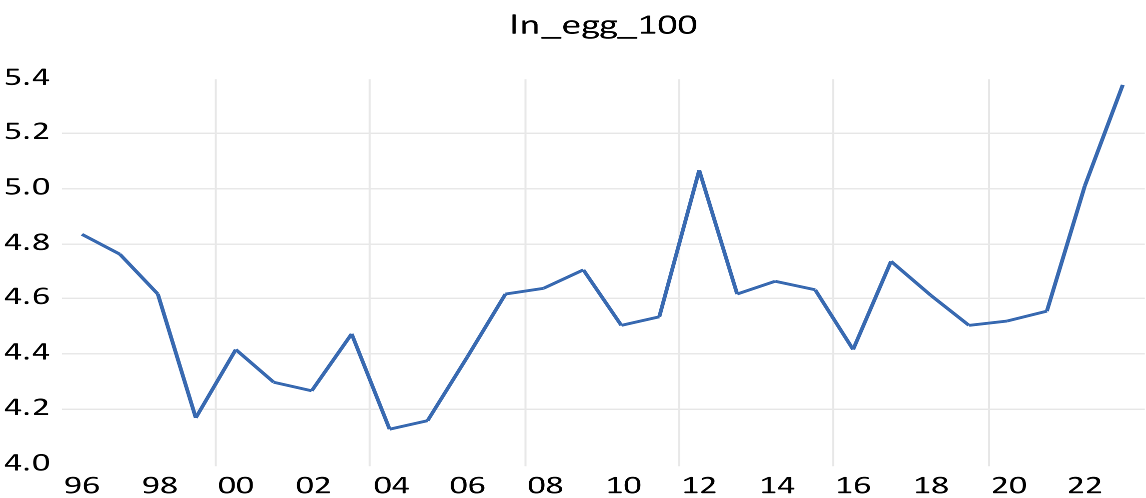
Graph 3: Autocorrelation and Partial Autocorrelation Analysis of Broiler Prices (First Difference)



Graph 4. Inverse Roots Plot for ARIMA Model Polynomial(s) (Broiler Prices)



Graph 5. Actual, Fitted, and Residual Values for Broiler Price Model



Graph 6: Spanish Egg Price Dynamics in Logarithmic Scale (€/100 kg)

Sample: 1996 2023
Included observations: 28

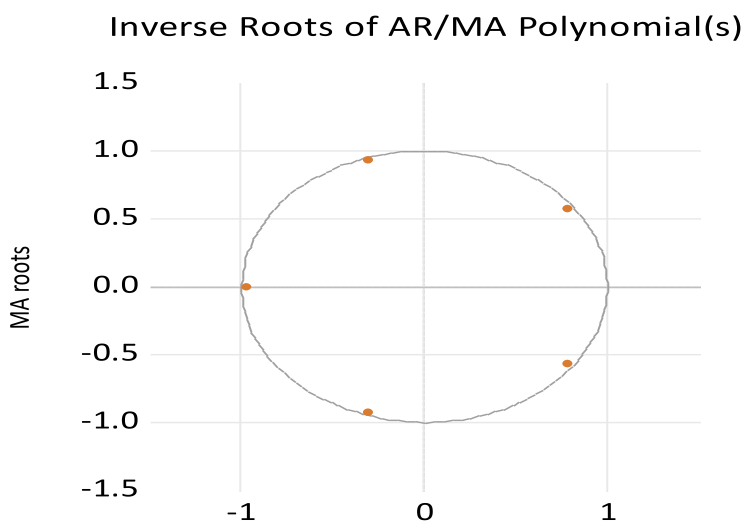
	AC	PAC	Q-Stat	Prob
1	0.437	0.437	5.9447	0.015
2	0.150	-0.051	6.6668	0.036
3	0.108	0.077	7.0609	0.070
4	0.016	-0.068	7.0699	0.132
5	0.166	0.228	8.0748	0.152
6	0.040	-0.167	8.1354	0.228
7	-0.227	-0.243	10.203	0.177
8	-0.206	-0.037	11.977	0.152
9	-0.086	0.097	12.306	0.197
10	-0.004	0.010	12.307	0.265
11	0.135	0.154	13.210	0.280
12	-0.071	-0.179	13.473	0.336

Graph 7: Autocorrelation and Partial Autocorrelation Analysis of Spanish Egg Prices (Level)

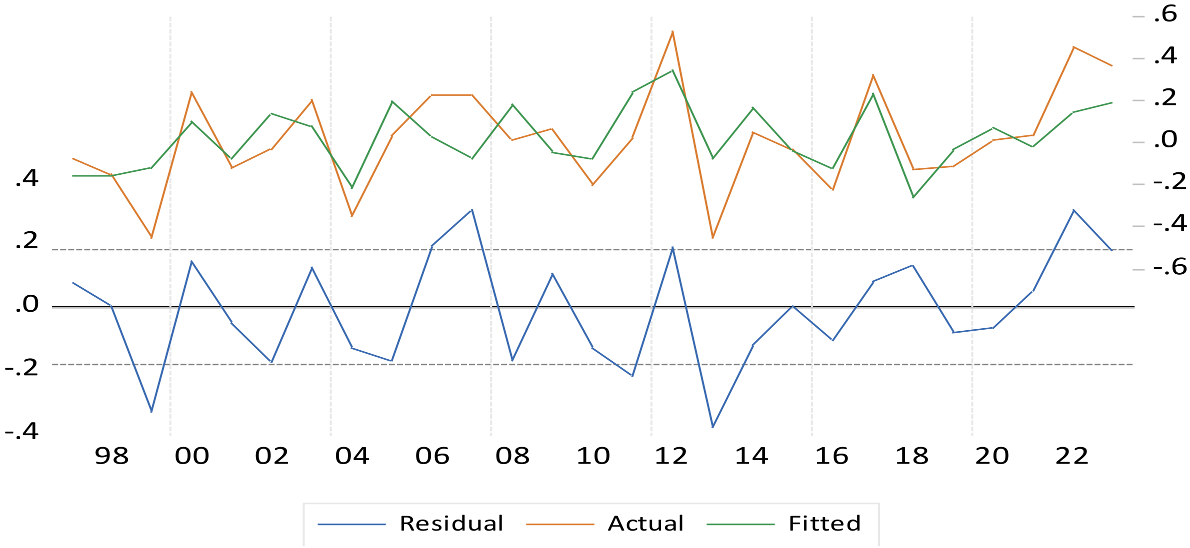
Sample (adjusted): 1997 2023
Included observations: 27 after adjustments

	AC	PAC	Q-Stat	Prob
1	-0.164	-0.164	0.8059	0.369
2	-0.068	-0.098	0.9513	0.621
3	0.149	0.125	1.6754	0.642
4	-0.344	-0.320	5.6945	0.223
5	0.314	0.279	9.1990	0.101
6	0.117	0.127	9.7103	0.137
7	-0.245	-0.130	12.059	0.099
8	-0.185	-0.464	13.473	0.097
9	0.018	0.162	13.487	0.142
10	-0.091	-0.110	13.868	0.179
11	0.174	0.095	15.355	0.167
12	0.087	-0.059	15.750	0.203

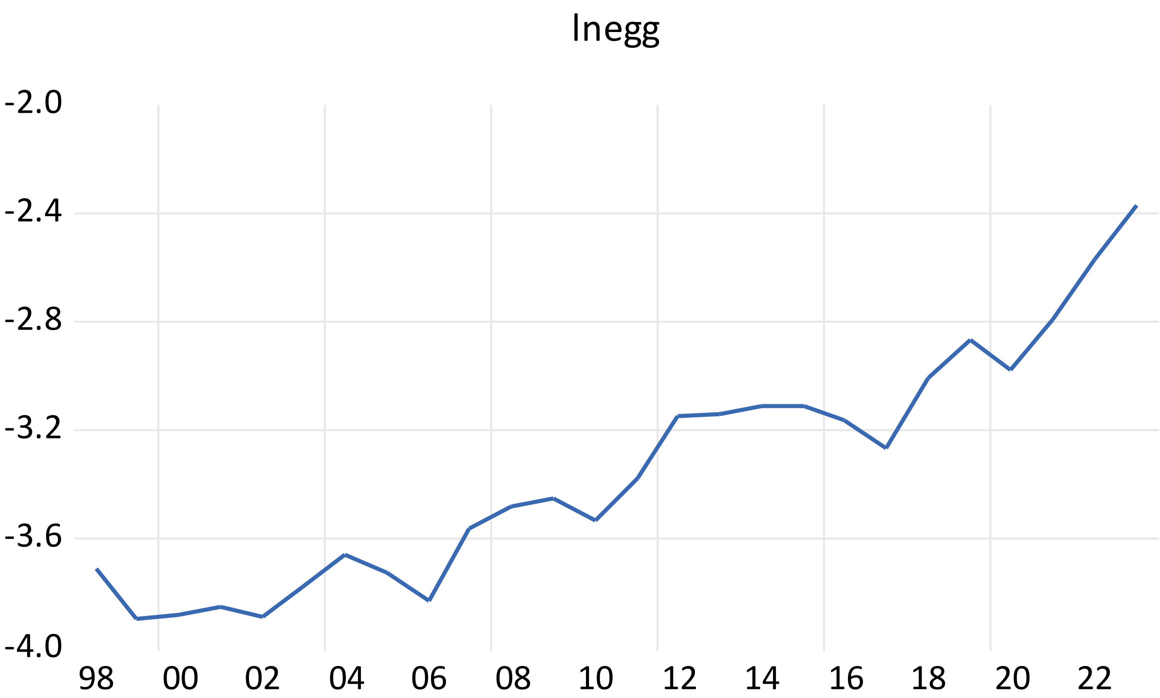
Graph 8: Autocorrelation and Partial Autocorrelation Analysis of Spanish Egg Prices (First Difference)



Graph 9. Inverse Roots Plot for ARIMA Model Polynomial(s) (Spanish Egg Prices)



Graph 10. Actual, Fitted, and Residual Values for Spanish Egg Price Model



Graph 11: Tunisian Egg Price Dynamics in Logarithmic Scale (€/egg)

Sample: 1998 2023
Included observations: 26

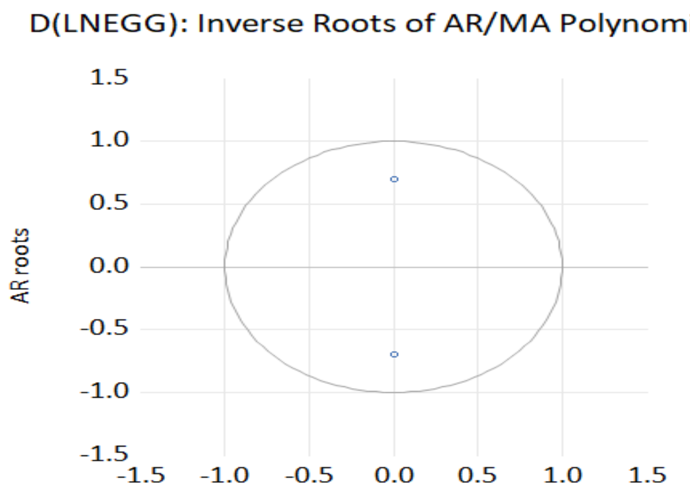
Autocorrelation	Partial Correlation		AC	PAC	Q-Stat	Prob
		1	0.829	0.829	20.009	0.000
		2	0.668	-0.062	33.532	0.000
		3	0.573	0.118	43.925	0.000
		4	0.501	0.017	52.223	0.000
		5	0.368	-0.210	56.920	0.000
		6	0.269	0.040	59.551	0.000
		7	0.237	0.101	61.711	0.000
		8	0.155	-0.201	62.688	0.000
		9	0.060	-0.018	62.843	0.000
		10	-0.016	-0.060	62.854	0.000
		11	-0.097	-0.184	63.310	0.000
		12	-0.215	-0.135	65.719	0.000

Graph 12: Autocorrelation and Partial Autocorrelation Analysis of Tunisian Egg Prices (Level)

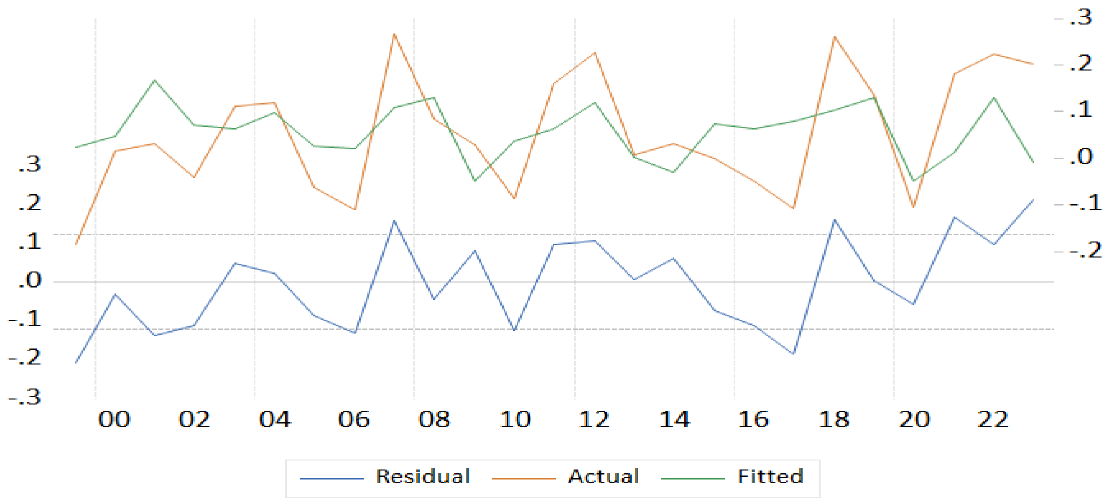
Sample (adjusted): 1999 2023
Included observations: 25 after adjustments

Autocorrelation	Partial Correlation		AC	PAC	Q-Stat	Prob
		1	0.034	0.034	0.0321	0.858
		2	-0.352	-0.354	3.6769	0.159
		3	0.073	0.116	3.8419	0.279
		4	0.227	0.105	5.5046	0.239
		5	-0.090	-0.058	5.7767	0.329
		6	-0.122	-0.010	6.3015	0.390
		7	0.131	0.076	6.9424	0.435
		8	-0.215	-0.337	8.7841	0.361
		9	-0.112	0.041	9.3105	0.409
		10	0.098	-0.072	9.7455	0.463
		11	0.344	0.407	15.451	0.163
		12	-0.129	-0.153	16.310	0.177

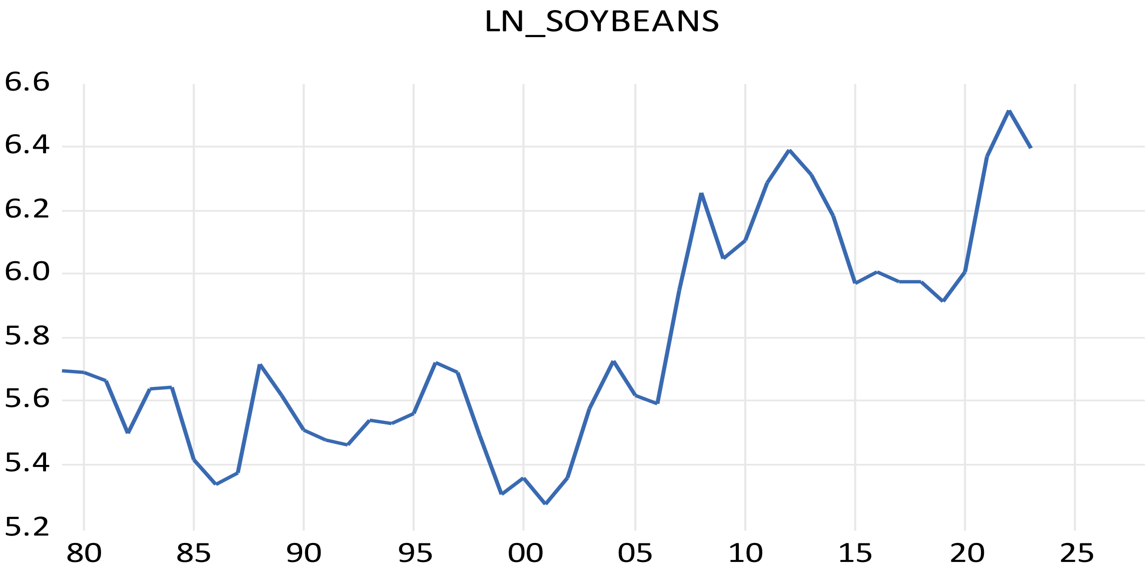
Graph 13: Autocorrelation and Partial Autocorrelation Analysis of Tunisian Egg Prices (First Difference)



Graph 14. Inverse Roots Plot for ARIMA Model Polynomial(s) (Tunisian Egg Prices)

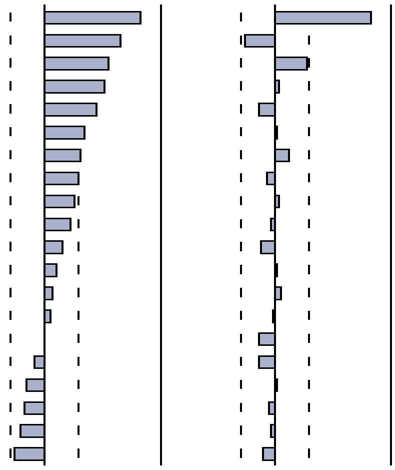


Graph 15. Actual, Fitted, and Residual Values for Tunisian Egg Price Model



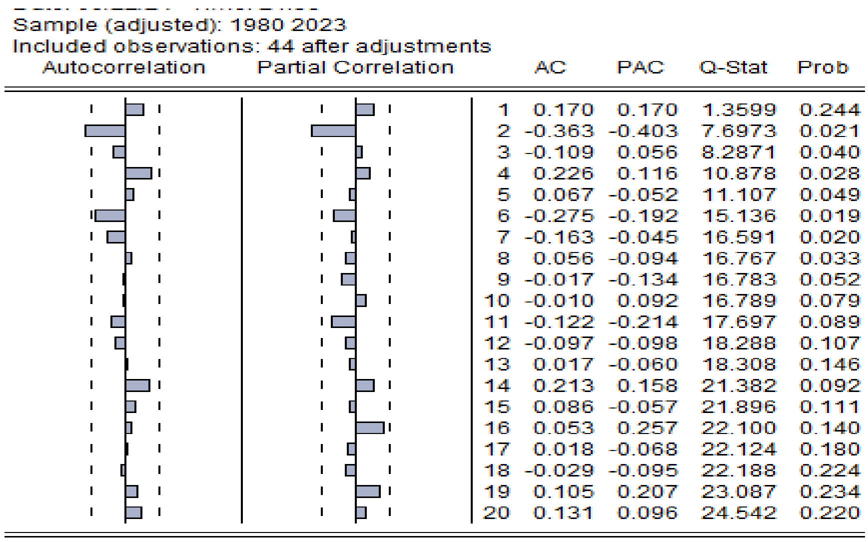
Graph 16: Soybean Price Dynamics in Logarithmic Scale (€/ton)

Sample (adjusted): 1979 2023
Included observations: 45 after adjustments



	AC	PAC	Q-Stat	Prob
1	0.863	0.863	35.830	0.000
2	0.676	-0.272	58.320	0.000
3	0.575	0.284	74.955	0.000
4	0.534	0.038	89.671	0.000
5	0.462	-0.146	100.97	0.000
6	0.368	0.016	108.31	0.000
7	0.322	0.124	114.09	0.000
8	0.301	-0.075	119.27	0.000
9	0.272	0.033	123.60	0.000
10	0.223	-0.031	126.60	0.000
11	0.156	-0.136	128.11	0.000
12	0.099	0.009	128.74	0.000
13	0.070	0.045	129.06	0.000
14	0.056	-0.023	129.28	0.000
15	0.007	-0.145	129.28	0.000
16	-0.088	-0.142	129.84	0.000
17	-0.157	0.015	131.70	0.000
18	-0.184	-0.055	134.36	0.000
19	-0.210	-0.048	137.96	0.000
20	-0.274	-0.112	144.33	0.000

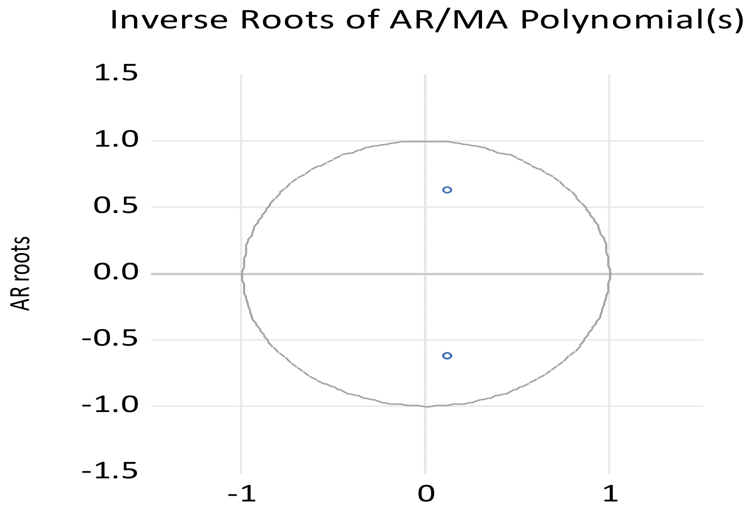
Graph 17: Autocorrelation and Partial Autocorrelation Analysis of Soybean Prices (Level)



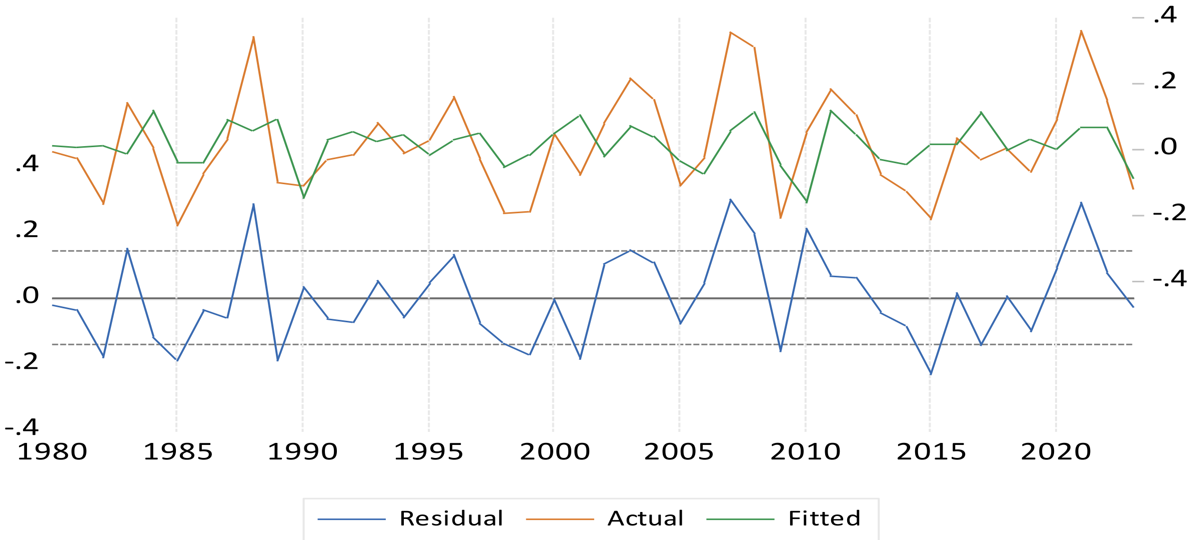
Sample (adjusted): 1980 2023
Included observations: 44 after adjustments

Autocorrelation	Partial Correlation		AC	PAC	Q-Stat	Prob
		1	0.170	0.170	1.3599	0.244
		2	-0.363	-0.403	7.6973	0.021
		3	-0.109	0.056	8.2871	0.040
		4	0.226	0.116	10.878	0.028
		5	0.067	-0.052	11.107	0.049
		6	-0.275	-0.192	15.136	0.019
		7	-0.163	-0.045	16.591	0.020
		8	0.056	-0.094	16.767	0.033
		9	-0.017	-0.134	16.783	0.052
		10	-0.010	0.092	16.789	0.079
		11	-0.122	-0.214	17.697	0.089
		12	-0.097	-0.098	18.288	0.107
		13	0.017	-0.060	18.308	0.146
		14	0.213	0.158	21.382	0.092
		15	0.086	-0.057	21.896	0.111
		16	0.053	0.257	22.100	0.140
		17	0.018	-0.068	22.124	0.180
		18	-0.029	-0.095	22.188	0.224
		19	0.105	0.207	23.087	0.234
		20	0.131	0.096	24.542	0.220

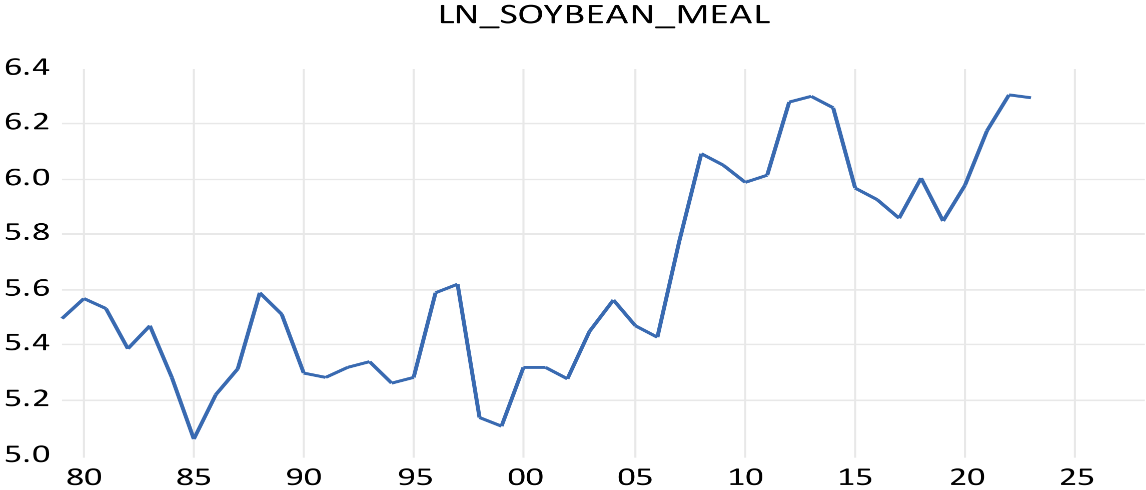
Graph 18: Autocorrelation and Partial Autocorrelation Analysis of Soyabean Prices (First Difference)



Graph 19. Inverse Roots Plot for ARIMA Model Polynomial(s) (Soybean Prices)



Graph 20. Actual, Fitted, and Residual Values for Soybean Price Model



Graph 21: Soyabean Meal Price Dynamics in Logarithmic Scale (€/ton)

Date: 09/22/24 Time: 22:35
Sample (adjusted): 1979 2023
Included observations: 45 after adjustments

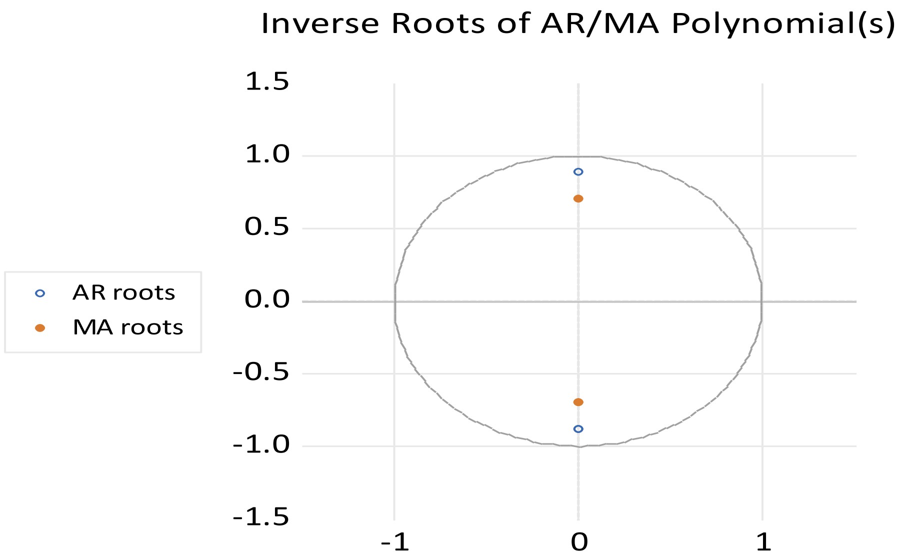
	AC	PAC	Q-Stat	Prob
1	0.863	0.863	35.824	0.000
2	0.702	-0.168	60.095	0.000
3	0.633	0.281	80.265	0.000
4	0.609	0.067	99.384	0.000
5	0.550	-0.087	115.40	0.000
6	0.465	-0.038	127.14	0.000
7	0.430	0.139	137.41	0.000
8	0.402	-0.097	146.65	0.000
9	0.326	-0.135	152.89	0.000
10	0.230	-0.052	156.10	0.000
11	0.166	-0.029	157.82	0.000
12	0.106	-0.148	158.54	0.000
13	0.067	0.130	158.84	0.000
14	0.007	-0.165	158.85	0.000
15	-0.057	-0.045	159.08	0.000
16	-0.121	-0.087	160.14	0.000
17	-0.177	-0.017	162.51	0.000
18	-0.216	-0.045	166.17	0.000
19	-0.236	0.084	170.70	0.000
20	-0.262	-0.097	176.52	0.000

Graph 22: Autocorrelation and Partial Autocorrelation Analysis of Soyabean Meal Prices (Level)

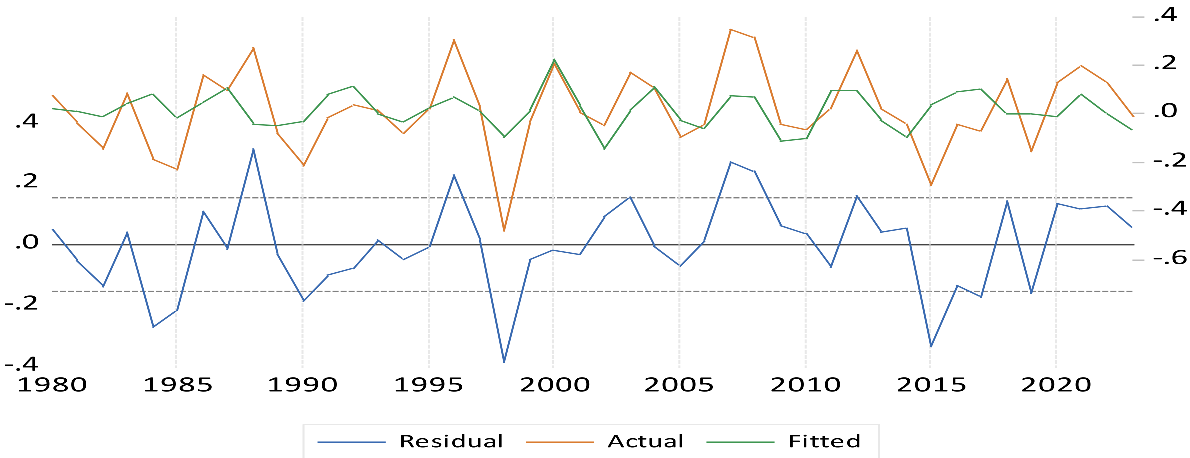
Date: 09/23/24 Time: 00:17
Sample (adjusted): 1980 2023
Q-statistic probabilities adjusted for 2 ARMA terms

	AC	PAC	Q-Stat	Prob
1	0.164	0.164	1.2681	
2	-0.034	-0.063	1.3242	
3	-0.182	-0.171	2.9520	0.086
4	-0.088	-0.034	3.3472	0.188
5	-0.040	-0.035	3.4323	0.330
6	0.027	0.005	3.4725	0.482
7	-0.049	-0.081	3.6025	0.608
8	0.057	0.067	3.7837	0.706
9	-0.141	-0.175	4.9321	0.668
10	-0.122	-0.098	5.8116	0.668
11	-0.003	0.038	5.8120	0.759
12	-0.139	-0.227	7.0373	0.722
13	0.087	0.111	7.5286	0.755
14	0.098	0.029	8.1775	0.771
15	0.047	-0.033	8.3296	0.821
16	0.073	0.080	8.7099	0.849
17	0.079	0.087	9.1758	0.868
18	-0.045	-0.063	9.3355	0.899
19	0.038	0.035	9.4547	0.925
20	0.003	0.083	9.4557	0.948

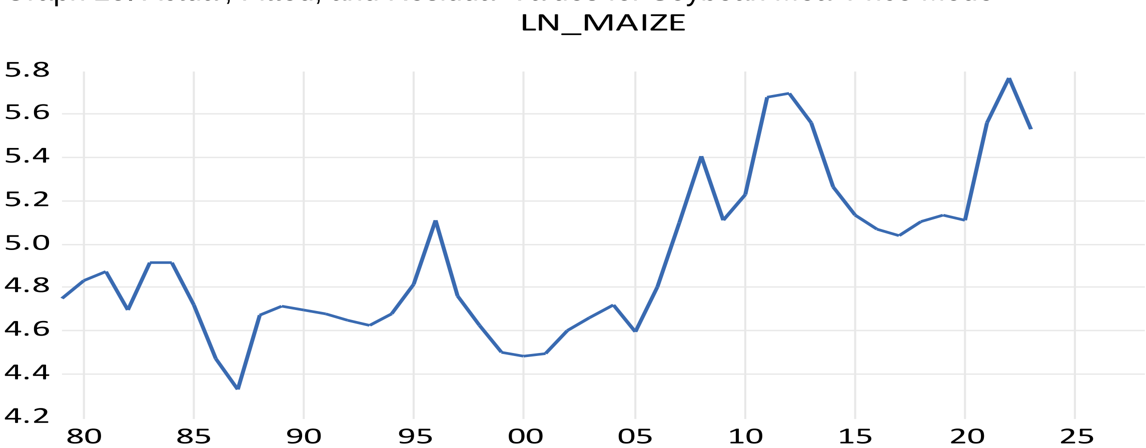
Graph 23: Autocorrelation and Partial Autocorrelation Analysis of Soyabean Meal Prices (First Difference)



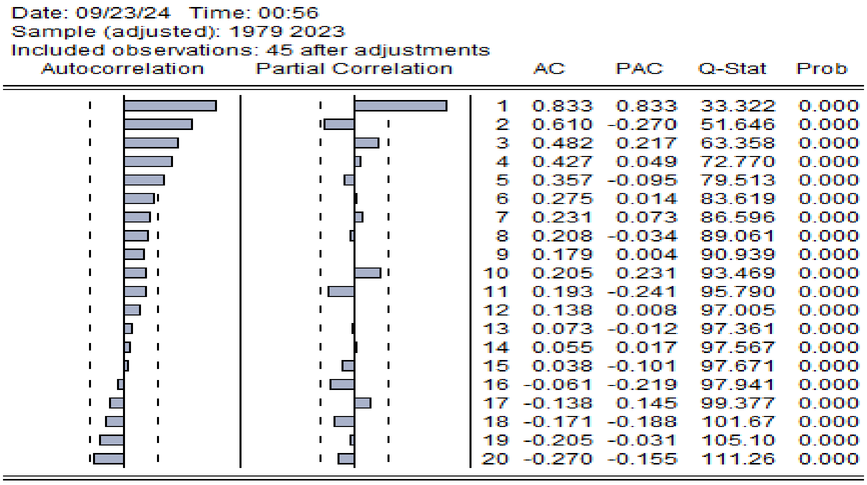
Graph 24. Inverse Roots Plot for ARIMA Model Polynomial(s) (Soybean Meal Prices)



Graph 25. Actual, Fitted, and Residual Values for Soybean Meal Price Model



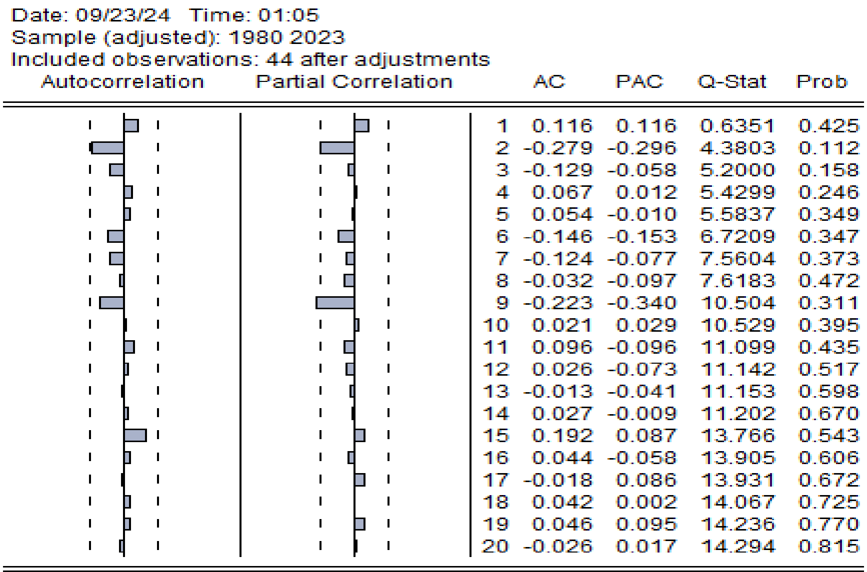
Graph 26: Corn Price Dynamics in Logarithmic Scale (€/ton)



Date: 09/23/24 Time: 00:56
Sample (adjusted): 1979 2023
Included observations: 45 after adjustments

Lag	AC	PAC	Q-Stat	Prob
1	0.833	0.833	33.322	0.000
2	0.610	-0.270	51.646	0.000
3	0.482	0.217	63.358	0.000
4	0.427	0.049	72.770	0.000
5	0.357	-0.095	79.513	0.000
6	0.275	0.014	83.619	0.000
7	0.231	0.073	86.596	0.000
8	0.208	-0.034	89.061	0.000
9	0.179	0.004	90.939	0.000
10	0.205	0.231	93.469	0.000
11	0.193	-0.241	95.790	0.000
12	0.138	0.008	97.005	0.000
13	0.073	-0.012	97.361	0.000
14	0.055	0.017	97.567	0.000
15	0.038	-0.101	97.671	0.000
16	-0.061	-0.219	97.941	0.000
17	-0.138	0.145	99.377	0.000
18	-0.171	-0.188	101.67	0.000
19	-0.205	-0.031	105.10	0.000
20	-0.270	-0.155	111.26	0.000

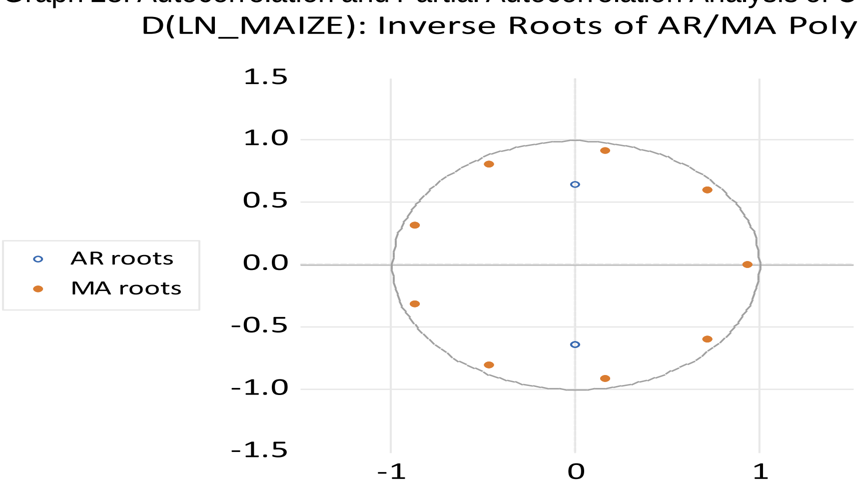
Graph 27: Autocorrelation and Partial Autocorrelation Analysis of Corn Prices (Level)



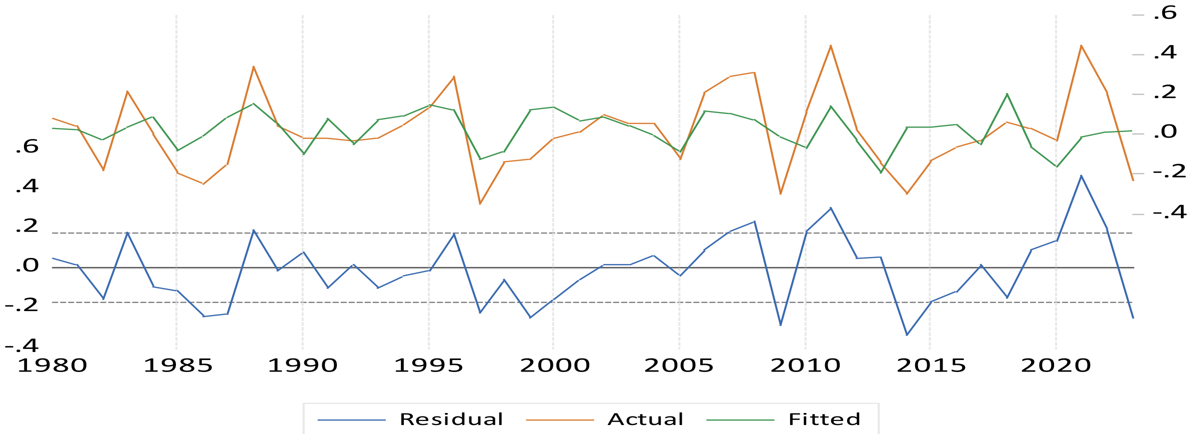
Date: 09/23/24 Time: 01:05
Sample (adjusted): 1980 2023
Included observations: 44 after adjustments

Lag	AC	PAC	Q-Stat	Prob
1	0.116	0.116	0.6351	0.425
2	-0.279	-0.296	4.3803	0.112
3	-0.129	-0.058	5.2000	0.158
4	0.067	0.012	5.4299	0.246
5	0.054	-0.010	5.5837	0.349
6	-0.146	-0.153	6.7209	0.347
7	-0.124	-0.077	7.5604	0.373
8	-0.032	-0.097	7.6183	0.472
9	-0.223	-0.340	10.504	0.311
10	0.021	0.029	10.529	0.395
11	0.096	-0.096	11.099	0.435
12	0.026	-0.073	11.142	0.517
13	-0.013	-0.041	11.153	0.598
14	0.027	-0.009	11.202	0.670
15	0.192	0.087	13.766	0.543
16	0.044	-0.058	13.905	0.606
17	-0.018	0.086	13.931	0.672
18	0.042	0.002	14.067	0.725
19	0.046	0.095	14.236	0.770
20	-0.026	0.017	14.294	0.815

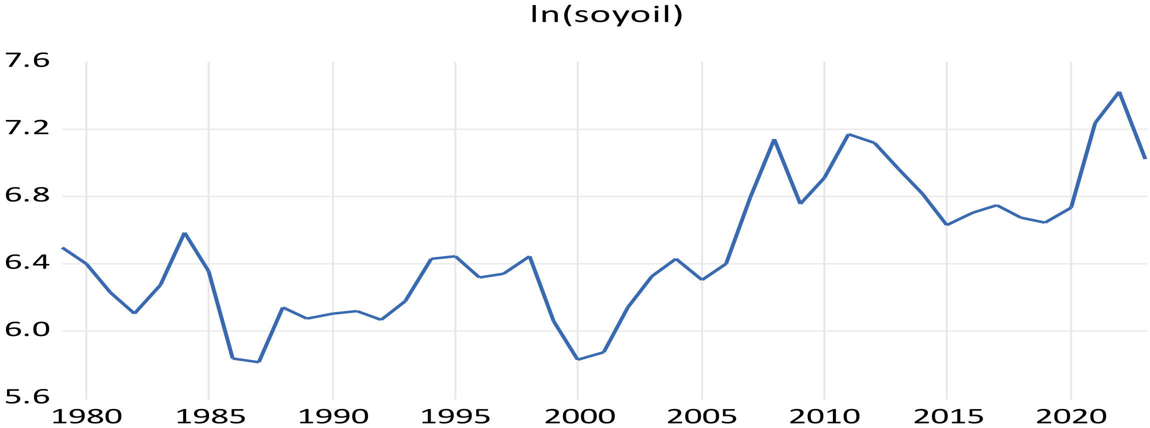
Graph 28: Autocorrelation and Partial Autocorrelation Analysis of Corn Prices (First Difference)



Graph 29. Inverse Roots Plot for ARIMA Model Polynomial(s) (Corn Prices)

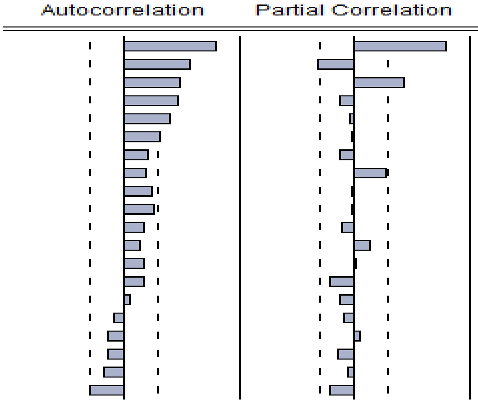


Graph 30. Actual, Fitted, and Residual Values for Corn Price Model



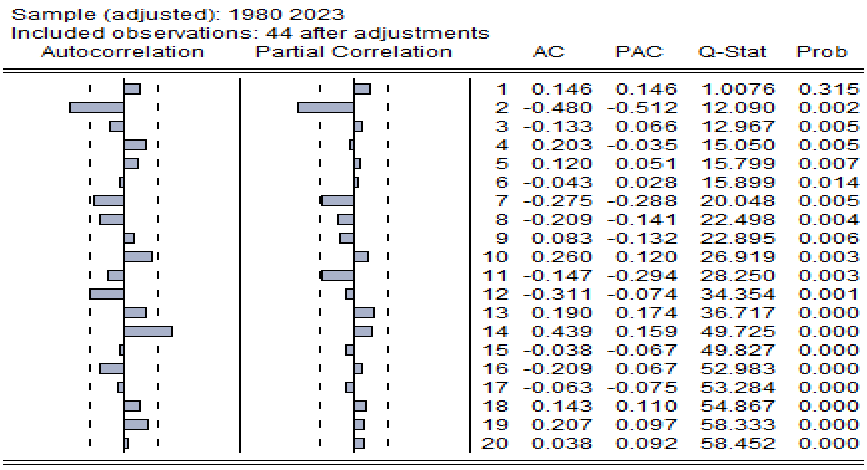
Graph 31: Soybean Oil Price Dynamics in Logarithmic Scale (€/ton)

Sample: 1979 2023
Included observations: 45



	AC	PAC	Q-Stat	Prob
1	0.831	0.831	33.208	0.000
2	0.588	-0.334	50.188	0.000
3	0.498	0.454	62.700	0.000
4	0.486	-0.126	74.881	0.000
5	0.419	-0.030	84.168	0.000
6	0.313	-0.017	89.493	0.000
7	0.215	-0.131	92.056	0.000
8	0.200	0.284	94.351	0.000
9	0.252	-0.010	98.085	0.000
10	0.263	-0.013	102.28	0.000
11	0.185	-0.107	104.41	0.000
12	0.137	0.141	105.61	0.000
13	0.174	0.011	107.61	0.000
14	0.173	-0.228	109.66	0.000
15	0.053	-0.127	109.86	0.000
16	-0.087	-0.089	110.42	0.000
17	-0.140	0.053	111.90	0.000
18	-0.145	-0.153	113.55	0.000
19	-0.185	-0.063	116.35	0.000
20	-0.297	-0.219	123.82	0.000

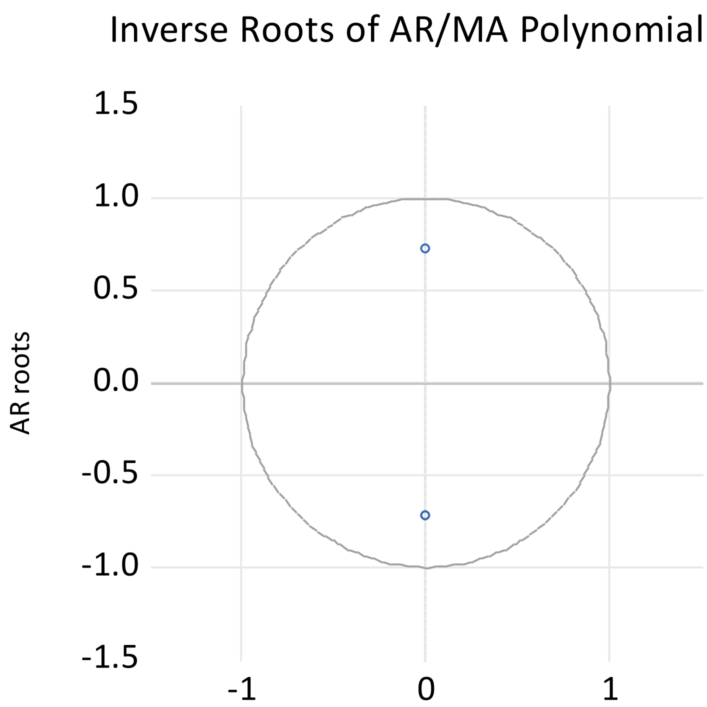
Graph 32: Autocorrelation and Partial Autocorrelation Analysis of Soybean Oil Prices (Level)



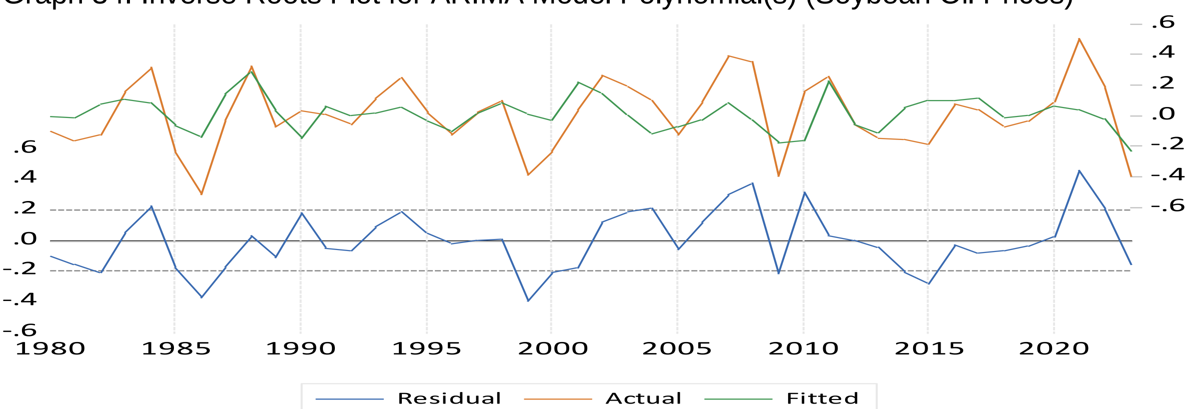
Sample (adjusted): 1980 2023
Included observations: 44 after adjustments

Autocorrelation	Partial Correlation		AC	PAC	Q-Stat	Prob
		1	0.146	0.146	1.0076	0.315
		2	-0.480	-0.512	12.090	0.002
		3	-0.133	0.066	12.967	0.005
		4	0.203	-0.035	15.050	0.005
		5	0.120	0.051	15.799	0.007
		6	-0.043	0.028	15.899	0.014
		7	-0.275	-0.288	20.048	0.005
		8	-0.209	-0.141	22.498	0.004
		9	0.083	-0.132	22.895	0.006
		10	0.260	0.120	26.919	0.003
		11	-0.147	-0.294	28.250	0.003
		12	-0.311	-0.074	34.354	0.001
		13	0.190	0.174	36.717	0.000
		14	0.439	0.159	49.725	0.000
		15	-0.038	-0.067	49.827	0.000
		16	-0.209	0.067	52.983	0.000
		17	-0.063	-0.075	53.284	0.000
		18	0.143	0.110	54.867	0.000
		19	0.207	0.097	58.333	0.000
		20	0.038	0.092	58.452	0.000

Graph 33: Autocorrelation and Partial Autocorrelation Analysis of Soybean Oil Prices (First Difference)



Graph 34. Inverse Roots Plot for ARIMA Model Polynomial(s) (Soybean Oil Prices)



Graph 35. Actual, Fitted, and Residual Values for Soybean Oil Price Model