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Avena sativa AV25-T (Altoandina) Supplementation as Alternative for Colombia's High-Altitude Dairy Systems: An Economic Analysis

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In the Colombian high-altitude tropics (2,200–3,000 m.a.s.l.), Kikuyu grass (*Cenchrus clandestinus*) is the main feed source for the dairy system. This grass species has good characteristics regarding adaptability and productivity, but is affected by frost, grass bugs (*Collaria spp*.) and precipitation-related production seasonality. Forage deficits might thus be a problem at several times in a year. As a strategy to maintain production stable, dairy farmers use commercial feed concentrates increasing their production costs. Agrosavia, as a response to this, started in 2005 with the evaluation and selection of new forage species for the Colombian high-altitude tropics. The oat *Avena sativa* AV25-T was identified as promising alternative to supply the requirements of dry matter in times of deficit and released as cultivar in 2018 under the name Altoandina. The objective of this study was to evaluate the economic viability of Altoandina in Colombia's high-altitude dairy systems. Altoandina (Aa) was provided as silage in two different diets: 35%Aa–65% Kikuyu (Yellow Diet) and 65%Aa-35% Kikuyu (Red Diet). The diet for comparison was traditional grazing with 100% Kikuyu grass (Blue Diet). All diets were supplemented with 6kg commercial feed concentrate, 0.5 kg cotton seeds and 0.5 kg Alfalfa meal per cow/day, respectively. To estimate economic indicators, we used a cashflow model and risk assessment under a Monte Carlo simulation model. Including Altoandina incremented productivity per hectare by 82.3 and 220% in the Yellow and Red Diets, respectively. According to the results of our economic model, the Yellow Diet is the best alternative. Its average Net Present Value (NPV) was superior in >80% and showed a lower variability. The indicators Value at Risk (VaR) and probability (NPV < 0) show the Yellow Diet to have the lowest risk for economic loss under different yield/market scenarios. The Yellow Diet also has the lowest unit production costs and uncertainty of productive parameters. According to our findings, supplementation with Altoandina at 35%, i.e., during critical times, has high potential to improve efficiency and profitability. This information is key for the decision-making process of dairy farmers on whether to adopt this technology.

Keywords: sustainability, Monte Carlo simulation, silage, oat, dairy system

INTRODUCTION

The livestock sector and, particularly the cattle subsector, is a critical component of food systems since it provides food with high quality protein (i.e., 14% of the calorie and 33% of the protein intake of the global human diet comes from livestock) that is in most cases produced on marginal lands not suitable for crop production. Additionally, livestock provides people with incomes, assets, alternative energy, animal draft power, and livelihoods (FAO, 2018). Especially, dairy production is crucial for income generation and food security, mainly in (the rural areas of) developing countries where the dairy sector is dominated by smallholder production systems (World Bank, 2005; Reisinger and Clark, 2018). Globally, there are around 300 million poor people whose livelihoods depend on the daily income and nutrition provided through milk production (World Bank, 2005). The dairy sector is of great economic and social importance in Colombia. It contributes with 36.7% to the national livestock and 12% to the agricultural Gross Domestic Product (GDP), respectively, and generates 20% of the jobs in the agricultural sector (MADR, 2020). According to the Colombian Cattle Federation (FEDEGAN, 2018), there are about 319,000 milk-producing families in Colombia, and the dairy sector is predominated by small-scale or subsistence producers (with less than 10 animals). Milk production in the country happens under two differentiated systems linked to specific environmental conditions. First, the specialized dairy systems, located in the higher tropics (>2,000 m.a.s.l.), mainly in the departments of Antioquia, Boyacá, Cundinamarca, and Nariño, which provide 45% of the total national milk supply and use only 6% of the total cattle inventory (1.72 million heads) (Carulla and Ortega, 2016; FEDEGAN, 2020b). Second, the dual-purpose production systems, located in the lower tropics (<1,200 m.a.s.l.), which contribute with 55% of the national milk supply using 39% of the total cattle inventory (10.08 million heads) (FEDEGAN, 2018, 2020a).

The dairy sector has had high growth rates in the last two decades, with an increase in total milk supply of 35% between 2000 and 2019, which is equivalent to a production of 5,295 and 7,257 ml, respectively (FEDEGAN, 2020b). Production and productivity, however, are strongly linked to the local climatic conditions present in the production areas (FEDEGAN, 2018), making the dairy sector dependent on rainfall regimes and periods of drought that affect the availability and quality of the forages used as animal feed (FEDEGAN, 2018). Because of climate change, this situation has been aggravating in recent years, given the progressive increase in global and local average temperatures and variations in rainfall patterns. This is directly affecting cattle production through impacts on pasture availability, animal comfort (heat stress), water availability and biodiversity (Rojas-Downing et al., 2017). In addition to the above, the increasingly frequent occurrence of extreme climatic phenomena in the country, such as *La Niña* and *El Niño*, causing heavy rainfall, flooding, and extreme droughts, makes the situation even more critical, particularly when it comes to milk production, since dairy cows are more susceptible to heat stress (SIPSA/DANE, 2016). This is evidenced by milk production decreases of on average 4.9% in years with presence of the *El Niño* phenomenon [UNGRD (Unidad Nacional para la Gestión del Riesgo de Desastres-Colombia), 2016].

In the specialized dairy systems of Colombia, the predominant feed base is grazing of Kikuyu grass (*Cenchrus clandestinus*) and the use of supplementation with commercial concentrates, the latter representing a significant percentage of the total production costs (∼37%) (Cárdenas, 2003; Campuzano et al., 2018; Castillo et al., 2019). Kikuyu grass, although with good characteristics in terms of adaptability and productivity (biomass production), is affected by frost and grass bugs (*Collaria scenica*) (Campuzano et al., 2018). It also has nutritional limitations that can affect the production and compositional quality of milk, such as high levels of soluble nitrogen and low levels of non-structural carbohydrates (Correa et al., 2008). In addition, the production systems based on Kikuyu are associated with deficient pasture management, mainly in terms of fertilization (Campuzano et al., 2018), and residual grass management, restricting both levels of production and productivity. This leads to impacts at the environmental level, since soil and water are being contaminated with nitrogen (N) that is not usable by the animal and released with the urine (given the levels of soluble N in Kikuyu, the inadequate management of grazing and low levels of supplementation) (J. Castillo, Agrosavia, personal communication).

Consequently, there are important bottlenecks related to the deficit of forage at different times of the year, high production costs of animal feed and negative effects at the environmental level. Considering the climate change scenarios for the region, this situation is likely to worsen: The Colombian Institute of Hydrology, Meteorology and Environmental Studies (IDEAM) forecasts for the Departments of Cundinamarca, Boyacá, and Antioquia (which make up 40% of the national dairy production mainly under specialized dairy systems) increases in precipitation levels of more than 4% and in temperature of at least 2°C until the year 2100 (IDEAM, 2015). This would lead to a lower water use efficiency and possibly greater water stress for the Kikuyu grass (Vargas-Martínez et al., 2018) and largely affect dairy production in those regions.

In this sense, the Colombian Agricultural Research Corporation (ICA and CORPOICA before, now Agrosavia) has conducted forage research to improve the efficiency and reduce the seasonality of milk production in the higher tropics of Colombia. These studies have focused on seeking strategies for soil recovery and renovation of pastures, establishment and management of forage grazing systems, and production of forage crops for ruminant feeding systems (Castillo et al., 2019). Although there is no germplasm improvement and evaluation program specifically for the higher tropics, the research processes carried out by Agrosavia have led to the release of six oat cultivars in the country since the 1960s: ICA Bacatá (*Avena fauta*) (1963), ICA Soracá (*Avena byzantina*) (1965), ICA Gualcalá (*Avena byzantina*) (1968), ICA Cajicá (*Avena sativa*) (1976), Avena Obonuco Avenar (*Avena sativa*) (2003) and Avena Altoandina (AV25; High-Andean Oat) (2018) (Bustamante, 1965; Arias et al., 1972; Bolaños-Alomía et al., 2003; Campuzano et al., 2018). Despite its release over 45 years ago and the release of other cultivars thereafter, ICA Cajicá still predominates on the market and is one of the most used oats for animal feeding (through silage). It is, however, susceptible to rust (*Puccinia spp.*) which is predominant in many parts of the Colombian higher tropics. The cultivar Altoandina, released in 2018, is the most recent oat made available to dairy producers, and is the result of an evaluation process which began in 2005. Compared to the previously released materials and commercial oats used in the region, Altoandina stands out for its higher biomass production, better nutritional quality, and greater resistance to rust and overturning (Campuzano et al., 2018, 2020), making it a promising alternative for supplying the forage deficit of the prairies in times of scarcity (drought) and improving the productivity of the specialized dairy systems in the Colombian higher tropics. In general terms, oats stand out as a forage crop widely used as a source of animal nutrition throughout the world, especially in European countries and the United States (Fraser and McCartney, 2004; Suttie and Reynolds, 2004; Harper et al., 2017). *Avena sativa* is predominant there and used either in grazing systems or as supplement in the form of hay and silage. In South America, a harvested area of 806,000 hectares was registered for 2019, with an average annual growth rate of 8% between 2010 and 2019 (FAOSTAT, 2021), indicating the interest of dairy producers in this material. In Colombia, oats are mainly used as basis for silage production in the higher tropics, but, to a limited extent also for grazing in the lower to medium tropics. Using oats has been gaining importance in cattle production, especially in the technified dairy systems in the higher tropics, but adoption rates remain low on farms with less technical level (FEDEGAN, 2012).

The technical evaluation of oats in Colombia is being led by Agrosavia, which has focused on evaluating the effects of using it as a supplementation strategy in critical times (through silage) on the production and composition of milk in the higher tropics (Barahona et al., 2003; León et al., 2008; Mojica et al., 2009; Campuzano et al., 2018, 2020). Although variable effects on production have been reported, most of these studies have shown how the use of oats allows maintaining milk production stable when compared to feeding strategies solely based on Kikuyu grass (León et al., 2008; Mojica et al., 2009; Campuzano et al., 2018, 2020). Studies on the economic viability of including oat varieties in cattle systems were, however, not conducted yet for Colombia. Even though oats (due to their beneficial characteristics such as higher biomass availability, maintenance of production levels in critical times, and reduction in the use of commercial concentrates) have positive impacts on economic viability and economic indicators, it is also evident that the implementation of feeding strategies based on oats imply higher costs at the productive level compared to grazing systems, making it necessary to provide information on the profitability of these technologies in order to facilitate dissemination and adoption processes.

In this sense, the present study aims to evaluate, from an economic perspective, the viability of the oat Avena AV25-T (Altoandina) as a feeding strategy for dairy systems in the Colombian higher tropics. Altoandina (Aa) was provided as silage in two different diets: 35%Aa−65% Kikuyu (Yellow Diet) and 65%Aa−35% Kikuyu (Red Diet). The diet for comparison was traditional grazing with 100% Kikuyu grass (Blue Diet). Through a discounted cash flow model and a quantitative risk analysis using a Monte Carlo simulation, we provide economic indicators, such as Net Present Value (NPV), Internal Rate of Return (IRR), and Benefit-Cost Ratio (B/C), that help in identifying the best diet for the system under evaluation. This document is structured as follows: after this introduction, the main characteristics of the evaluated variety are presented [Section Description of the technology: Avena AV25-T (Altoandina)]. The methodology, assumptions, and data sources used are explained in Section Materials and Methods, the results are provided in Section Results and discussed in Section Discussion, and conclusions and recommendations for various stakeholders are presented in Section Conclusion.

DESCRIPTION OF THE TECHNOLOGY: AVENA AV25-T (ALTOANDINA)

In 1992, the oat accession with the experimental name AV25 was introduced to the National Germplasm Bank System for Food and Agriculture of Colombia (SBGNAA) managed by Corpoica (now Agrosavia). The accession was delivered by the International Maize and Wheat Improvement Center (CIMMYT) from Mexico. The evaluation process of this accession began in 2005 with the aim of offering forage alternatives for the cattle systems in the Colombian higher tropics. In total, 18 oat genotypes from New Zealand, CIMMYT, SBGNAA and commercial national varieties were evaluated. The AV25 genotypes were selected for presenting high Dry Matter yields, tolerance to overturn and resistance to leaf and stem rust (Campuzano et al., 2020). From 2016 to 2017, agronomic evaluations were carried out in eight locations in the Colombian Andean region, selecting the cultivar AV25-T (Altoandina) as most promising material for covering the feed requirements of the high-altitude dairy systems during critical times (Campuzano et al., 2018), particularly for milk production in the subregions of the savannas of Bogotá, upper Chicamocha, the Ubaté and Chiquinquirá valleys, and the highlands of the Nariño Department (Campuzano et al., 2018).

Altoandina is a forage oat with a semi-erect growth habit with an average height of 108–143 cm and an average density of 27 leaves per plant. It adapts well to altitudes between 2,600 and 3,000 m.a.s.l. and to soils with a moderately acidic to neutral PH value. Compared to other commercial oats (e.g., Cayuse), Altoandina has a shorter flowering time (92–107 days compared to 110-150), being considered an intermediate cycle oat. The average harvest period until a state of milky to pasty grains [7.9 points on the Zadoks growth scale (Zadoks et al., 1974)] is reached, varies between 130 to 140 days. It is characterized by high biomass production (up to 64.9 t ha^{-1} of green forage and up to 25 t ha^{-1} of Dry Matter, depending on the management and environmental conditions), resistance to overturning (5.2% compared to 30% for commercial varieties), low incidence of leaf and stem rust (*Puccinia spp.*) (<20% compared to 60% for commercial varieties), and higher crude protein values in the

TABLE 1 | Forage production and nutritional quality of Altoandina and commercial oat varieties.

Variable	Altoandina (Mean ± SD)*	Commercial varieties (Mean ± SD)*
Biomass production (t DM^{-1**} ha^{-1})	10.6-24.8	3.6-19.3
Crude protein (%)	7.5 ± 1.4	4.7 ± 1.27
Neutral Detergent Fiber (NDF, %)	57 ± 3.15	58 ± 3.16
Total digestible nutrients (TDN, %)	51 ± 3.15	50 ± 3.24

**Mean values and standard deviations reported for a total of 6 evaluations: two each in the Nariño, Boyacá, and Cundinamarca Departments; **DM, Dry Matter.*

Source: Own elaboration based on the study carried out by AGROSAVIA "Evaluación y selección de nuevas especies forrajeras, and estrategias para mejorar la competitividad y sostenibilidad de los sistemas de producción de leche y/o carne en la región andina" (Campuzano et al., 2018, 2020; LF. Campuzano, Agrosavia, personal communication). The technical parameters obtained by Campuzano et al., were used for the economic evaluation presented in this article.

TABLE 2 | Composition of the evaluated diets.

Category	Composition	Evaluated diets		
		Blue	Yellow	Red
Forage composition (%)	Kikuyu grass	100%	65%	35%
	Altoandina silage	0%	35%	65%
Supplements (kg $AU^{-1*}d^{-1}$)	Feed concentrate Standard 70 (kg/DM)	6.0	6.0	6.0
	Cotton seeds (kg/DM)	0.5	0.5	0.5
	Alfalfa flour (kg/DM)	0.5	0.5	0.5
Consumption (kg $AU^{-1}d^{-1}$)	Kikuyu grass	57.5	33.4	16.7
	Altoandina silage	0.0	12.0	25.9
	Supplements	7.0	7.0	7.0

**AU, Animal Unit. One Animal Unit is equivalent to an adult cow of 450 kg live weight.*

milky to pasty grain state, where starch levels are at their highest point and improve the nutritional quality of the forage (59% higher than for the commercial varieties Cayuse and Cajicá) (Campuzano et al., 2018). A summary of the characteristics of Altoandina is provided in **Table 1**. Altoandina was released by Agrosavia in 2018 and is commercially available to cattle producers since then.

In the present study, Altoandina was evaluated as silage for supplementation in times of feed scarcity in the higher tropics of Colombia. The evaluation considered two different silage supplementation percentages of the total diet: 35% (Yellow Diet) and 65% (Red Diet) of Altoandina silage. This was compared with a traditional grazing scenario with 100% Kikuyu grass (Blue Diet) (see **Table 2**). Prior to the entry of the animals to the systems, the chemical composition of the Kikuyu grass and the Altoandina silage were measured. In the case of the Altoandina silage, the levels of Crude Protein were 8.7%, Neutral Detergent Fiber 51.5%, and Total Digestible Nutrients 52.6%, respectively. For the Kikuyu grass, the levels of Crude Protein were 17.8%, Neutral Detergent Fiber 58.1%, and Total Digestible Nutrients 24.7%, respectively (J. Castillo, Agrosavia, personal communication). The composition of the diet presented in **Table 2** refers to the percentages available and supplied to the animals. The actual consumption of the animals, might differ since animals were offered voluntary feed intake. To ensure that each cow ate the planned amount, the silage was supplied individually, and the silage surplus was weighed daily. The residual silage did not reach higher levels than 3.9 and 3.6% for the two evaluated diets (65 and 35% of Altoandina silage) (A. Albarracín, Agrosavia, personal communication).

In the three diets, additional supplementation was carried out with Standard 70 feed concentrate, cotton seed and Alfalfa flour, at an amount of 6, 0.5, and 0.5 kg AU^{-1} d^{-1}, respectively. These amounts are assumed as constant throughout the year and are identical for the three evaluated diets. The productivity data for Altoandina were obtained from field evaluations carried out by Agrosavia in 2008 in the municipality of Tibasosa in the Boyacá Department in Colombia (5°44′53″ north latitude and 72°59′56″ west longitude, at an altitude of 2,528 m.a.s.l.). The experiment was carried out between July and August 2007, during the dry season of the second semester of the year. The average temperature there is 13°C with fluctuations between 0 and 20°C and a relative humidity of 80 to 85%. Frosts occur in the area in the months of January, February and early August, the average annual rainfall is 528.9 mm. Altoandina was sown in an area of 5,500 m^2, on soils with moderate to strong acidity (PH 5.9), medium percentages of organic matter, medium levels of Phosphorus (P) and Sulfur (S), and a low level of Boron (B). The oat harvest for silage production was carried out 119 days after sowing when 70% of the crop was in the state of milky to pasty grains, with an approximate Dry Matter production of 20 t ha^{-1}. Animal productivity was evaluated in 15 Holstein cows in a specialized dairy system under conditions of the higher tropics (2,200–3,000 m.a.s.l.). The animal productivity evaluations were performed in a crossover design with three treatments, where the experimental unit consisted of five Holstein cows in the first third of the lactation period. Each treatment involved three groups each of five cows who had between three and five calvings in the past. The silage supply was offered individually in the pasture with portable feeders, dividing the daily amount of silage into two fractions supplied after each milking process. The total evaluation period was 21 days, with daily milk yield measurements in seven-day blocks. To determine grazing area in each diet, the total available forage was calculated, and to determine the dry matter intake, the weight of the cows was measured. The measurements of forage availability were made before and after grazing to determine the consumption of Kikuyu grass. For the Blue Diet (100% Kikuyu grass), forage was provided to the animals through grazing on a daily plot size of 241 m^2 and the total area used was 4824 m^2. For the Yellow (35% Altoandina silage) and Red (65% Altoandina silage) Diets, Kikuyu forage was provided to the animals through grazing on a daily plot size of 140.1 and 69.9 m^2, and the total area used was 2802 and 1398 m^2, respectively.

MATERIALS AND METHODS

Discounted Cash Flow Model

A cost-benefit analysis (CBA) was carried out to determine the viability of the different interventions with Altoandina as a supplementation strategy in critical times. The CBA is based on a discounted free cash flow model and a quantitative risk analysis. The analysis was carried out by comparing the profitability indicators of the technology in different diets (Red Diet and Yellow Diet) and the traditional scenario (Blue Diet) for the study region. For each case, the economic costs and benefits were determined. Regarding the cost categories, the following have been considered (per hectare): total costs of establishment and maintenance, opportunity costs of capital, and operating costs (e.g., for animal health, supplementation, permanent and occasional labor). The benefits are derived from the production of milk in a specialized dairy system, according to the animal response indicators obtained for each diet. The estimated profitability indicators include the total production costs, the gross income, the net profit, the profit margin per liter of milk, and financial indicators such as the Net Present Value (NPV) and the Internal Rate of Return (IRR).

Model Assumptions

For the construction of the cash flow, it was necessary to establish different economic and technical assumptions, which are in detail described below.

Technical Parameters of Dairy Production

Since animal productivity was only measured in terms of milk production per day, the other technical parameters are the same for the three diets according to the average indicators for the study area: (i) a milk production period of 305 days; (ii) a calving interval of 401–450 days; and (iii) a productive lifespan of dairy cattle of 6 years. The purchase price of dairy cattle (US$ 812 AU^{-1}) was amortized for the period of analysis and the price for culled cows was adjusted for inflation at 6 years and added in the last year (US$ 406 AU^{-1}).

Sowing Frequency of Altoandina

Altoandina is sown twice a year—in March/April and October/November. Oat silage is prepared and offered to the animals in periods of frost or drought to cover the supply of forage required in the diet—usually from December to February and July to September. In other words, oat supplementation is assumed for a total of 180 days per year for the Red and Yellow Diets. It is necessary to emphasize that the planting of Altoandina must be linked to a farm development plan to fulfill this assumption. If the supply of forage is low, two sowings are planned, otherwise the producers sow oats, especially between March and April.

Pasture Renewal of Kikuyu Grass

The renewal is assumed once every 2 years, according to the trend in the region (J. Castillo, Agrosavia, personal communication). This is done to improve the physical and chemical quality of the soil, as well as to recover the productive capacity and quality of the Kikuyu grass.

Evaluation Horizon

The evaluation horizon is established according to the lifespan of the main assets for each diet. In the case of Altoandina, an evaluation period of 6 years was considered (from 2020 to 2025), according to the productive lifespan of the Holstein cows used in the specialized dairy system in the Colombian higher tropics (M. Sotelo, Alliance of Bioversity International and CIAT, personal communication).

Discount Rate

The financing cost is chosen as the discount rate in accordance with the rural credit lines of the Colombian Fund for the Financing of the Agricultural Sector (FINAGRO). This financing cost is considered the opportunity cost of capital and is associated with a risk factor present in the activities of the rural sector. Therefore, the following discount rate was established: Fixed-term deposit rate (DTF) + 5% effective annual interest rate. The projection of the discount rate in the corresponding periods was carried out following the DTF projections, according to the Annual Report of Economic Projections Colombia 2020 (Bancolombia, 2020).

Permanent Labor

The need for permanent labor was established according to the labor weights of FEDEGAN (2003), referring to a need of 7.8 permanent workers for every 100 animals in specialized dairy systems. The 2019 basic salary, transportation assistance, social security contributions, social and parafiscal benefits were considered for establishing the cost of one permanent farm worker, which is US$ 422 per month. For the projection of wages during the period of analysis, the universal rule was assumed: Variation of the minimum salary (in %) = expected inflation (in %) + observed variation of workforce productivity (WP, in %). A WP of 1% is assumed, according to historical estimates derived from the National Administrative Department of Statistics of Colombia (DANE, 2020a).

Taxes

Income tax was considered as dictated by law 2010 of 2019 (Congress of the Republic, 2020). Here a rate of 32% was established for 2020, 31% for 2021 and 30% for 2022, remaining fixed at the latter value for the subsequent years.

Currency at Current Prices

Inflation was considered to estimate income flows and costs in the evaluation period. In the case of income, the projection of the Consumer Price Index (CPI) estimated by Bancolombia (2020) for the period 2020–2023 was considered. For production costs, the Producer Price Index (PPI) provided by the National Administrative Department of Statistics of Colombia (DANE, 2020b) was considered.

Milk Price

Price information was obtained from the Milk Price Monitoring Unit for Region 1, where specialized dairy production systems predominant (MADR/USP, 2020). The prices were projected according to the CPI projections. Additionally, this projection included variations in milk prices, associated with the presence of extreme weather events such as *El Niño* and *La Niña*. According to Abril et al. (2017), the occurrence of these phenomena caused a significant increase in food inflation, particularly when the phenomenon is of a strong category. In Colombia, milk prices have had variations of more than 7% in the years with the presence of these events, compared to variations of less than 1% in the years without phenomenon (DANE, 2020b,c).

Quantitative Risk Analysis

Risk is defined as the possibility that the real return on an investment is less than the expected return (Park, 2007). Therefore, profitability is associated with the variability of the flows of benefits and costs, and these in turn of the randomness of the main variables of the investment project (e.g., yields, market prices). Investment projects at the rural level pose a high risk, resulting from a dependence on a wide set of variables, in many cases, not controlled by the producer (e.g., climatic factors). In this sense, it is necessary to incorporate risk levels associated with the profitability indicators of each of the diets evaluated. For this, a Monte Carlo simulation model was carried out. The simulation was performed for a total of 5,000 simulations or iterations, with a 95% confidence level, with the software package @Risk (Paladise Corporation). The objective of this analysis is to determine the standard deviation mean values of the profitability indicators through the variable parameters: price per liter of milk, milk production per day in each of the diets, fertilization costs, variation in the discount rate and in the CPI indicator. These variables are assigned a probability distribution according to their empirical behavior, literature or based on expert interviews. The yields were modeled according to expert knowledge and the best fit in @Risk following a Pert distribution, where the predominance of values in the most probable range was assumed. In the case of costs and price variations, a triangular distribution was assumed according to the reported minimum and maximum values and assigning a greater probability to the extremes. **Table 3** shows the simulated variables, the range values, and the probability distributions used. In the simulation, values of the variables identified as critical are randomly assigned, according to their probability distribution functions, to later calculate the determined profitability indicators.

Decision Criteria

As decision criteria, the mean values and the variance of the profitability indicators resulting from the simulation are used. The use of the mean value criterion is based on the law of large numbers, which states that if many repetitions of an experiment are carried out, the average result will tend toward the expected value (Park, 2007). The variance of the indicators determines the degree of spread or dispersion on both sides of the mean value (Park, 2007). In other words, the lower the variance, the lower the variability (loss potential) associated with the indicators.

$$NPV_{(Mean)} = \sum\nolimits_{t=0}^{n} \frac{E(FC_t)}{(1+r)^t} \quad (1)$$

$$IRR_{(Mean)} = \sum\nolimits_{t=0}^{n} \frac{E(FC_t)}{(1+r^*)^t} = 0 \quad (2)$$

Where,

E (FCt) = Expected value of the net profit flow for period t
Var (FCt) = Net profit flow variance for period t
r = Real discount rate
r* = Internal Rate of Return
t = Evaluation horizon of the project

TABLE 3 | Variables simulated in the Monte Carlo model.

Variable	Distribution	Most likely value	Lower limit	Upper limit
Milk price (US$ l^{-1})	Triangular	0.31	0.28	0.34
Milk productivity Blue Diet* (l AU^{-1} d^{-1})	Pert	20.48	17.63	23.32
Milk productivity Yellow Diet** (l AU^{-1} d^{-1})	Pert	21.67	19.09	24.24
Milk productivity Red Diet*** (l AU^{-1} d^{-1})	Pert	19.01	16.85	21.17
Fertilizer/corrective costs for Kikuyu renewal (US$ ha^{-1})	Triangular	80	54	303
Periodicity of the *El Niño* phenomenon	Discreet uniform	n.a.	2	7
Variation of the discount rate (%)	Triangular	0%	1%	2%
Variation of the CPI (%)	Triangular	−0.50	0	0.50

**100% Kikuyu grass, **35% Altoandina silage and 65% Kikuyu grass, ***65% Altoandina silage and 35% Kikuyu grass.*

The NPV at risk indicator (VaR) and the probability of success of the evaluated diets [Prob (NPV (Medium)>0] were also estimated. The VaR is defined as the maximum expected loss of the investment project in a time interval and with a certain level of confidence (Manotas and Toro, 2009). Additionally, a sensitivity analysis was performed using a tornado graph, which sensitizes each variable in order to measure its impact on the profitability indicators and to identify within the critical variables those with the greatest effects on the profitability indicators.

RESULTS

Figure 1 shows the information corresponding to the technical indicators of animal productivity for each of the evaluated diets. These indicators show that the inclusion of Altoandina silage in a percentage of 35% (Yellow Diet) allowed to increase the daily milk production per cow by 5.8% and per hectare by 82.3% compared to the Kikuyu grazing system (Blue Diet). When the percentage of silage in the diet increased by 65% (Red Diet), daily milk production per cow was reduced by 7.7% and per hectare increased by 220% compared to the Blue Diet. The higher per hectare milk production is associated with the higher availability of forage and, therefore, an increase in the animal stocking rate of 42% and 71% for the Yellow and Red Diets, respectively. In addition, the inclusion of Altoandina silage makes it possible to reduce the rate of milk production decline in critical times and, in the end, to increase milk production per unit area. It should be noted that, of the evaluated diets, the highest variability in animal production is observed for the Red Diet, measured by the standard deviation indicators and coefficient of variation. It is important to highlight that, as mentioned in the methodology, the data were collected during the dry season of the second

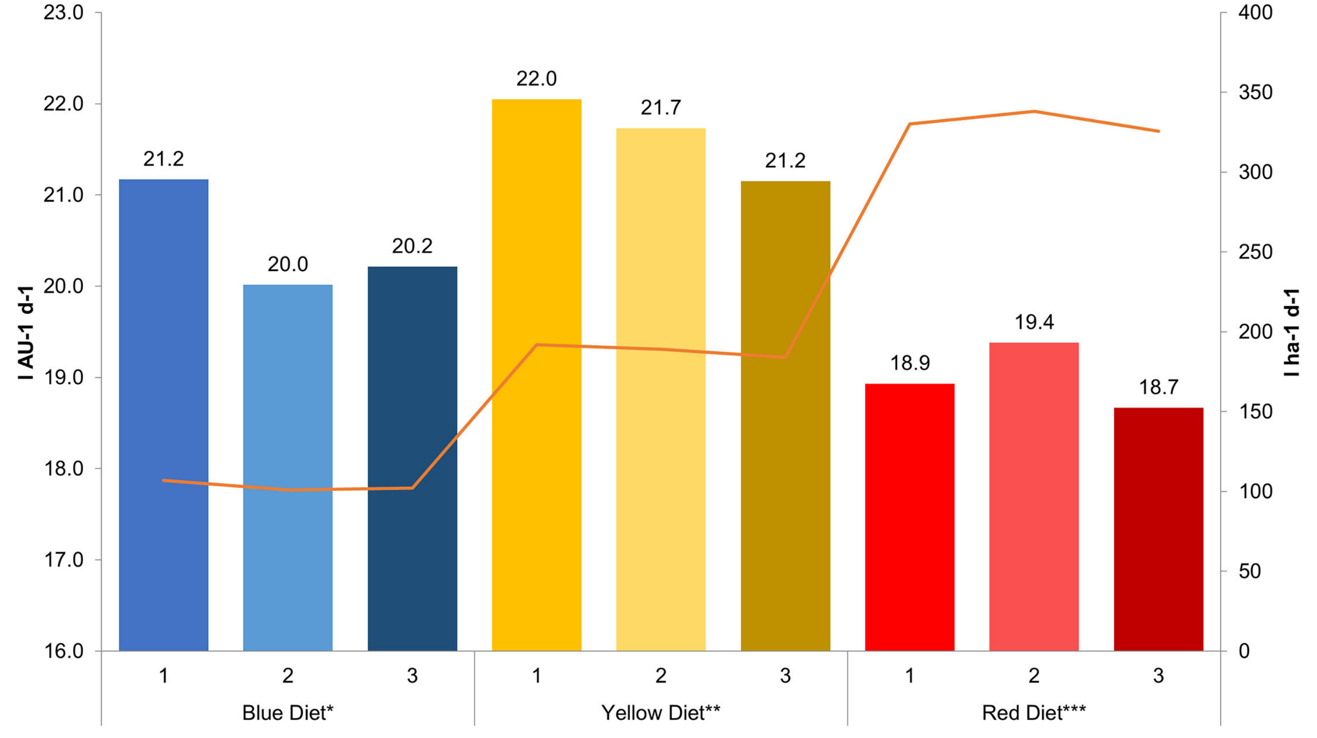


FIGURE 1 | Milk production per three cycles for the diets with Altoandina and the Kikuyu diet (each cycle was a 7-day evaluation, the total evaluation period was 21 days). *100% Kikuyu grass, **35% Altoandina silage and 65% Kikuyu grass, ***65% Altoandina silage and 35% Kikuyu grass.

semester and were used to estimate the total annual production under each diet. However, given that production levels tend to be higher in rainy seasons, which is associated with the better forage availability, the data estimations used in this study could be underestimating production levels for the whole year. In this sense, better annual milk yields could be expected.

Table 4 presents the summary of the average costs and income for each of the evaluated diets. The cash flow models include the variable costs and revenues associated with the establishment of each technology (Altoandina, Kikuyu). The income results from the sale of raw milk under a specialized dairy production system, according to the technical parameters presented in **Figure 1**. The average annual milk yields are 31,522, 57,316 and 101,543 L/ha for the Blue, Yellow and Red Diets, respectively. This results in a gross income for the sale of raw milk of US$ 10,091 for the Blue, US$ 18,335 for the Yellow, and US$ 32,483 for the Red Diet, respectively. Regarding production costs, animal feed and labor costs are the most significant items in this production system, making up 52 ± 3% and 23 ± 1% of the total cost of each diet. The costs corresponding to inputs for pastures, animal health, and others add up to the remaining 25%, which results in a production cost per liter of milk of US $0.31 for the Blue, US$ 0.29 for the Yellow, and US$ 0.34 for the Red Diets, respectively. The feed cost includes those costs related to supplementation with Standard 70 concentrate, cotton seed and Alfalfa flour, at an amount of 6 kg, 0.5 kg, and 0.5 kg AU^{-1} d^{-1}, respectively, adding to a total cost of US$ 2.34 AU d^{-1} and US$ 836 AU y^{-1}. This amount is assumed constant throughout the year and the same for the three evaluated diets. The net profit per hectare and year was US$ 1,226, US$ 2,620, and US$ 2,351 for the Blue, Yellow and Red Diets, respectively.

From a purely technical point of view, the Red Diet presents the highest values for the indicator milk production per hectare. When estimating the costs and economic viability indicators,

TABLE 4 | Overview of principal economic indicators per diet.

Economic indicator	Blue Diet*	Yellow Diet**	Red Diet***
Milk production (l ha^{-1} y^{-1})	31,544	57,316	101,544
Gross income from milk sales (US$ ha^{-1} y^{-1})	11,355	20,631	36,552
Production Costs (US$ ha^{-1} y^{-1})	9,695	16,815	34,383
Net utility (US$ ha^{-1} y^{-1})	1,381	2,949	2,646
Unit Production Cost (US$ l^{-1})	0.31	0.29	0.34
Milk price (US$ l^{-1})	0.36	0.36	0.36
Unit Profit Margin (US$ l^{-1})	0.05	0.07	0.02
Financial Viability indicators[a]			
NPV_mean	5,194	11,842	7,853
IRR	40.8%	49.9%	23.5%

[a] *NPV and IRR; NPV mean value obtained through Monte Carlo simulation (5,000 repetitions with a 95% confidence level).*

**100% Kikuyu grass, **35% Altoandina silage and 65% Kikuyu grass, ***65% Altoandina silage and 35% Kikuyu grass.*

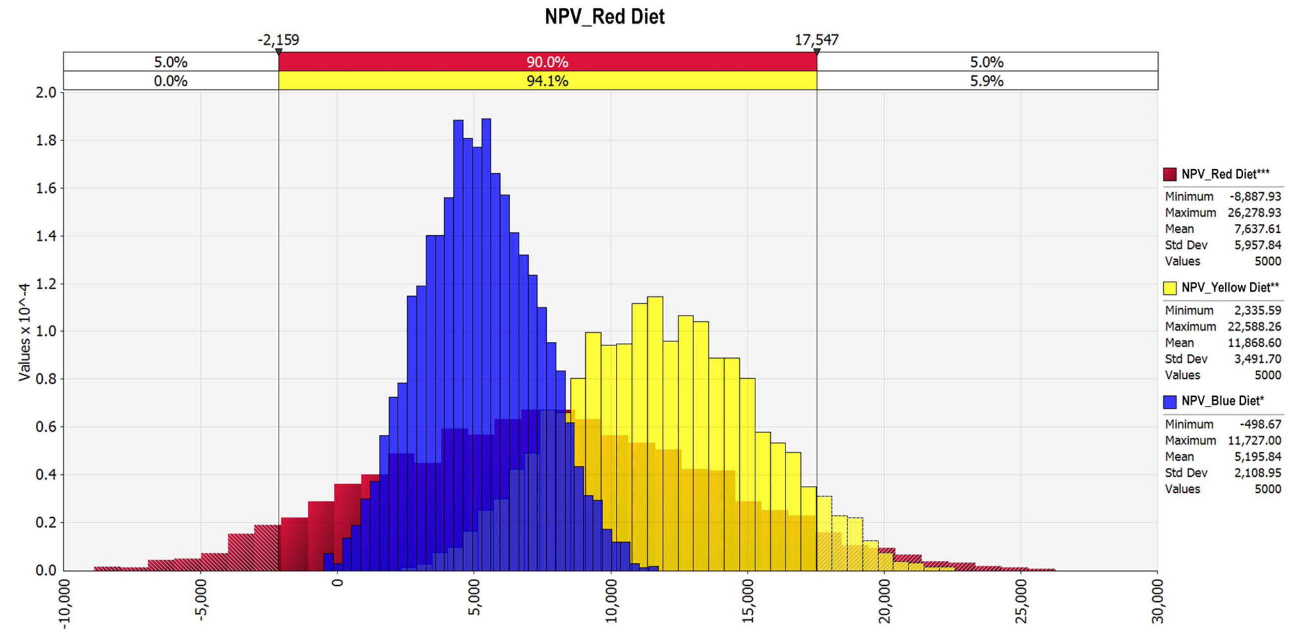


FIGURE 2 | Probability density of the NPV per evaluated diet. *100% Kikuyu grass, **35% Altoandina silage and 65% Kikuyu grass, ***65% Altoandina silage and 35% Kikuyu grass.

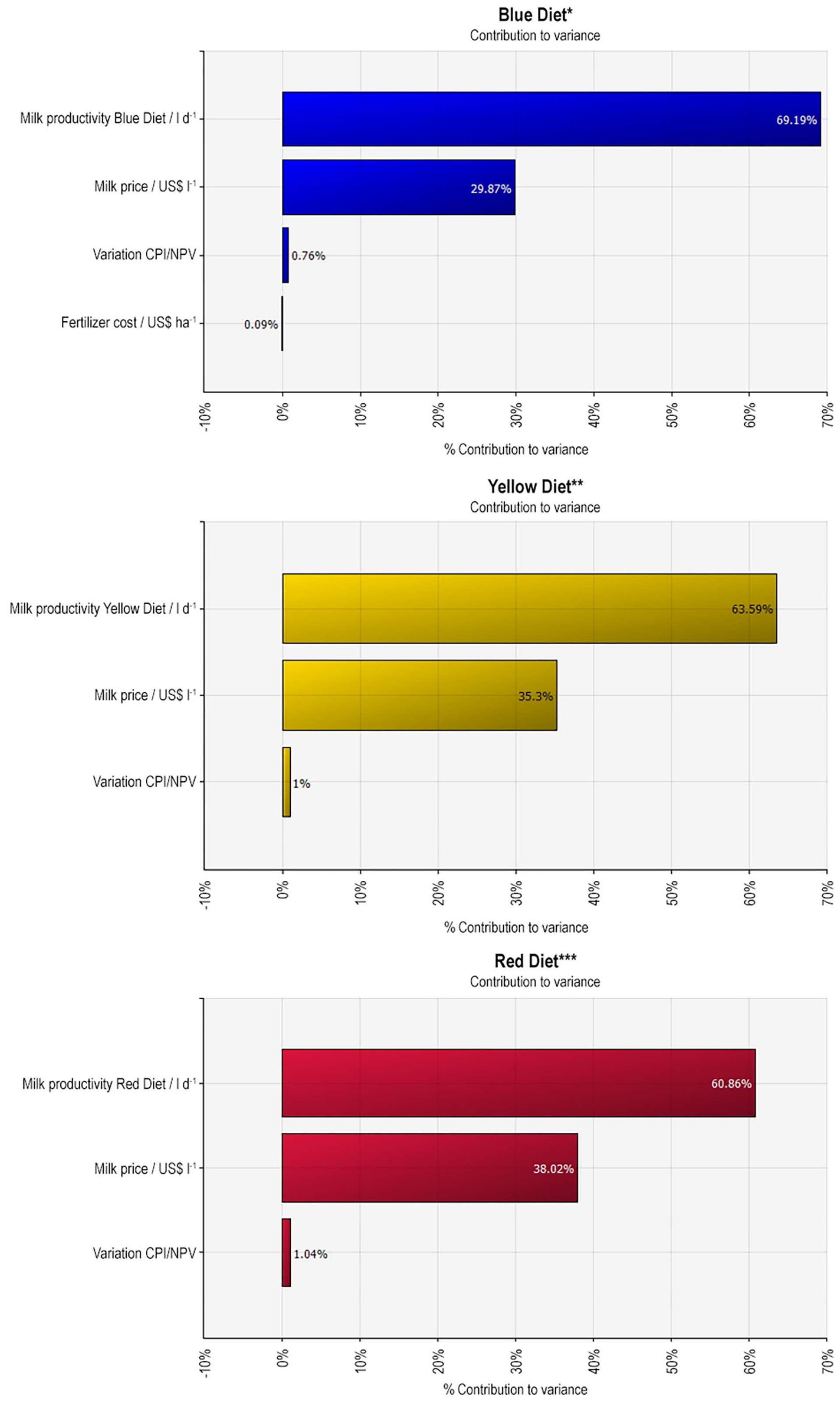
however, the Yellow Diet turns out to be the more efficient one with lower unit production costs and higher daily milk productivity per cow. Therefore, a higher profit margin can be obtained per liter of milk produced. The cost of establishing one hectare of Altoandina is estimated at US$ 886, which includes the costs required in its establishment and for ensilaging. The green forage yield is 46,545, the amount silage obtained from that is 41,891, and the DM production is 14,155 kg ha^{-1}, respectively. The cost per kg of DM produced is estimated at US$ 0.06.

The summary of the main financial indicators obtained from the Monte Carlo simulation is presented in **Table 4**. Under the assumptions used for the modeling, all diets result in economically viable alternatives (NPV>0). The best indicators are, however, associated the Yellow Diet. Its mean NPV is 128% and 55% higher than the ones of the Blue and Red Diets, respectively, and a lower dispersion of the indicators is observed according to the Coefficient of Variation (29%, compared to 41% and 76% for the Blue and Red Diets, respectively). Regarding the probability of not obtaining financial feasibility of the three diets, the results of the probability distribution of the NPV are presented in **Figure 2**. Here, the amplitude of the variation for the NPV indicator can be observed with a confidence level of 95%. For the Blue Diet, the indicator can take negative values close to US$ 990 and positive values close to US$ 11,554, with a probability of economic loss of less than 1%. For the Yellow Diet, the distribution curve shifts to the right, with a range that varied between US $2,075 and US$ 23,050. The curve for the indicator for the Red Diet presents a more dispersed behavior around the mean value, reaching minimum values close to -US$ 9,862 and maximum values of US$ 27,278, where 10% of the simulated scenarios presented an NPV<0.

For all three evaluated diets, the economic viability indicators are highly sensitive to changes in the daily milk production variable, meaning that 70, 62.9, and 60% of the variations in the NPV indicator of the Blue, Yellow and Red Diets can be explained by variations in daily milk production. The second most impactful variable is milk price, which explains on average 30% of the variations in the NPV. The Red Diet is the most sensitive to changes regarding milk price (38.7%), which suggests that it would pose a greater risk in the face of market conditions that cause price reductions (**Figure 3**).

DISCUSSION

The use of Altoandina as a supplementation strategy in times of food scarcity proved to be a viable alternative at both the technical and economic levels in specialized milk production systems in the Colombian higher tropics. The higher availability of feed in the evaluated diets based on Altoandina silage allow to increase milk production per hectare substantially (82 and 220% for the Yellow and Red Diets). The daily milk production is, however, 7.7% lower for the Red Diet (which has the highest share of Altoandina silage with 65%) than for the Blue Diet (control scenario, 100% Kikuyu), which is associated with the lower nutritional quality of the silage compared to the higher quality of Kikuyu grass. According to literature, although the effects on milk production can be highly variable, most studies have reported how the use of oats has allowed to maintain and even improve production in critical times. For example, some studies report that the



Blue Diet* Contribution to variance

Yellow Diet** Contribution to variance

Red Diet*** Contribution to variance

FIGURE 3 | Contribution of variables to the NPV variance for the evaluated diets. *100% Kikuyu grass, **35% Altoandina silage and 65% Kikuyu grass, ***65% Altoandina silage and 35% Kikuyu grass.

supplementation with oat silage has allowed increases in the production and percentage of milk fat, without detriments to protein and total solids (Campuzano et al., 2018). This increase is associated with the greater supply of forage available in diets that include silage, which balances a diet rich in protein and energy (J. Castillo, Agrosavia, personal communication). Mojica et al. (2009) found a higher milk production in cows fed with Kikuyu grass with a supply of oat silage (*Avena sativa*) of 0.7 kg DM per 100 kg of live weight (equivalent to a supplementation of 17.5% of the total diet), although this increase in production was statistically similar to the diets where only Kikuyu grass was fed. Similarly, León et al. (2008), Harper et al. (2017), Burbano-Muñoz et al. (2018), and Castro-Rincón et al. (2020) report no significant differences in the DM consumption, milk production and composition for supplementation diets with 10–35% oat silage (*Avena sativa*). These results show that the inclusion of oat silage in low percentages of the diet does not affect the nutritional value of forage and, therefore, production is maintained. On the contrary, León et al. (2008) and Mojica et al. (2009) reported reductions in milk production when up to 1.4 kg DM of oat silage per 100 kg liveweight were incorporated into the diet (33–36% of the total diet). This effect was associated with a possible negative effect on the nutrient balance since DM consumption was similar with respect to the diet based only on Kikuyu grass. Barahona et al. (2003), however, reported an optimal level of silage utilization for supplementation of up to 75% of the total diet, with acceptable and profitable levels of milk production. In general, these variable results regarding the effects of oat silage on milk production can be associated with multiple factors, such as nutritional quality and cutting age of the oat (variation in the amount of nutrients), the type of silage and its interaction with the grass feed base, lactation (differences in nutritional requirements), availability and level of DM consumption, and level of energy consumption (Bhandari et al., 2008; León et al., 2008; Mojica et al., 2009; Harper et al., 2017).

At an economic level, the results indicate the Yellow Diet as the best alternative, yielding an average NPV higher than for the other alternatives and a lower variability for said indicator. Similarly, the risk indicators VaR (Value at Risk at 95% confidence) and Prob (NPV < 0) are more favorable for this diet. These results are associated with greater efficiency in terms of production costs, which allows for increasing the profit margin per liter of milk produced. The Yellow Diet with 35% Altoandina silage can therefore be considered the best alternative from an economic point of view under different performance scenarios and market conditions. Sections 1 and 2 of this article evidenced the lack of economic studies regarding the implementing of oat supplementation strategies in the Colombia. In fact, the only study we found was conducted in the highlands of Mexico (Burbano-Muñoz et al., 2018). According to the results, production costs per kilogram of milk increased by 25 and 50% for inclusion levels of *Avena sativa* cv. Chihuahua oat silage of 3 and 6 kg DM per cow and day, respectively. Since there were no significant differences in yields or milk composition, the diet with only Kikuyu grass had the highest profit margin. This study, however, highlights the importance of this feeding strategy to maintain production levels in places where grazing conditions are limited. Likewise, the use of oat silage makes it possible to reduce the use of feed concentrates or expensive by-products for feeding animals—which are mainly imported at high prices and are subject to often strong price fluctuations. Both are also important attributes observed in our study. In addition, Altoandina has tolerance to rust (*Puccinia spp.*), higher drought tolerance and resistance to frost, which make it an option less likely to be affected by specific climatic conditions and pests present in the Colombian higher tropics. Altoandina can also be conserved for up to 3e years when proper oat conservation processes are guaranteed (silo, silage), which helps in reducing production seasonality and improving productive parameters.

Given the presence of periods of drought or frost that reduce the biomass supply in grazing systems in the Colombian high tropics, alternatives, such as supplementation with oat silage, that allow to maintain milk production levels stable throughout the year, are of great importance for the dairy sector. Achieving stable milk production would improve the income level of producers, contributing to their livelihoods, but also to food security and a better nutrition in the region. Although there is a visible trend toward using feed supplementation strategies in dairy farms in the high tropics (e.g., hay and silage in critical times), this rather applies to the more technified farms. Farms with low to medium technification are more reluctant resulting in low levels of adoption of such supplementation strategies, which is evidenced by less than 5% and 20% of the producers using hay and silage supplementation, respectively (FEDEGAN, 2012). Among the main barriers that limit the adoption of supplementation strategies are the lack of equipment to chop the silage (Reiber et al., 2010, 2013; Bernardes and do Rêgo, 2014), and the lack of labor (Bernardes and do Rêgo, 2014). On the other hand, factors that favor the adoption of supplementation strategies are financial and agricultural resources, continuity and intensity in rural extension, access to demonstration farms and the participation of key innovators, the lack of alternative feeds for the dry season, the perceived benefits of silage feeding, and the presence of a favorable milk market (Reiber et al., 2010, 2013). This highlights the importance of providing support in the diffusion processes of these technologies in terms of training and education on the use of supplementation strategies as well as their technical and economic benefits. Likewise, facilities for producers to access the required equipment (e.g., machine rings) can help in technology adoption and diffusion processes.

The inclusion of oat silage in animal diets can also have positive effects at the environmental level, given the reduction of greenhouse gas emissions in the specialized dairy systems of the higher tropics. In Colombia, those systems present a high level of emissions of both Nitrogen (N) and Phosphorus (P) (León et al., 2008), which is associated with the levels of conventional fertilization with N used for the maintenance of (Kikuyu) pastures (around 400 kg N ha^{-1} y^{-1} are used), the high levels of protein consumption (e.g., 17–21% of protein levels in Kikuyu), and the consumption of P (through mineralized salts) not fully used at the ruminal level (León et al., 2008).

Different studies have proposed the use of cereal silages rich in starches as a strategy to reduce the consumption of N and P, increasing the efficiency in the use of these minerals and, therefore, reducing greenhouse gas emission levels. For example, León et al. (2008) evaluated the balance of N and P in 18 cows under grazing of Kikuyu grass and compared the results with a diet based on the inclusion of oat silage (*Avena sativa*). According to their results, the decrease in nutrient consumption through supplementation with oat silage decreased the excretion of N in the urine and reduced the P balance. On the other hand, it increased the excretion of N in feces which is associated with the lower degradability of the silage compared to Kikuyu grass. The above-described changes were not affecting milk production levels and composition. The authors state that the reduction of N in the urine significantly contributes to the reduction of greenhouse gas emissions, since it degrades faster than fecal N. Dhiman and Satter (1997) observed that the total excretion of N to the environment was reduced from 6 to 15% with diets that contained corn silage. Ramin et al. (2021) described that a higher inclusion of oats linearly reduced CH_4 emissions from 467 to 445 g d^{-1}, and the intensity of CH_4 from 14.7 to 14.0 g per kg of milk, without having adverse effects on productivity or energy balances. Other studies have confirmed that reducing the level of protein in the diet (i.e., from 18% to 15%) does not affect production, but reduces the excretion of N into the environment (Wattiaux and Karg, 2004; León et al., 2008). In summary, including grain silage, such as Altoandina, into the cattle diet may help to reduce greenhouse gas emissions without affecting productivity levels and thus, has positive effects on the environment when compared with traditional diets based on grazing (of Kikuyu) and feed concentrates. To achieve the maximum benefits in this regard, it is, however, important to ensure that the oats are being harvested at the optimum time (milky-pasty grains) and that the grains are being mixed with the forage.

CONCLUSIONS

The results of this study suggest that supplementation with Altoandina oat silage is an efficient alternative to meet feed requirements in critical times of milk production in the Colombian higher tropics. The inclusion of Altoandina silage as supplement into the Kikuyu dairy cattle diet in a 35% :65% proportion (Yellow Diet) results in the best per animal milk productivity indicators, whereas in a proportion of 75:25% (Red Diet), daily milk production declines. This is associated with the loss of nutritional quality of the forage at a level of 75% oat silage supplementation, affecting the nutrient balance and, therefore, the daily per animal milk productivity. This is consistent with other studies, which suggest oat silage supplementation as a promising alternative to maintain milk production levels in times of forage scarcity. Prior to the planting forage crops such as oats, it is, however, important to conduct technical and economic evaluations focused on the use of supplements to lower the excess protein levels that Kikuyu grass could present, according to the productive potential of the animals and the goals proposed in farm development plans. In addition, we recommend including the supply of supplements, such as Altoandina oat silage, into forage budget calculations (feed budget) to estimate the actual supply and demand of feed of the dairy herd, and to assess production costs for grass and supplements. Finally, it is important to carry out or publish results of the protein-energy balance in the Colombian higher tropics, focusing on the efficiency and importance of balancing diets based on forage crops such as oats.

According to the economic evaluation, the Yellow Diet turned out to be the best alternative to improve efficiency and profitability at the farm level when facing problems of seasonality in dairy production and increasing the income of producers. The evaluation also shows that implementing this diet is less risky than implementing the traditional diet based on Kikuyu (Blue Diet) and, considering the risk aversive behavior of many dairy farmers, this is a key aspect to promote diffusion and adoption. Altoandina also shows tolerance to stem rust (*Puccinia ssp.*) and drought, as well as resistance to frost, which makes it a valuable option for specific climatic conditions and pests in the Colombian higher tropics that can contribute both to reducing the seasonality of production and improving production parameters. Likewise, when there is an excess of protein in the pasture (as in the case of the 100% Kikuyu grass diet), supplying oat silage with high starch levels helps balancing the protein:energy ratio and thus, improves the efficiency of the system.

The use of supplementation alternatives such as oats contributes to achieving more sustainable food systems, through improving the efficiency of animal feeding. This leads to an increase in the availability of milk for consumption, which is key to nutrition and food security, and to improvements in the livelihoods of the producers. Commercial seed for growing oats is easily accessible and the establishment of the materials is relatively easy for the producers, making supplementation an attractive alternative to them. The use of Altoandina as supplementation thus helps improving the feeding efficiency by either maintaining the same production levels but reducing the use of more expensive feeds (e.g., concentrates) or producing more milk at lower per unit costs. This stabilizes the income flow of the dairy producers and, therefore, improves their livelihoods. The increased availability of milk for consumption also contributes to improving food security and the nutrition of, above all, the rural population. In addition, oats can also be a nutrient-rich food source for human consumption and contribute to the nutrition of the producer households. Likewise, the use of oats as a supplementation strategy also contributes to the reduction of N and P emissions to the environment, since oats, in their milky to pasty grain state, increase starch levels and balance the protein:energy ratio, and thus, contribute to reducing greenhouse gas emissions while improving economic efficiency. This makes oat supplementation a triple win alternative: more efficient production, increased livelihoods, reduced emissions. Although the experiments used as a basis for this study were carried out in the Boyacá Department of Colombia, it is important to note that they served as an important input for technology scaling processes and further evaluations in other high-altitude regions of the country with similar specialized dairy systems, such as in the Nariño (Castro-Rincón et al., 2020), Cundinamarca, and Antioquia Departments as well as in other areas of the Boyacá Department (J. Castillo, Agrosavia, personal communication). Likewise, the economic results obtained in this study have been key to identifying the percentage of the diet with the best economic viability at the producer level and helped to define a pathway for scaling this technology package in larger areas of the high-altitude tropics of Colombia. In this sense, Agrosavia in 2021 has been working on a plan for promoting Altoandina at the regional level, by providing dairy producers with technical recommendations and supporting them in increasing the planted areas. It is recommended, however, to conduct further trials and analyses in other countries with similar conditions (e.g., Ecuador, Peru, Bolivia) to support technology release and adoption processes there, too.

We also recommend including measurements at the environmental level in future studies on Altoandina, so that the technology's potential for reducing greenhouse gas emissions can be quantified and other potential ecosystem services identified. Such measurements should be included in the agronomic evaluations, which would then allow for accounting greenhouse gas emission reductions in the economic valuation exercise and to project them as additional benefits derived from the dairy system. Likewise, we recommend evaluating the use of Altoandina as dual-purpose crop, meaning in a mixed grazing-cutting system, where the animals graze the oat in the stuffing state, and after that fertilizer is being applied and the oat is being harvested for silage production once the grains reach the milky-pasty state. This approach could increase system efficiency and land use optimization. In addition, Altoandina is frost resistant, and intercropping with Kikuyu grass could help mitigating the effects of frost on the production system through improving the total on-farm DM availability. We thus recommend evaluations for determining the intercropping potential of Altoandina and its effects when it comes to the adaptation to climate change.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

AUTHOR CONTRIBUTIONS

SB, KE, and JC: conceptualization, methodology, and formal analysis. KE, LA, LC, and SB: writing the original draft and review and editing. JC, KE, LA, LC, MS, and SB: resources. SB: supervision and funding acquisition and project administration. All authors contributed to the article and approved the submitted version.

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