

## The Integration of Dry Matter Intake and Residual Feed Intake into a Selection Index for Dairy Cattle

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Submitted: 2025-07-12, Revised: 2025-08-09, Accepted: 2025-08-28

### Abstract

As production costs continue to rise, the global population expands, and sustainability becomes a more pressing concern, enhancing the efficiency of dairy cows has emerged as a vital objective for the dairy industry. Recent evaluations have examined the implications of including feed efficiency (FE) in a selection index through both indirect selection methods, such as dry matter intake (DMI), and direct selection approaches such as residual feed intake (RFI), utilizing deterministic modelling techniques. Such methods aim to create a more sustainable dairy industry by optimizing resource use and improving overall productivity. The study examined two traits using three different methods: (1) setting the genetic gain of the traits to zero, (2) implementing negative selection pressure, and (3) utilizing positive selection pressure. To assess the effects of integrating FE into a selection index, changes in both economic and genetic gains were analysed. The findings revealed that enhancing FE through direct selection based on residual feed intake yielded the most favourable results. This approach provided the highest overall economic benefits and also led to positive outcomes in production and FE selection. Overall, focusing on direct selection for FE proved to be the most effective strategy among the scenarios evaluated. The evaluation of how the weights of relative indexes change, along with the anticipated effectiveness of the suggested selection indexes compared to a baseline index, has been conducted. This assessment also included the response of indices to selection and the effects on various traits due to selection. Notably, the most significant change in the index response to selection occurred when aiming to increase dry matter intake (DMI), leading to an 8.42% enhancement in the response index. Conversely, attempts to decrease DMI resulted in a detrimental effect, causing a 7.68% decline in the response index. This illustrates the complexities involved in selection index management, highlighting those strategies focused on improving DMI can yield positive outcomes, while reductions in DMI may negatively influence overall selection effectiveness. Over time, the cumulative effects of selection can lead to a significant reduction in daily dry matter intake, ranging from 0.16 kg to 2.7 kg, all while sustaining production levels. The findings suggest that while residual feed intake (RFI) has minimal influence on the existing efficiency metrics, it could be a valuable trait to consider breeding programs aimed at enhancing feed efficiency in dairy cattle. This research sheds light on the potential long-term benefits of prioritizing feed efficiency through the lens of RFI, indicating that such selection practices may yield substantial improvements in overall productivity and sustainability within dairy operations.

**Keywords:** Dairy cattle, Dry matter intake, Residual feed intake, Selection index.

## Introduction

Rapid growth the global population is driving urgent conversations about sustainable food production, particularly in the dairy sector. As the demand for sustainably dairy produced increases, dairy farmers face significant financial challenges. Notably, feed costs constitute over half of a dairy producer's total expenses, and these costs are on the rise [1,2]. Improving the ability of cows to efficiently transform their feed into milk presents a viable solution to help mitigate these rising costs [1].

Historically, genetic selection of dairy cattle was focused primarily on increasing milk production, but additional traits, such as fertility and health, have been incorporated into selection programs around the world over the last 25 years [1]. Due to an increased focus on the financial aspects of dairy production, dairy producers prioritize selecting traits related to healthy and high-producing cows that are reproductively fit and have a long productive life in the herd. Thus, there is an opportunity to include an FE trait in selection indices to improve the sustainability of dairy production.

Improving the efficiency of a cow can significantly reduce the cost of feed while sustaining or even boosting the amount of milk produced. An efficient cow utilizes nutrients more effectively, resulting in lower feed consumption for the cow same or higher levels of milk output. This not only benefits the farmer by cutting down expenses, but also contributes to a more sustainable agricultural practice. By focusing on breeding and management practices that enhance cow efficiency, farmers can achieve better production outcomes while minimizing costs [3].

This improvement not only supports the economic viability of dairy farms, but also contributes to more sustainable

agricultural practices, ultimately benefiting the environment and society as a whole. By focusing on enhancing the feed to milk conversion rate, the dairy industry can address both economic pressures and sustainability goals simultaneously. The selection of animals with better feed efficiency has proven effective in various agricultural species, including pigs, cattle, and poultry. Research shows that even among dairy cows producing at similar levels, there is a noticeable difference in their dry matter intake (DMI). This variation indicates that by focusing on breeding animals that utilize feed more effectively, we can reduce the financial losses that arise from poor feed efficiency. Successful selection for feed efficiency (FE) has already been achieved in other livestock species like pigs and chickens. In the case of dairy cattle, researchers have noted that even among animals with similar production levels, there can be significant differences in feed intake. This variation indicates that it is possible to identify and breed animals that utilize feed more effectively. This insight has sparked interest in incorporating feed efficiency into global breeding goals. However, the challenge lies in the absence of practical methods for assessing feed intake across large populations of animals, which has limited the integration of FE into breeding initiatives. Given that many factors regarding the inclusion of FE in breeding programs remain unclear, this study aimed to estimate initial genetic and phenotypic correlations between dry matter intake, residual feed intake, and other traits currently being evaluated. Additionally, it sought to simulate the effects of adding FE to a selection index through both direct and indirect selection methods. The study highlights that DMI and RFI exhibit differing relationships with production, health, and fertility traits. Using technologies

such as milk mid-infrared spectroscopy and 3D cameras to estimate feed intake could enable more large-scale phenotyping, allowing for easier implementation of FE into breeding programs. By exploring these relationships, we seek to enhance breeding strategies that could lead to improved overall performance and well-being in dairy herds. Understanding how these traits interact can ultimately help in making informed decisions that benefit both dairy production and animal health. This research contributes to our understanding of how to improve feed efficiency in dairy cattle breeding.

## Materials and Methods

### *Data and Traits Investigated*

In this study, all herds were systematically monitored by the Iranian Livestock Breeding Center. The research focused on two key production traits: fat yield (FY) and protein yield (PY), alongside one fertility trait: age at first service (AFS). These traits were deliberately selected because they are likely to be significantly influenced by the incorporation of feed efficiency metrics. They formed the essential set of traits evaluated in each scenario. Additionally, two more traits were included: dry matter intake (DMI) and residual feed intake (RFI). DMI refers to the total feed consumed during the first 150 days of lactation, while RFI measures the total feed that remains unused during this same period. This selection aims to provide a comprehensive understanding of how feed efficiency can impact production and reproductive performance in dairy herds. The parameters for production traits evaluated in this study were quantified as the total kilograms of fat and protein yield generated during a 305-day lactation period for heifers in their first

lactation. Fertility indicators were tracked in terms of days for these first lactation cows. Dry matter intake was assessed by measuring the total intake, recorded in kilograms, during the initial 150 days in milk (DIM) for the first-lactation cows. Likewise, the Residual Feed Intake (RFI) was calculated as the cumulative RFI (the sum of daily RFI values), expressed in kilograms over the same 150 DIM period for these cows. This structured approach provides a comprehensive understanding of the productivity and efficiency of first lactation dairy cows, which is crucial for improving breeding and management strategies in dairy farms.

### *Genetic Parameters*

The genetic relationships between all traits were assessed using a series of bivariate animal models, employing WOMBAT version 07-02-2020 for the analysis. The overarching statistical framework utilized can be described as follows:

$$y = Xb + Xb + Za + Wh + e$$

Where,  $y$  is the vector of the observed phenotypes;  $b$  contains fixed effects, which include variables such as the season, year of calving, and the age class at calving. Random additive genetic effects are captured by the vector  $a$ , while the vector  $h$  accounts for random effects related to the herd and year of calving.  $X$ ,  $Z$ , and  $W$  are used to associate these effects fixed, genetic, and herd-year, respectively, with the phenotype data in  $y$ . The model includes  $e$  a vector representing random errors that cannot be attributed to the other components. This comprehensive model enables researchers to dissect and understand the different influences on the phenotypic traits being studied [4].

This approach allows for the exploration of how these traits

interrelate genetically, providing insights into their heritable characteristics and potential interactions. By applying the bivariate models, we gain a clearer understanding of the genetic architecture underlying these traits, which is crucial for breeding and selection strategies in the relevant fields. The use of WOMBAT enhances the accuracy of these estimates, making it a valuable tool for researchers aiming to unravel the complexities of genetic correlations among traits. Cross-validation applied to check the robustness of estimates.

### *Economic Values*

In the dairy cattle industry, fat and protein yields play a crucial role in generating income for producers. As a result, the primary goal of breeding programs has been to enhance these yields while also focusing on improving fertility rates. The economic value refers to the monetary benefit gained from a one-unit change in a particular trait. According to research by [5], the economic value associated with health and fertility traits is estimated at \$2.57 per day. Furthermore, the economic values for production traits were derived using specific equations (Equations 1 and 2). This approach highlights the importance of balancing production efficiency with reproductive success, ensuring that dairy operations remain profitable, while maintaining the health and fertility of the cattle. By optimizing both fat and protein yields and fertility, producers can maximize their revenue potential in a competitive market.

$$\text{Economic value } (v) = \text{Revenue} - \text{Costs} \quad (1)$$

$$\text{Costs} = \text{Cost of 1 kg of DM} * \text{Amount of DM to produce 1 kg of the trait} \quad (2)$$

The price for 1.00 kg of dry matter (DM) was estimated at \$0.29. To produce 1.00 kg of fat, 6.00 kg of DM is required,

while for 1.00 kg of protein, 3.70 kg of DM is needed [6]. The revenue for fat and protein was determined by taking the average monthly price paid to producers in 2017, which was \$10.64 per kg for fat and \$6.82 per kg for protein [7]. Using these figures, the profit calculation for fat yield resulted in an economic value of \$8.90, and for protein yield, it was \$5.75. Since the goal of breeding is to enhance these production traits, they were assigned positive economic values. It was also noted that the economic value for both (DMI) and (RFI) was set at \$0.29, which reflects the cost of 1.00 kg of DM (6). To improve efficiency in breeding, RFI was assigned a negative economic value of \$0.29, indicating that a reduction in this trait is desired. The impact of DMI was analyzed with both positive (increasing intake) and negative (decreasing intake) economic values, highlighting the complexity of feeding efficiency in livestock management.

### *Index Parameters*

The overall genotype ( $Hq$ ) was based on the premise that the breeding goal could be expressed as a linear combination of the genetic quality for various traits, including FY, PY, and age at first service (AFS). Additionally, when relevant, it also incorporates either DMI or RFI. Each of these traits was assigned a weight according to their economic significance, as expressed in Equation 3. This means that the breeding strategy aims to optimize these key characteristics by considering their individual contributions to overall economic value, thereby enhancing the breeding program's effectiveness in achieving desirable outcomes, where  $vq$  is the trait economic value, and  $gq$  is the true genetic value for the  $q$ th economic trait [8]:

$$Hq = v_1g_1 + v_2g_2 + v_3g_3 \dots + v_qg_q \quad (3)$$

This research focused on five specific traits: FY, PY, AFS, DMI, and RFI. Variations of a foundational index were developed by considering different combinations of these traits based on their correlations. The goal was to analyze the effects of incorporating either dry matter intake (DMI) or residual feed intake (RFI) into a selection index. For both the original scenario and its variations, economic selection indices ( $I_k$ ) were formulated according to the structure outlined in Equation 4. This approach allowed for a comprehensive evaluation of how these traits interact and influence the overall selection process, thereby providing insights into optimizing breeding strategies in this context, where  $I_k$  is the  $k$ th linear economic selection index that includes  $j$  traits,  $b_j$  is an index weight for the  $j$ th trait, and  $y_j$  is the phenotype adjusted for known environmental factors for the  $j$ th trait [8]:

$$I_k = \sum_{j=1}^j b_j y_j \quad (4)$$

## Results and Discussion

### Genetic Parameters

The estimates of heritability for DMI were found to be  $0.39 \pm 0.09$ , which aligns with earlier findings [9,10]. Similarly, the heritability estimation for RFI was  $0.27 \pm 0.11$ , consistent with previous research that employed similar calculations for RFI [11,12]. These results suggest that both traits exhibit moderate heritability, making them strong candidates for inclusion in a breeding program. Moreover, the positive genetic correlations observed between production traits and both DMI and RFI corroborate earlier studies [13,14]. This understanding emphasizes the significance of these traits in breeding efforts aimed at improving efficiency in livestock production. The foundational

index lacks specific traits related to FI or FE. In the primary scenario, FY and PY traits are prioritized, making up about 70% of the overall emphasis of the index. Within this allocation, fat content holds a significant weight of around 55%, while protein is given approximately 15% of the focus. This distribution highlights the importance of these traits in the evaluation process, suggesting that enhancing fat and protein levels is critical for optimizing production outcomes. The absence of novel traits in feed management indicates a traditional approach, emphasizing the need to consider these factors when assessing overall efficiency in production systems. The scenario that showed the greatest importance for integrating increased dry matter intake (DMI) as a trait was characterized by a strong positive correlation of 0.71 with production and a slight negative correlation of -0.02 with fertility (+DMI (0.70/-0.10)). In contrast, the least significant scenario for DMI occurred when it was still correlated at 0.70 with production but had a more pronounced negative correlation of -0.32 with fertility (+DMI (0.70/-0.30)). This difference might stem from the stronger beneficial relationship between DMI and production traits, suggesting that enhancing one will lead to improvements in the other. When the objective shifted to reducing feed intake, there was a wide range of relative index weights observed. Similar to when the focus was on increasing DMI, efforts to lower DMI led to significant shifts in how production traits were prioritized within the selection index. For example, the relative importance assigned to fat yield varied from 27.06% in the scenario of DMI (0.60/-0.30) to 54.82% in -DMI (0.70/-0.30). The weighting for protein yield also varied, ranging from 1.32% for -DMI (0.70/-0.30) to 24.56% for -DMI (0.60/-0.30). Although these ranges include some extreme values, most scenarios

indicate a general emphasis around 50% for fat yield and about 16% for protein yield. This illustrates the dynamic nature of selection traits in breeding programs, where the goals can significantly alter the emphasis placed on various production characteristics. The feed efficiency metric employed in this study was RFI. RFI is independent of production levels; however, the importance assigned to production characteristics varies when RFI is factored in, particularly regarding its correlations with health and fertility. As the correlation between RFI and health or fertility increases, the significance of production traits diminishes. For instance, when RFI shows the weakest negative correlation with fertility, the relative importance of fat and protein yields is 56.62% and 16.44%, respectively. Conversely, at the strongest negative correlation with fertility, these values drop to 35.23% for fat yield and 13.73% for protein yield. This indicates that the relationship

between feed efficiency and overall animal health plays a crucial role in shaping production priorities in livestock management. As we consider these dynamics, it becomes essential to balance feed efficiency with reproductive and health outcomes to enhance overall productivity.

RFI is a significant trait in animal breeding, as it encapsulates the dynamics of protein metabolism, digestibility, and fermentation processes. This measure is often regarded as an indicator of an animal's metabolic efficiency [3]. When selecting for RFI, the focus is on breeding animals that exhibit lower RFI values. A negative RFI value suggests that the animal is consuming less feed than what would be anticipated based on its level of production and other relevant factors [15]. This trait is crucial for improving feed efficiency, which ultimately leads to better resource utilization and sustainability in livestock production systems (Table 1).

**Table 1** Economic values, genetics and phenotypic standard deviations, heritability, and genomic accuracies used as input parameters

Trait	Economic Value (\$USA)	Genetic Standard Deviation	Phenotypic Standard Deviation	Heritability	Genomic Accuracy
Fat Yield	9.22	32.41	57.39	0.27	0.82
Protein Yield	6.31	25.38	44.31	0.26	0.80
Age at First Service	-2.85	13.47	49.14	0.07	0.70
Dry Matter Intake	0.39	134.82	220.11	0.39	0.60
Residual Feed Intake	0.31	4.09	9.22	0.27	0.52

By understanding and implementing RFI in breeding programs, producers can enhance the overall productivity and health of their animals while minimizing waste and costs associated with feed. Research by Kennedy *et al.* [16] and Lu *et al.* [17] explored the inclusion of FE in selection indexes through both direct and indirect selection methods. The findings of this study align with their earlier conclusions, indicating that similar outcomes in selecting for FE can be

achieved using either approach. Direct selection for FE focuses on the specific trait, in this case, residual feed intake (RFI), while indirect selection involves integrating various components that contribute to FE into the selection index. This suggests that breeders can successfully select for feed efficiency through either method, providing flexibility in breeding strategies. By understanding how these selection methods work, we can optimize breeding

programs to enhance feed efficiency effectively, which is crucial for improving overall productivity in livestock (Tables 2, 3, and 4).

**Table 2** Relative index weights<sup>1</sup>, expected response in the aggregate genotype (per year), and deficiency of variations of the base index when increasing dry matter intake is included as a breeding goal in economic selection indexes

	Indexes									
	Base	+DMI (0.50/ -0.10)	+DMI (0.50/ -0.20)	+DMI (0.50/ -0.30)	+DMI (0.60/ -0.10)	+DMI (0.60/ -0.20)	+DMI (0.60/ -0.30)	+DMI (0.70/ -0.10)	+DMI (0.70/ -0.20)	+DMI (0.70/ -0.30)
	Relative Index Weights									
Fat Yield	258.81	257.47	259.59	261.52	255.31	259.47	263.35	252.44	258.14	269.57
Protein Yield	71.39	70.41	72.32	77.12	69.03	72.18	79.52	66.33	71.63	87.67
Age at First Service	-14.62	-13.28	-13.41	-16.24	-13.14	-14.29	-17.42	-13.45	-13.92	-19.27
Dry Matter Intake	-	37.53	29.57	17.41	40.51	30.85	14.46	46.42	33.49	-2.53
Expected Response per Year (\$)	72.25	76.31	76.44	76.69	76.44	76.59	76.68	76.72	76.84	76.98
Efficiency of Index (%)	-	6.39	6.47	6.59	6.85	7.06	7.49	7.83	8.05	8.42

**Table 3** Relative index weights<sup>1</sup>, expected response in aggregate genotype (per year), and efficiency of variations of the base index when decreasing dry matter intake is included as a breeding goal in economic selection indexes

	Indexes									
	Base	-DMI (0.50/ -0.10)	-DMI (0.50/ -0.20)	-DMI (0.50/ -0.30)	-DMI (0.60/ -0.10)	-DMI (0.60/ -0.20)	-DMI (0.60/ -0.30)	-DMI (0.70/ -0.10)	-DMI (0.70/ -0.20)	-DMI (0.70/ -0.30)
	Relative Index Weights									
Fat Yield	257.69	259.23	261.34	267.51	259.80	265.34	353.80	261.72	281.59	231.36
Protein Yield	71.65	75.29	82.39	118.82	75.43	86.43	300.11	81.49	111.08	10.49
Age at First Service	-14.39	-16.38	-21.44	-49.05	-16.50	-22.49	-	-16.15	-31.14	30.30
Dry Matter Intake	-	-33.59	-42.81	-60.11	-31.72	-42.13	-68.15	-31.08	-54.31	-86.47
Expected Response per Year (\$)	72.31	68.27	67.95	67.73	67.83	67.90	67.98	66.81	66.74	66.64
Efficiency of Index (%)	-	-5.13	-5.32	-5.42	-6.25	-6.44	-6.69	-7.39	-7.52	-7.68

**Table 4** Relative index weights<sup>1</sup>, expected response in aggregate genotype (per year), and efficiency of variations of inclusion of residual feed intake as a breeding goal in economic selection indexes<sup>2</sup>

	Base	Indexes				
		RFI (-0.10)	RFI (-0.20)	RFI (-0.30)	RFI (-0.40)	RFI (-0.50)
		<b>Relative Index Weights</b>				
Fat Yield	257.14	255.49	247.10	244.18	238.48	223.16
Protein Yield	71.14	71.59	72.09	73.28	76.51	84.13
Age at First Service	-14.14	-14.93	-15.21	-19.28	-32.16	-47.14
Residual Feed Intake	-	-5.18	-10.73	-20.33	-32.47	-80.31
Expected Response per Year (\$)	72.24	72.24	72.32	72.52	72.65	72.90
Efficiency of Index (%)	-	0.02	0.07	0.23	0.34	0.86



**Figure 1** Relative emphasis of traits in variations of potential correlations between residual feed intake with production traits and fertility

*Trait Response to Selection*

In evaluating the response to selection for different traits, the study compared how each trait performed when using indexes that incorporated either DMI or RFI, as opposed to results from a standard index. The analysis aimed to understand the impact of including these specific intake measures on trait outcomes, providing insights into their

effectiveness in selection processes. By examining the variations in trait performance across these indexes, researchers aimed to determine the potential advantages of integrating DMI or RFI into selection criteria, thereby enhancing breeding strategies. In the baseline index, the estimated response to selection for production traits was found to be 5.73 kg (\$51.28) for Fat Yield (FY) and 4.08 kg (\$20.42) for Protein Yield

(PY). Additionally, fertility traits showed an estimated response of -0.22 days (\$0.61) for Age at First Service (AFS). When selection aimed at increasing DMI was included, there was a slight reduction in the response to its selection for FY, while PY experienced a marginal increase. Interestingly, the AFS showed a positive response to selection, indicating an improvement in this area. Overall, these findings suggest that while DMI selection can influence production traits, the effects are minimal. The favourable response for AFS indicates potential benefits in reproductive efficiency, which is crucial for overall herd productivity. The varying responses to selection indicate that efforts to enhance dry matter intake (DMI) might be influenced by the relationships between different traits. The initial belief was that by boosting DMI, animals would receive more nutrients, which could subsequently improve their overall health and fertility. The analysis revealed that all examined correlations were predominantly negative. Nevertheless, the study did not investigate the possibility of a positive correlation or the absence of any correlation between DMI and fertility traits. This aspect remains unexplored and could offer alternative insights. If such a positive correlation exists, it could lead to outcomes contrary to those observed in this study. The findings suggest that increasing feed intake could result in higher operational costs for farms, as a greater quantity of feed would be necessary to support this enhanced intake. Therefore, while the goal of increasing DMI seems beneficial, careful consideration of the associated costs and potential correlations is essential for effective management and breeding strategies. Producers generally view the choice to lower dry matter intake (DMI) as unfavourable, primarily because it can lead to decreased production levels and increase the risk of

fertility issues and health problems [18]. The findings of this study indicate that intentionally reducing DMI adversely affected most of the traits evaluated. The research incorporated residual feed intake (RFI) as a key indicator of feed efficiency. This study included RFI as a measure of feed efficiency, and when included in the selection index, it generally had little impact on the other traits. Unsurprisingly, due to the traits being uncorrelated, there was very little change in the response of the production traits compared to the base. This result should be taken with caution as in this work RFI is assumed to be genetically and phenotypically uncorrelated with production. Some studies have suggested that RFI is in fact genetically correlated with milk yield. Previous studies have indicated a potential genetic correlation between RFI and milk production. For instance, Van Arendonk *et al.* [19] examined the relationship between RFI and milk yield across two lactation periods. Their analysis revealed a slight genetic correlation of 0.02 between RFI and milk yield during the first 105 days in milk (DIM), but this correlation shifted to -0.12 by 305 DIM. This suggests that the relationship between feed efficiency and milk production may vary significantly over time, highlighting the complexity of animal breeding decisions.

The most significant change in comparison to the base scenario was noted in the RFI scenario, which showed a reduction (-0.50). In this context, the FY trait exhibited a notable increase in response to selection at 0.39%, while the PY trait demonstrated an even larger response of 1.59% compared to the baseline. On the other hand, the AFS trait showed a slightly negative reaction to selection. While the influence of RFI on the traits currently in the selection index appears to be limited, it indicates that incorporating RFI could be advantageous. This suggests that RFI has the potential

to enhance the selection index by adding value. Considering RFI as part of the selection process could offer benefits, even though its impact on existing traits is not substantial right now. This limited impact may be influenced by the low weight assigned to RFI within the index. Therefore, it is essential to conduct further analysis on how varying the index weight for RFI could affect its overall contribution before deciding to integrate it into a selection index. This investigation will provide a clearer understanding of RFI's potential role and effectiveness improving selection outcomes.

The largest change compared to the base scenario was observed in scenario RFI (-0.50). In this scenario, FY had a greater response to selection of 0.39% and PY had a greater response to selection of 1.59% compared to the base. A slightly unfavourable response to selection was observed in AFS. On average AFS had a response of 0.85% less than the base (Figure 1). With this minor impact on the existing traits within the current index, it may appear that RFI is the optimal trait to include in a selection index. However, this small impact may be due to the relatively small index weight for RFI. Therefore, further work should be done on the impact of a varying index weights for RFI prior to its inclusion in a selection index.

## Conclusion

This research provides an initial assessment of the benefits of integrating feed intake and feed efficiency traits into a selection index for dairy cattle. The findings indicate that there is a greater potential for improvement in the selection index when the goal is to enhance dry matter intake compared to the traditional index. While this might

appear advantageous, aiming to increase intake can result in higher operational costs for farms, which is not ideal. Conversely, attempts to decrease dry matter intake (DMI) adversely affected the rate of genetic improvement when compared to the regular index. Generally, decreasing DMI did not yield favourable results, suggesting that such a strategy should be approached with caution. Including RFI in the selection index had a minimal effect, leading to only a modest improvement in genetic progress compared to the basic index. The addition of RFI did not significantly alter the overall outcomes. Resulting in just a slight enhancement in genetic advancement, it seems that residual feed intake does not significantly influence the overall response of the index or individual traits when considered alongside DMI. Given these observations, RFI could be a worthwhile trait to focus on for enhancing feed efficiency in dairy cattle. However, its relatively low weight in the index might explain the limited effect on selection outcomes. Therefore, further investigations are needed to explore the implications of assigning a greater weight to RFI in the selection index.

## Acknowledgments

This research was supported by the research grant of the University of Mohaghegh Ardabili extract from the postdoctoral project with contract number 380, 2024/09/22.

## Competing Interests

The authors declared that there were no competing interests.

## Authors' Contributions

Reza Seyedsharifi conceived and designed the study; Reza Seyedsharifi and Fatemeh Ala Noshahr supervised the

student thesis; Reza Seyedsharifi, Fatemeh Ala Noshahr, and Nemat Hedayat-Evrigh conducted the study; Reza Seyedsharifi and Jamal Seifdavati supervised the study; Reza Seyedsharifi, Jamal Seifdavati, and Nemat Hedayat-Evrigh prepared the manuscript. Abdolfattah Zeidan Mohammad Salem contributed data or analysis tools. All authors approved the manuscript.

## Funding

This research was funded by Mohaghegh Ardabili, Iran).

## Availability of Data and Materials

All data and materials are available.

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#### **How to cite this article:**

R. Seyedsharifi, F. Ala Noshahr, J. Seifdavati, N. Hedayat-Evrigh, A. Z. M. Salem. The Integration of Dry Matter Intake and Residual Feed Intake into a Selection Index for Dairy Cattle. *International Journal of Advanced Biological and Biomedical Research*, 2026, 14(1), 1-12.

DOI: <https://doi.org/10.48309/ijabbr.2026.2065608.1633>

Link: [https://www.ijabbr.com/article\\_728692.html](https://www.ijabbr.com/article_728692.html)

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