**Assessing the Feasibility of Sweet Lupin Grain as a Substitute for Soybean Cake in Lactating Crossbred Dairy Cow Diets at Andassa Livestock Research Center**

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**ABSTRACT**

Sweet annual lupins are well suited to local growing regions and offer high productivity. With a lower alkaloid content and higher crude protein levels in forage and seeds, sweet lupins are a preferred homegrown protein source for livestock feed. A feeding trial conducted at the Andassa Livestock Research Center aimed to assess the impact of varying inclusion levels of sweet lupin grain (SLG) as a protein supplement on the milk yield and composition of lactating crossbred dairy cows. The experiment involved substituting 0%, 25%, 50%, 75%, and 100% of soybean cake (SBC) with SLG in the cows’ diet. A 5x5-crossover design was used, involving five lactating crossbred dairy cows over five periods, with blocking based on initial milk yield. Data were analyzed using the GLM procedure in SAS (version) and included feed intake, milk yield, milk composition, milk yield efficiency, fat- and protein-corrected milk production, and methane emissions. Significant differences were determined by the Tukey's HSD test. Results showed no significant difference in dry matter intake or methane emissions (P > 0.05) across substitution levels. However, the substitution of 75% SBC with SLG in the diet led to the highest milk yield (9.57 liters/day) compared to other inclusion levels (P < 0.001), followed by 100% SBC and 100% SLG. While milk composition did not vary significantly across substitution levels (P > 0.05), milk fat content was significantly higher (P < 0.0001) in cows fed 50%, 75%, and 100% SLG (5.042%, 5.239%, and 6.728%, respectively) compared to 0% and 25% SLG. The highest fat-protein corrected milk (FPCM) was recorded at 75% SLG inclusion (10.169 kg/day). Additionally, 75% SLG inclusion resulted in the highest daily profit (170.277 birr/animal) and benefit-to-cost ratio (2.034 birr). In conclusion, the study suggests that sweet lupin can be successfully incorporated into dairy cow diets at various levels, yielding benefits in terms of milk production and composition. However, the optimal inclusion level for maximizing milk yield, milk fat content, and profitability is 75%. Further research and promotion of this inclusion level for crossbred dairy cows are recommended.

**Key words: Cross-over design, Fat, Inclusion level, Milk yield efficiency, Protein supplement**

1. **INTRODUCTION**

Many small-scale subsistence farmers in Ethiopia struggle to provide their livestock with a balanced, nutritious diet (Ayalew et al., 2003). While farmers have access to a variety of locally available feed ingredients, they often lack the knowledge to properly combine these resources into balanced rations. As a result, by-products can serve as an affordable and environmentally sustainable feed option for livestock farmers, improving both cost-effectiveness and nutrition (Oishi et al., 2011). In Ethiopia, dairy cows are commonly fed a combination of natural pasture, hay, agricultural waste, fodder, agro-industrial by-products (AIBPs), compound feeds, and non-conventional feed sources (CSA, 2021).

Lupins have been shown to be an effective protein source for dairy cows. White et al. (2007) found that including lupins at a rate of 75% in dairy cattle diets maximized milk yield, with results comparable to those achieved by soybean meal (SBM). Numerous studies confirm that replacing grains with lupins in the diet leads to higher milk, fat, and protein production. Additionally, replacing oilseed meals with lupins does not negatively affect milk, fat, or protein yields. Given these benefits, sweet lupin can be an ideal protein supplement to address nutritional challenges in the region.

In Ethiopia’s mixed crop-livestock farming system, native white lupin is a valuable traditional crop (Yeheyis et al., 2010). Sweet annual lupins are particularly well-suited to traditional lupin-growing regions due to their adaptability and high productivity (Yeheyis et al., 2011b). Sweet lupins are favored for use as a homegrown protein source in livestock feed because of their low alkaloid content and high crude protein content in both seeds and forage (Likawunt et al., 2012).

To improve dairy cow nutrition and productivity, the most effective approach may be to incorporate appropriate supplemental feedstuffs. Likawent et al. (2012) suggest that sweet blue lupin seed can replace commercial concentrate mixes in the diet of Washera sheep. Similarly, research at Tottori University in Japan has examined the nutritional composition of various feedstuffs, aiding in the formulation of balanced rations for dairy animals (Shigdaf et al., 2020). Thus, lupin holds potential as not only a protein source for livestock but also as a multipurpose crop, that enhances soil fertility.

However, there is limited information available on the nutritional benefits of sweet lupin as a protein source for Ethiopian dairy cows, particularly in our region. Therefore, exploring the inclusion of sweet lupin as a protein supplement could be key to addressing nutritional challenges and improving dairy cow productivity. This study aims to evaluate the effects of sweet lupin as a protein source in feed rations on milk yield and composition, as well as assess its economic viability for enhancing the productivity of lactating dairy cows.

1. **MATERIALS AND METHODS** 
   1. **Description of study area**

The study was conducted at the Andassa Livestock Research Center (ALRC), located in the Amhara Region of Ethiopia. The center is situated 486 kilometers north of Addis Ababa, the capital of Ethiopia, and 21 kilometers from Bahir Dar, the capital of the Amhara Region. Positioned at an altitude of 1,730 meters above sea level, ALRC lies at a latitude of 11°29'N and a longitude of 37°29'E. According to ARMA (2018), the center experiences an average annual rainfall of 1,330.4 mm, with maximum and minimum annual temperatures of 27.9°C and 13°C, respectively.

* 1. **Feeds, ration formulation and feeding management**

At the Andassa Livestock Research Center (ALRC), native pasture hay and Napier grass were harvested and used as the base diet for the dairy cows. Maize grain, wheat bran, common salt, limestone, and soybean cake (SBC) were purchased from the local market. Sweet lupin grain, sourced from South Achafer, located 95 km from ALRC, was used as a protein supplement, replacing soybean cake in the current study. For the mid-lactation dairy cows, feed processing and ration formulation were based on the available local feed resources. The formulation adhered to the NRC's 2001 guidelines for dairy cow nutrition, which account for factors such as body weight, daily milk production, production period, and the nutritional profile of the feed. The NRC (2001) recommends a crude protein (CP) requirement of around 16% in iso-nitrogenous diets for mid-lactation dairy cows. In this study, sweet lupin was incorporated into the diet at varying levels (0%, 25%, 50%, 75%, and 100%) to assess its potential as a protein source.

**Table 1** Chemical composition of Feed ingredients and Feed formulation

Chemical composition of Feed ingredients

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Feed ingredients | CP % | NDF% | ADF% | ADL% | GE(MJ/kg) |
| Maize | 10.6 | 73.12 | 39.70 | 9.52 | 13.4 |
| Hay | 7.22 | 68.86 | 38.06 | 10.81 | 16.4 |
| Napier | 12.22 | 64.47 | 33.12 | 6.85 | 16.0 |
| wheat bran | 14.96 | 39.45 | 10.59 | 3.15 | 13.2 |
| Soya bean Cake | 27.63 | 36.17 | 16.26 | 6.30 | 11.8 |
| Blue sweet lupin grain | 31.2 | 38.99 | 11.62 | 3.69 | 15.7 |

Source (Shigdaf et al., 2020)

**Feed formulation**

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Feed ingredients | % of sweet lupin inclusion level in the feed ration (Treatments) | | | | |
| 1 (0%) | 2 (25 %) | 3 (50%) | 4 (75%) | 5 (100%) |
| Maize | 30 | 37 | 45 | 53 | 59 |
| Wheat bran | 33 | 26 | 18 | 10 | 4 |
| Soybean cake | 33 | 24.75 | 16.5 | 8.25 | 0 |
| Sweet. Lupin | 0 | 8.25 | 16.5 | 24.75 | 33 |
| Lime | 2 | 2 | 2 | 2 | 2 |
| Slat | 2 | 2 | 2 | 2 | 2 |
| Total | 100 | 100 | 100 | 100 | 100 |
| CP | **16.04** | **16.06** | **16.058** | **16.05** | **16.11** |

* 1. **Experimental design, Treatments and Animal management**

For the feeding experiment, five crossbred lactating dairy cows, with a parity range of 2 to 5, were selected. The experimental design was a crossover design with five periods and five treatments. The initial daily milk yield of the cows was used to block the animals, ensuring that each group had comparable physiological conditions. Each of the five treatments was randomly assigned to the cows under the same management system. The experiment was conducted over five periods, each lasting 21 days, with 14 days allocated for adaptation and 7 days for actual data collection. The cows were manually milked twice a day, at 8:00 AM and 4:00 PM. In addition, the cows were treated for internal parasites at the start of the experiment, receiving 900 mg of Fascinox for fasciolosis treatment and 3,400 mg of Tetraclozan for parasite control. The experimental diets were divided into two equal portions, which were offered at 8:00 AM and 4:00 PM after weighing refusals. Water was provided ad libitum. Basal diets were given with an allowance of 20% refusal of the previous day’s intake. The treatment feed amounts were adjusted daily based on the average milk production from the previous day. The treatments were adjusted by mixing half a kilogram of ration feed with one liter of milk on a dry matter basis. The basal diet included a mix of improved forage and hay, as recommended by the NRC (2001) for dry matter intake. The sweet lupin inclusion in the treatment diets was calculated by replacing soybean cake (SBC) with sweet lupin as the protein source.

The experimental treatments were as follows:

**T1:** Concentrate mixture with only soybean cake (SBC) + basal diet

**T2:** 25% substitution of SBC with blue sweet lupin grain (BSLG) + basal diet

**T3:** 50% substitution of SBC with blue sweet lupin grain (BSLG) + basal diet

**T4:** 75% substitution of SBC with blue sweet lupin grain (BSLG) + basal diet

**T5:** 100% substitution of SBC with blue sweet lupin grain (BSLG) + basal diet

* 1. **Milk yield, composition and milk yield efficiency**

During the data collection period, milk yield was measured, and milk samples were taken for analysis. Milk samples were collected using graduated bottles at weekly intervals during both morning and evening milking sessions. Each cow provided 100 milliliters of milk, which were then analyzed using a Lacto Scan at the Andassa Livestock Research Center's health laboratory. Prior to analysis, the equipment was calibrated using distilled water.

Fat- and protein-corrected milk production (FPCM) (kg/d) was calculated following the method outlined by De Koster et al. (2019), using the formula:**FPCM = [(0.337 + 0.116 × milk fat + 0.06 × milk protein [%]) × milk yield].** Milk yield efficiency (MYE) was determined according to Nichols et al. (2019), using the formula: **MYE= milk yield (kg)/DMI (kg),**  
where DMI refers to dry matter intake. The enteric methane emissions from lactating dairy cows were calculated using the equation developed by Mutian et al. (2018): **CH4 production (g/day per cow) = 124 + 13.3 × DMI (kg/day),** where DMI is the dry matter intake of the cows.

* 1. **Partial budget analysis**

Each variable cost was recorded for each individual cow during each period. The variable costs included labor, feed, and veterinary expenses. Total milk yield was recorded for each treatment, and income was calculated by multiplying the market price by the milk yield for each treatment. The partial budget analysis involved determining the variable costs and profits from milk sales. The total variable costs (TVC) encompassed labor, feed, and veterinary costs. Net income (NI) was calculated using the formula: **NI = TR − TVC**, where TR represents total revenue.

* 1. **Data collection**

Data for each individual cow were recorded daily on prepared sheets by trained enumerators. The collected data included milk yield, milk composition, feed offered and refused, health records, all costs, body condition, body weight, and parity, which were documented at each stage of the experiment.

* 1. **Data Analysis**

An analysis of variance (ANOVA) was performed using SAS’s GLM procedure (2002) to assess feed intake, milk yield, milk composition, milk yield efficiency, fat- and protein-corrected milk production, and methane emissions. Treatment mean differences were compared using the Tukey's Significant Difference (HSD) test at a 95% confidence level (P ≤ 0.05).

The model used for the analysis was:  
**Yijk = μ + Ti + βj + Eijk**

Where:

* **Yijk** = response variable (observation for treatment αi and block βj)
* **μ** = overall mean
* **Ti** = treatment effect (inclusion levels 1 to 5 of sweet lupin)
* **βj** = block effect
* **Eijk** = random error

1. **RESULTS AND DISCUSSIONS** 
   1. **Milk yield, feed intake and CH4**

The overall mean milk yield of crossbred dairy cows fed different levels of sweet lupin as a protein source is presented in Table 2. There were no significant differences between the treatment groups for initial milk yield (before the experiment), CH4 emissions, or feed intake. The highest milk yield was recorded in treatment group 4 (9.57 liters/day), while the lowest was observed in treatment groups 2 and 3. The average milk yield in this study was 9.313 liters/day. This result is higher than that reported by Misganaw et al. (2018), who found an average yield of 4.93±0.25 liters/day when feeding grass hay and a 100% concentrate mix to crossbred dairy cows at Andasa. The difference may be attributed to variations in the bloodlines of the cows and the types of feed used in the experiment. Similarly, the yield in the present study was higher than the 7.01 liters/day reported by Belay et al. (2012) for crossbred lactating dairy cows in the first stage of lactation in Jimma Town, Ethiopia. However, the milk yield in this study was lower than the 10.96 liters/day reported by Adebabay (2009) for the first stage of lactation in crossbred cows in Bure District, Western Ethiopia. This discrepancy could be due to differences in animal management, cow bloodlines, and feed types used in the studies.

The mean dry matter intake (DMI) of crossbred cows fed different levels of sweet lupin as a protein source showed no significant difference (P = 0.0561) across treatment groups. This may be attributed to the high quality of the feeds provided and the similar levels of crude protein (CP) content in all treatments. In terms of CH4 emissions, the current study recorded 415.24 g/day, which is higher than the emissions from Fogera indigenous lactating cows fed natural pasture (206.5 g/day) and improved forage (Napier grass hay at 231.7 g/day) with concentrate supplementation, as reported by Shigdaf et al. (2020). This difference may be due to variations in breed and feed types during the experimental period.

The highest milk yield efficiency (MYE) was observed in treatment group 4 (0.444 kg/day), while the lowest MYE was recorded in treatment group 3 (0.412 kg/day). The MYE in this study is higher than that reported for Fogera indigenous lactating cows fed natural pasture (0.28 kg/day) and improved forage (Napier grass hay at 0.35 kg/day) with concentrate supplementation (Shigdaf et al., 2020).

The highest fat-protein-corrected milk (FPCM) was observed in treatment group 4 (10.619 kg/day), while the lowest was in treatment group 3 (9.945 kg/day). The FPCM in this study is higher than that reported for Fogera indigenous lactating cows fed natural pasture (2.06 kg/day) and improved forage (Brachiaria grass hay at 3.4 kg/day) with concentrate supplementation (Shigdaf et al., 2020). These differences may be due to variations in breed, feed ingredients, feed intake, and the milk yield performance of the experimental dairy cows.

**Table 2** Milk yield, feed intake and CH4 of experimental cross breed dairy lactating cows feed on different levels of sweet lupin as protein source

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Treatments | **Variables** | | | | | |
| IMY (L) | MY( L) | CH4(g) | DMI(Kg) | MYE (kg/d) | FPCM (kg/d) |
| 1 | 6.12 | 9.328b | 415.216 | 21.896 | 0.433b | 10.012b |
| 2 | 6.04 | 9.187c | 414.592 | 21.849 | 0.416c | 9.383d |
| 3 | 6.11 | 9.149c | 417.823 | 22.092 | 0.412d | 9.945c |
| 4 | 6.08 | 9.57a | 413.195 | 21.744 | 0.444a | 10.619a |
| 5 | 6.06 | 9.33b | 415.376 | 21.908 | 0.419c | 10.142b |
| Mean | 6.082 | 9.313 | 415.24 | 21.898 | 0.425 | 9.902 |
| CV | 6.53 | 8.143 | 6.841 | 6.84 | 11.5 | 8.67 |
| SEM | 0.113 | 0.119 | 0.151 | 0.121 | 0.0057 | 0.069 |
| P-value | 0.071 | <.0001 | 0.0561 | 0.0561 | <.0001 | <.0001 |

*1=, Formulated feed without sweet lupin + basal diet , 2=, Formulated feed with 25% sweet lupin +basal diet , 3= Formulated feed with 50% sweet lupin +basal diet,4= Formulated feed with 75% sweet lupin +basal diet ,5= Formulated feed with 100% sweet lupin +basal diet, CV= coefficient of variation, SEM= standard error of mean, IMY= initial milk yield, MY= milk yield, DMI, dry matter intake, MYE= milk yield efficiency, CH4 = methane emission ,FPCM= fat protein corrected milk.*

* 1. **Milk composition cross dairy cows feed on different levels of sweet lupin**

The overall mean milk composition (%) of crossbred dairy cows fed different levels of sweet lupin as a protein source is presented in Table 3. Except for fat content, other milk composition parameters—such as density, lactose, SNF (solids-not-fat), protein, and ash—showed no significant differences among the feeding treatments. However, fat content exhibited a significant difference (P < 0.001) across the feeding treatment groups. The overall mean fat percentage in this study was 4.94%. This result is higher than the 4.28% fat content reported by Teshome et al. (2015) for milk samples collected from dairy cooperatives, milk collection centers, hotels, small shops, and small-scale milk producers. Conversely, the fat content in this study is lower than the 5.22% reported by Dehninet et al. (2013) for milk samples collected from smallholder producers in Oromia and Amhara regions of Ethiopia. The higher average fat percentage in the current study could be attributed to the inclusion levels of sweet lupin as a protein source in the dairy feeding rations, as suggested by White et al. (2007). According to the Ethiopian Standard Agency (ESA, 2009), the minimum fat percentage for whole milk should not be less than 3.5%. Therefore, the average fat percentage in this study is above the recommended range and is comparable to that of local dairy breeds in Ethiopia.

The average protein content obtained in this study was 2.747%. This result is lower than the protein content reported by several authors: 3.48% (AbdElrahman et al., 2009), 3.46±0.04% (Fikirneh et al., 2012), 3.31% (Alganesh et al., 2007), and 3.42% (Teklemichael, 2012) from milk samples collected from local cows, crossbred cows, local Horro cows, and dairy farms in Dire Dawa, respectively. This difference may be due to various factors such as the breed of the cow, the feeding levels (particularly the inclusion of sweet lupin), and the stage of lactation, which could have influenced the protein content of the milk samples in the current study. According to the Ethiopian Standard Agency (ESA, 2008), the minimum protein content for whole milk should be 3.20%. Therefore, the average protein content in this study is slightly below the recommended standard for the country.

**Table 3** Milk composition of cross breed lactating dairy cows feed on different levels of sweet lupin as protein source

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| Treatments | Variables | | | | | | |
| Fat | Density | Lactose | SNF | Protein | Ash |  |
| 1 | 4.941b | 24.815 | 4.102 | 7.454 | 2.720 | 0.600 |  |
| 2 | 4.474c | 25.261 | 4.148 | 7.545 | 2.755 | 0.610 |  |
| 3 | 5.0417a | 25.495 | 4.154 | 7.536 | 2.753 | 0.744 |  |
| 4 | 5.239a | 25.345 | 4.168 | 7.569 | 2.749 | 0.621 |  |
| 5 | 5.076a | 24.780 | 4.054 | 7.276 | 2.686 | 0.599 |  |
| Mean | 4.94 | 25.386 | 4.146 | 7.511 | 2.747 | 0.637 |  |
| CV | 27.949 | 12.151 | 6.305 | 6.977 | 6.413 | 54.3 |  |
| SEM | 0.140 | 0.302 | 0.023 | 0.046 | 0.015 | 0.029 |  |
| P-value | <.0001 | 0.435 | 0.1221 | 0.072 | 0.1147 | 0.602 |  |

*NNF= solid not fat,*

* 1. **Partial Budget Analysis**

Table 4 below presents the results of the partial budget analysis for the experiment. The total variable costs (costs that fluctuate) were subtracted from the gross benefits to determine the net benefits of nursing crossbred dairy cows fed different levels of sweet lupin as a protein source. The daily value for each cow was calculated, and the average daily value for each treatment was used in the analysis. Due to variations in feed ingredient costs, there were differences in the gross benefits across treatments. According to the partial budget analysis, which used current market prices for milk (benefits) and feed ingredients (costs), the average net benefit from milk sales for dairy cows fed on T1, T2, T3, T4, and T5 were 165.733, 153.34, 152.65, 170.27, and 149.4 birr, respectively. Treatment 4 produced the highest net benefit, followed by treatment 1, while treatment 5 had the lowest net benefit (Table 3). Additionally, treatment 4 had the highest benefit-cost ratio (2.034), while treatment 5 had the lowest (1.843).

**Table 4** Partial budget analysis of cross breed lactating dairy cows feed on different levels of sweet lupin as protein source

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Attributes | **Treatments** | | | | |
| 1 | 2 | 3 | 4 | 5 |
| Benefits |  |  |  |  |  |
| DMY | 9.328 | 9.187 | 9.149 | 9.57 | 9.33 |
| Price of milk (liter) | 35 | 35 | 35 | 35 | 35 |
| **Gross benefit (A)** | **326.48** | **321.545** | **320.215** | **334.95** | **326.55** |
| Variable costs (birr) |  |  |  |  |  |
| ADFI (kg)(B) | 4.95 | 4.825 | 4.48 | 4.02 | 4.25 |
| Price feed (kg) (C) | 19.5 | 19.478 | 19.47 | 19.46 | 19.38 |
| Total Feed cost ( C\*B) | 96.525 | 93.981 | 87.226 | 78.229 | 82.365 |
| Transport cost | 22.22 | 26.67 | 30 | 33.33 | 36.11 |
| Plantation cost | 0 | 5.555 | 8.333 | 11.111 | 16.666 |
| **Total cost (D) (birr)** | **160.747** | **168.202** | **167.559** | **164.673** | **177.142** |
| **Gross Profit (A-D)** | **165.733** | **153.3426** | **152.6564** | **170.277** | **149.408** |
| **Benefit cost ratio (A/B)** | **2.031** | **1.912** | **1.911** | **2.034** | **1.843** |

*DMY= dry matter yield, ADFI= Average daily feed intake*

1. **CONCLUSION AND RECOMMENDATIONS**

The substitution of soybean cake with sweet lupin grain had a significant effect on milk yield and composition. Substituting 75% of soybean cake with sweet lupin grain resulted in the highest milk yield. Furthermore, substituting 50%, 75%, and 100% of soybean cake with sweet lupin grain led to higher fat percentages compared to the 0% and 25% substitution rates. Following the 75% substitution rate, the substitution of 0% and 100% soybean cake with sweet lupin grain resulted in higher milk yields than the 25% and 50% substitution rates. The concentrate mixture without sweet lupin grain and the 75% substitution of soybean cake with sweet lupin grain had the highest benefit-cost ratios. Therefore, substituting 75% of soybean cake with sweet lupin grain in the concentrate mixture is the most biologically and economically optimal option for supplementing lactating crossbred dairy cows fed Napier grass as a basal diet. It is recommended to promote the 75% inclusion level of sweet lupin as a protein source in areas where sweet lupin is produced.

**ACKNOWLEDGEMENTS**

The authors would like to extend their heartfelt gratitude to the farmers involved in the production of sweet lupins, as well as to the Amhara Agricultural Research Institute (ARARI) for their invaluable financial support, which was crucial to the success of this study. We also wish to sincerely thank everyone who contributed to the preparation of the meals, the harvesting of experimental green forage, and the selection of the crossbred dairy cows from the herd for the experiment.

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