Pol. J. Environ. Stud. Vol. 32, No. 5 (2023), 4177-4189
DOI: *10.15244/pjoes/166344* ONLINE PUBLICATION DATE: 2023-07-24

Original Research

Applying Polysaccharides Regulatory Complex as a Frugal Innovation in Dairy Farms

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Received: 12 December 2022
Accepted: 20 May 2023

Abstract

The use of polysaccharide regulatory complex ensures an efficient energy exchange of the animal, resulting in higher milk yields, lower feed costs (and lower methane emissions). These benefits have a direct impact on a farm's profitability. The study aims to form a methodological approach to assess the effectiveness of frugal innovation (implementing polysaccharide regulatory complex) in dairy cattle breeding. Applying economical innovations on a dairy farm based on polysaccharide regulatory complex use resulted in reduced feeding costs, increased milk yields, improved milk quality, and improved functioning of animals' immune system. The study provides opportunities to increase the consumption of basic foodstuffs of animal origin based on the effective implementation and management of frugal innovations that involve qualitative changes that can ensure economic competitiveness in national and foreign markets and state food security.

Keywords: dairy farming, economic performance, feeding ration, field experiment, frugal innovation

Introduction

Frugal innovation is often associated with sustainability (environmental and social), as it is characterized by a reduction of resource consumption (raw materials, production and financial means, energy, fuel, water, waste) [1]. It is more affordable and accessible than traditional innovations [2]. Minimizing resource consumption makes products affordable, which in turn leads to environmentally sustainable consumption, an inclusive approach to innovation and frugality concepts [3]. Frugal innovations arise at the grassroots level in developing countries and use new business models to promote sustainable development. Frugal innovation transforms underserved grassroots customers into new consumer groups [4]. In addition, there are synergies in the concepts of frugal innovation and sustainability in supply chains [5]. Frugal innovation develops as a paradigm that challenges established sectors of innovation and can bring diverse stakeholders together to achieve long-term development goals [6]. However, summarizing the above information, frugal innovation in the context of the present research is the implementation of innovative solutions for local problems in sustainable, affordable, and effective way.

The global growing demand for milk and milk products stimulates the production of dairy products in the developed and developing countries. World per capita consumption of dairy products tends to raise by 1.0% p.a. during the decade [7]. The invention

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and application of innovations are significant aspects in boosting the efficiency of dairy cattle breeding development. Innovationsl in dairy cattle breeding should be aimed primarily at increase in productivity and expansion of dairy cattle, use of the best world and domestic genetic resources, radical modernization of fodder production, animal housing technology, milking technology using the leading technical developments and prevention or introduction of effective and relatively inexpensive disease treatment schemes. Thus, the dairy cattle breeding industry can reach a higher level only with: intensification of dairy cattle breeding, rational use of the industry resource potential [8], improvement of the cattle's genetic potential, application of intensive milk production technologies, aimed at increasing competitive production, including by improving the quality and quantity of milk [9].

Energy feed additives are widespread around the world. By incorporating specialized preparations rich in energy into the ration, cows conserve their body reserves to a greater extent. The use of energy supplements in animal feeding helps to increase milk production and improve milk quality. Feeding energy feed preparations ensures good health and fertile insemination of cows at optimal times [10].

The influence of energy feed additives on milk production and health indicators has been studied in sufficient detail. However, there is insufficient information in the literature on the effect of feed additives on animals' nutrition. At the same time, many scientific data confirm the existence of a reliable relationship between milk productivity and nutritional behavior of animals [11, 12].

The most identified behaviors when considering food activity are speed and duration of feed ingestion, number of water intakes and length of chewing period. It is known that speed of eating depends on taste, quality characteristics, size of a single portion of feed, habituation of animals to a particular type of feed, appetite, and other factors [13].

Thus, the nutritional behavior of cows largely characterizes the biological needs of the body and predicts the future productivity of the animals during lactation. It is well known that the greatest amount of milk from animals is obtained during the first months of lactation, so improving feeding systems and methods during this stressful period for the cow is of great scientific and practical interest. The usefulness of using an energy feed addition (polysaccharides liquid) in cows' diets during the first months of lactation to boost nutritional activity and milk output is crucial in this regard [14]. At the same time, many problems remain understudied and require more in-depth study. These are the issues of dairy cattle breeding development on an innovative basis. In this regard, the study aims to form a methodological approach to assess frugal innovation management effectiveness based on the results of implementing polysaccharide regulatory complex (PRC) in dairy cattle breeding. Polysaccharides are a complex of easily digestible carbohydrates, various dietary fibers consisting of polyunsaturated fatty acids, oligofructosans, arabinogalactans and phospholipids.

Testing frugal innovation (PRC) in this study aims to demonstrate its ability to fill dairy cows with healthy energy, strength, and ability to overcome stresses and health problems, while increasing productivity (milk yield). The motivation for conducting the study comes not only from improving dairy animal health, but also from improving dairy productivity in a sustainable way and providing an opportunity to manage the performance of frugal innovation for the benefit of society. This will fill the existing scientific gap and allow one to better understand the changes taking place in entrepreneurial and innovative livestock ecosystems and determine the extent to which these innovation forms contribute to progress in solving global problems, such as social inclusion and negative environmental impacts on farm development. As a result, the following scientific hypotheses were developed:

H1: the effectiveness of managing frugal innovation (PRC) on a livestock farm depends more on the economic factors of its implementation;

H2: the effectiveness of frugal innovation management on a livestock farm depends to a large extent on the socio-environmental factors of PRC implementation;

H3: the effectiveness of managing frugal innovation (PRC) on a livestock farm depends to a large extent on farm functionality factors.

Methods and Materials

Integration of Frugal Innovation Management Performance Indicators

To determine how PRC affects milk production increase, this study focuses on the fact that frugal innovation introduction on a livestock farm implies an increase in its efficiency in three areas: socio-environmental, economic, and farm efficiency. These areas impact the proposed comprehensive indicator of frugal innovation management of a dairy farm in the context of three indicators – socio-environmental efficiency of innovation (SEI), economic efficiency of innovation (EEI), and farm efficiency due to innovation (FEI). Therefore, to confirm this assumption, induction in the opposite direction is used. Wherein, x_1, x_2, x_3 denote the presented parameters of frugal innovation management effectiveness on a livestock farm, that is, SEI, EEI, and FEI. Since farm operation efficiency has a special role, in accordance with this, the optimizing model in relation to the control action will be expressed as follows:

$$\max_{e_3} \alpha E_2 x_3 - \beta E_2 (t_3 - t_0) - e_1 - e_2 - e_3$$

and the following condition must be fulfilled:

$$P_2(x_3 = 1) = \chi_3(1 - exp^{-\lambda_3 e_3})x_2 ,$$
$$t_3 = t_2 + a_3 ,$$
$$e_3 \geq 0.$$

It should be noted that $t_3 = t_2 + \alpha_3$ is fixed in the proposed formulation and does not depend on the controlling influence e_3. At the same time:

$$E_2 x_3 = 1 \cdot P_2(x_3 = 1) = \chi_3(1 - exp^{-\lambda_3 e_3})x_2.$$

This contributes to the following:

$$\max_{e_3 \geq 0} a\chi_3(1 - exp^{-\lambda_3 e_3})x_2 - e_3,$$

Based on this, the solution is easily found from first-order conditions:

$$e_3 = \frac{1}{\lambda_3} lna\chi_3\lambda_3 \text{ , if } a\chi_3\lambda_3 > 1 \text{ and } x_2 = 1,$$
$$e_3 = 0, \text{ if } a\chi_3\lambda_3 x_2 \leq 1.$$

Thus, the optimal model $F_3(.,.,.)$ of controlling influences e_3 in the proposed model's third direction is given as:

$$e_3 = F_3(e_2, x_2, t_2) = \frac{1}{\lambda_3} lna\chi_3\lambda_3, \text{ if } a\chi_3\lambda_3 > 1 \text{ and } x_2 = 1,$$
$$e_3 = F_3(e_2, x_2, t_2) = 0, \text{ if } a\chi_3\lambda_3 x_2 \leq 1.$$

The optimal model of frugal innovation management has no dependence on the amount of controlling influence on the other direction e_2, nor on the timing of achieving the goals t_2, but depends on the actual efficiency in other areas. Thus, this points to the need for effort (controlling influence on farm efficiency – e_3) to ensure further farm performance ($x_2 = 1$), than in the case of a decrease in its level (*c*).

Similarly to the direction of improving farm efficiency, the optimal controlling impact of innovations on a livestock farm's economic efficiency is formulated:

$$\max_{e_2} aE_1 x_3 - \beta E_1(t_2 + a_3 - t_0) - e_1 - e_2 - E_1 e_3.$$

In this case, it is necessary to satisfy the corresponding conditions; therefore, it should be noted that:

$$E_1 x_3 = E_1(E_2(x_3)) = E_1(\chi_3(1 - exp^{-\lambda_3 e_3})x_2).$$

Considering the level of optimal impact of frugal innovations on a livestock farm e_3, defined earlier, one can state:

$$E_1 x_3 = \chi_3(1 - \frac{1}{a\chi_3\lambda_3})P_1(x_2 = 1), \text{ if } a\chi_3\lambda_3 > 1$$
$$\text{and } E_1 x_3 = 0, \text{ if } a\chi_3\lambda_3 \leq 1.$$
$$E_1 e_3 = \frac{1}{\lambda_3} ln(a\chi_3\lambda_3)\, P_1(x_2 = 1)$$
$$= \frac{1}{\lambda_3} ln(a\chi_3\lambda_3)\chi_2(1 - exp^{-\lambda_2 e_2})x_1,$$
$$\text{if } a\chi_3\lambda_3 > 1, \text{ and } E_1 e_3 = 0, \text{ if } a\chi_3\lambda_3 \leq 1.$$

Thus, if $\alpha\chi_3\lambda_3>1$, the search for the optimal impact in the context of increasing economic efficiency e_2 can be reduced to:

$$\max_{e_2}(a\chi_3 - \frac{1}{\lambda_3} - \frac{1}{\lambda_3} ln(a\chi_3\lambda_3)\chi_2(1 - exp^{-\lambda_2 e_2})x_1 - \beta E_1(t_2 - t_1) - e_2$$

Considering a variable t_2, one can state:

$$\max_{e_2 \geq 0}(a\chi_3 - \frac{1}{\lambda_3} - \frac{1}{\lambda_3} ln(a\chi_3\lambda_3)\chi_2(1 - exp^{-\lambda_2 e_2})x_1 - \frac{\beta}{\mu_3}(\gamma_2 e_2 - \delta_2 e_1 + a_2) - e_2,$$

which is equivalent to

$$\max_{e_2 \geq 0} - (a\chi_3 - \frac{1}{\lambda_3} - \frac{1}{\lambda_3} ln(a\chi_3\lambda_3)\chi_2 exp^{-\lambda_2 e_2} x_1 - (\frac{\beta}{\mu_3}\gamma_2 + 1)e_2.$$

Similarly, in case $\alpha\chi_3\lambda_3\leq1$, the optimal control action in the context of increasing economic efficiency e_2 can be determined from the following:

$$\max_{e_2 \geq 0} - \frac{\beta}{\mu_3}(\gamma_2 e_2 - \delta_2 e_1 + a_2) - e_2,$$

which provides an opportunity to assert that $x_2 = 0$. Thus, if $\alpha\chi_3\lambda_3>1$, one can argue about the optimal model of frugal innovations' impact on a livestock farm in the context of increasing economic efficiency:

$$e_2 = F_2(e_1, x_1, t_1) = \frac{1}{\lambda_3} ln \frac{\mu_3\lambda_2\chi_2(a\chi_3 - (1 + ln(a\chi_3\lambda_3))/\lambda_3)}{\beta\gamma_2 + \mu_3},$$
$$\text{if } \frac{\mu_3\lambda_2\chi_2(a\chi_3 - (1 + ln(a\chi_3\lambda_3))/\lambda_3)}{\beta\gamma_2 + \mu_3} > 1 \text{ and } x_1 = 1;$$
$$e_2 = F_2(e_1, x_1, t_1) = 0, \text{ if } \frac{\mu_3\lambda_2\chi_2(a\chi_3 - (1 + ln(a\chi_3\lambda_3))/\lambda_3)}{\beta\gamma_2 + \mu_3} x_1 \leq 1.$$

At the same time, $e_2 = F_2(e_1, x_1, t_1) = 0$, if $\alpha\chi_3\lambda_3\leq1$.

An important component of frugal innovation management on a livestock farm is the inclusion of socio-environmental efficiency in its model, considering the control actions defined above in the other two directions. In this case, the target function for search e_1 may look like this:

$$\max_{e_1} aE_0 x_3 - \beta E_0(t_3 - t_0) - e_1 - E_0 e_2 - E_0 e_3$$

Therefore:
$E_0x_3 = E_0(E_1(E_2(x_3))) = E_0(E_1(\chi_3(1-exp^{-\lambda_3 e_3})x_2))$.

Thus,
$$E_0x_3 = \chi_3(1-\frac{1}{a\chi_3\lambda_3})E_0(P_1(x_2=1)) = \chi_3(1-\frac{1}{a\chi_3\lambda_3})E_0((1-exp^{-\lambda_2 e_2})x_1)),$$

if $a\chi_3\lambda_3 > 1$ and $E_0e_3 = 0$, if $a\chi_3\lambda_3 \leq 1$.

Consequently,
$$E_0x_3 = \chi_3(1-\frac{1}{a\chi_3\lambda_3})(1-\frac{\beta\gamma_2+\mu_3}{\mu_3\lambda_2\chi_2(a\chi_3-(1+ln(a\chi_3\lambda_3))/\lambda_3})$$
$$P_0(x_1=1) = \chi_1\chi_3(1-\frac{1}{a\chi_3\lambda_3})$$
$$(1-\frac{\beta\gamma_2+\mu_3}{\mu_3\lambda_2\chi_2(a\chi_3-(1+ln(a\chi_3\lambda_3))/\lambda_3})exp^{-\lambda_1 e_1}x_0,$$

If $\frac{\mu_3\lambda_2\chi_2(a\chi_3-(1+ln(a\chi_3\lambda_3))/\lambda_3)}{\beta\gamma_2+\mu_3} > 1$, and

$E_0x_3 = 0$, if $\frac{\mu_3\lambda_2\chi_2(a\chi_3-(1+ln(a\chi_3\lambda_3))/\lambda_3)}{\beta\gamma_2+\mu_3}x_1 \leq 1$ or $a\chi_3\lambda_3 \leq 1$.

As a result:
$$E_0(t_3-t_0) = E_0(t_2+a_3-t_0) = E_0(t_2-t_1)+E_0(t_1-t_0)+a_3,$$
$E_0(t_1-t_0) = E_0((\gamma_1e_1+a_2)\varepsilon_1) = \frac{\gamma_1e_1+a_2}{\mu_1}$ and $E_0(t_2-t_1)$
$$= E_0(\gamma_2e_2-\delta_2e_1+a_2)\varepsilon_2 = E_0\left(E_1((\gamma_2e_2-\delta_2e_1+a_2)\varepsilon_2)\right) = \frac{1}{\mu_2}E_0(\gamma_2e_2-\delta_2e_1+a_2).$$

It can be expressed otherwise if $\frac{\mu_3\lambda_2\chi_2(a\chi_3-(1+ln(a\chi_3\lambda_3))/\lambda_3)}{\beta\gamma_2+\mu_3}x_1 > 1$,
$$E_0(t_2-t_1) = \frac{a_2-\delta_2e_1}{\mu_2}+\frac{\gamma_2}{\mu_2\lambda_2}\ln\frac{\mu_3\lambda_2\chi_2(a\chi_3-(1+ln(a\chi_3\lambda_3))/\lambda_3)}{\beta\gamma_2+\mu_3}$$
$$P_0(x_1=1) = \frac{a_2-\delta_2e_1}{\mu_2}+\frac{\gamma_2\chi_1}{\mu_2\lambda_2}\ln\frac{\mu_3\lambda_2\chi_2(a\chi_3-(1+ln(a\chi_3\lambda_3))/\lambda_3)}{\beta\gamma_2+\mu_3} exp^{-\lambda_1 e_1}x_0.$$

At the same time, if $\frac{\mu_3\lambda_2\chi_2(a\chi_3-(1+ln(a\chi_3\lambda_3))/\lambda_3)}{\beta\gamma_2+\mu_3}x_1 \leq 1$ or $a\chi_3\lambda_3 \leq 1$,
$$E_0(t_2-t_1) = \frac{a_2-\delta_2e_1}{\mu_2}.$$

Moreover, in the case $\frac{\mu_3\lambda_2\chi_2(a\chi_3-(1+ln(a\chi_3\lambda_3))/\lambda_3)}{\beta\gamma_2+\mu_3}x_1 > 1$,
$$E_0e_2 = \frac{1}{\lambda_2}\ln\frac{\mu_3\lambda_2\chi_2(a\chi_3-(1+ln(a\chi_3\lambda_3))/\lambda_3)}{\beta\gamma_2+\mu_3}P_0(x_1=1)$$
$$= \frac{\chi_1}{\lambda_2}\ln\frac{\mu_3\lambda_2\chi_2(a\chi_3-(1+ln(a\chi_3\lambda_3))/\lambda_3)}{\beta\gamma_2+\mu_3}exp^{-\lambda_1 e_1}x_0.$$

On the contrary, in the case $\frac{\mu_3\lambda_2\chi_2(a\chi_3-(1+ln(a\chi_3\lambda_3))/\lambda_3)}{\beta\gamma_2+\mu_3}x_1 \leq 1$, or $a\chi_3\lambda_3 \leq 1$, $E_0e_2 = 0$

Thus,
$$E_0e_3 = \frac{1}{\lambda_3}\ln(a\chi_3\lambda_3)\,P_0(x_2=1) = \frac{\chi_2}{\lambda_3}\ln(a\chi_3\lambda_3)$$
$$E_0\left((1-exp^{-\lambda_2 e_2})x_1\right) = \frac{\chi_2}{\lambda_3}\ln(a\chi_3\lambda_3)\,1-1$$
$$-\frac{\beta\gamma_2+\mu_3}{\frac{\mu_3\lambda_2\chi_2(a\chi_3-(1+ln(a\chi_3\lambda_3))}{\lambda_3}})P_0(x_2=1) = \frac{\chi_1\chi_2}{\lambda_2}\ln(a\chi_3\lambda_3)$$
$$(1-\frac{\beta\gamma_2+\mu_3}{\frac{\mu_3\lambda_2\chi_2(a\chi_3-(1+ln(a\chi_3\lambda_3))}{\lambda_3}})exp^{-\lambda_1 e_1}x_0).$$

If $\frac{\mu_3\lambda_2\chi_2(a\chi_3-(1+ln(a\chi_3\lambda_3))/\lambda_3)}{\beta\gamma_2+\mu_3}x_1 > 1$.

If $\frac{\mu_3\lambda_2\chi_2(a\chi_3-(1+ln(a\chi_3\lambda_3))/\lambda_3)}{\beta\gamma_2+\mu_3}x_1 \leq 1$ or $a\chi_3\lambda_3 \leq 1$, $E_0e_3 = 0$

Integrating the obtained expressions into a single complex in the form of an objective function to determine the optimal model of the control action e_1, one obtains the following to determine e_1:
$$\max_{e_2\geq 0} -Aexp^{-\lambda_1 e_1}-Be_1,$$

where $B = 1-\beta(\frac{\delta_2}{\mu_2}-\frac{\gamma_1}{\mu_1})$, ,

while in the case $\frac{\mu_3\lambda_2\chi_2(a\chi_3-(1+ln(a\chi_3\lambda_3))/\lambda_3)}{\beta\gamma_2+\mu_3} > 1$,
$$A = -a\chi_1\chi_3(1-\frac{1}{a\chi_3\lambda_3})(1-\frac{\beta\gamma_2+\mu_3}{\frac{\mu_3\lambda_2\chi_2(a\chi_3-(1+ln(a\chi_3\lambda_3))}{\lambda_3}})x_0$$
$$-\beta(\frac{\gamma_2\chi_1}{\lambda_2\mu_2}\ln\frac{\mu_3\lambda_2\chi_2(a\chi_3-(1+ln(a\chi_3\lambda_3))/\lambda_3)}{\beta\gamma_2+\mu_3}x_0$$
$$+\frac{\chi_1}{\lambda_2}\ln\frac{\mu_3\lambda_2\chi_2(a\chi_3-(1+ln(a\chi_3\lambda_3))/\lambda_3)}{\beta\gamma_2+\mu_3}x_0+\frac{\chi_1\chi_2}{\lambda_2}$$
$$\ln(a\chi_3\lambda_3)\,(1-\frac{\beta\gamma_2+\mu_3}{\frac{\mu_3\lambda_2\chi_2(a\chi_3-(1+ln(a\chi_3\lambda_3))}{\lambda_3}})x_0),$$

and in case $\frac{\mu_3\lambda_2\chi_2(a\chi_3-(1+ln(a\chi_3\lambda_3))/\lambda_3)}{\beta\gamma_2+\mu_3}x_1 \leq 1$ or $a\chi_3\lambda_3 \leq 1$, $A = 0$.

Thus, it can be argued that the optimal level of control frugal impact in the direction of socio-environmental efficiency, in the case of $A\lambda_1/B > 1$ and $B > 0$, is equal to $e_1 = \frac{1}{\lambda_3}\ln\frac{A\lambda_1}{B}$; in case $A\lambda_1 \leq B$ and $B \geq 0$, is equal to $e_1 = 0$. Therefore, it can be argued that there is no comprehensive model of frugal innovation management on a livestock farm if $B < 0$ or at the same time $B = 0$ and $A > 0$. One can assume that in practice, such a situation is not possible.

Vector Model for Assessing the Level of Frugal Innovation Management on a Dairy Farm

The authors suggest interpreting the level of frugal innovation management on a dairy farm (based on calculating integral indicators: SEI, EEI, FEI) as a vector length [15]. The authors also suggest implementing regression analysis to identify key factors for improving innovation management efficiency and predictive modeling of the resulting indicators for a dairy farm. Fig. 1 shows the scheme for constructing the vector of frugal innovation management efficiency on a dairy farm based on the calculated integral indicators. As a result of the coordinate axes' mutual perpendicularity, one gets the vector length $\overrightarrow{IMV} = (\text{SEI}; \text{EEI}; \text{FEI})$, which can be defined as a rectangular parallelepiped diagonal length formed from vectors $\overrightarrow{\text{SEI}_\iota}; \overrightarrow{\text{EEI}_J}; \overrightarrow{\text{FEI}_k}$ and expressed as follows:

$$\overrightarrow{|\text{FIMPI}|} = \sqrt{\text{SEI}^2 + \text{EEI}^2 + \text{FEI}^2}$$

where $\overrightarrow{\text{FIMPI}}$ – the length of the vector "Frugal Innovation Management Performance Index";
SEI – Socio-Environmental Index;
EEI – Economic Efficiency Index;
FEI – Farm Efficiency Index.

Values of SEI, EEI, FEI on the specified model are determined by calculating the arithmetic mean of the indicators that are part of SEI, EEI, FEI. For example, the value of SEI is found by summing the normalized data of such indicators as the indicator of CH4 emissions, the indicator of harmful substances in the production, the level of energy production from alternative sources (in this case, biogas).

EEI level is found by summing normalized data of such indicators as unit production costs indicator, veterinary costs indicator, production volume indicator. FEI includes such indicators as lactation level indicator, somatic cell level indicator, and animal health indicator.

Experimental Part of Applying Frugal Innovation (PRC) on a Dairy Livestock Farm

The testing was conducted on Campus (Evrofarma). Evrofarma is a dairy factory that has a subsidiary farm "Campus", it also owns biogas production "Biomesti". The company carries out a full milk production cycle, including methane utilization. Campus (Evrofarma) is the biggest in Greece and has 2700 cows, including 1380 high-yielding dairy cows. The farm is modern; it uses quality standards and innovation. The farm has comfortable conditions, bedding per cow is 20 m^2, 5 times more than EU average. The study used the data collection software 'GEA Westfalia', which is integrated in the farm's IT system. It was applied to collect statistical information about milk production volume.

For the monitoring and control of health parameters, blood tests were conducted, provided by the independent laboratory, and control of somatic cells count. Animal health and disease data were provided by farm veterinarians and company records.

Furthermore, the data (health parameters of the dairy cows; volume of milk production) were collected before the start of PRC implementation. The input data of the farm were investigated; interviews with farm owners and veterinarians about the product effects were conducted. The farm owners and veterinarians defined the priorities for the farm: first – boost milk production, second – improve animal health (mastitis, laminitis decrease), and third – reduction of feeding costs. Check

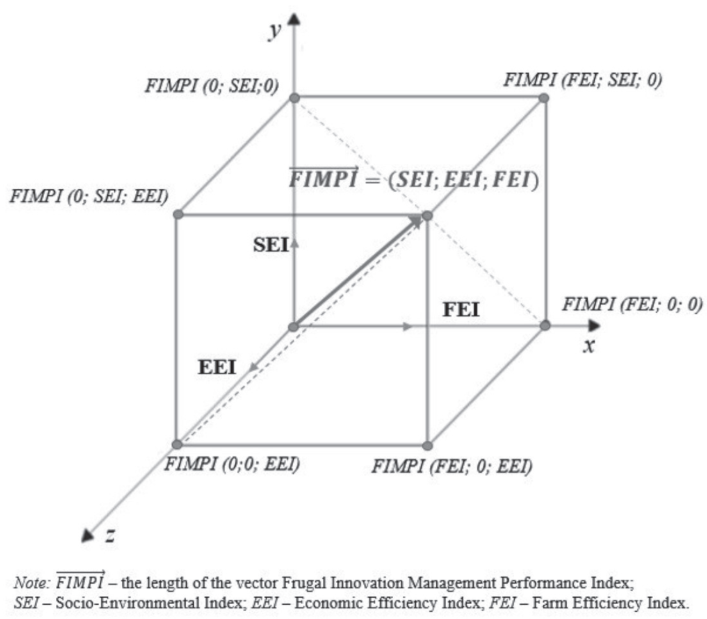


Fig. 1. Scheme for constructing the vector of frugal innovation management efficiency on a dairy farm. Source: developed by the authors.

sheet was used as a basic quality tool to collect data, and check list – as protocol for the accurate processing of testing. All the data were analyzed, and the results are reflected.

Testing lasted for 3 months from 4 May 2020 to 4 Aug 2020.

There were around 200 high-yielding cows: 50-70 cows in dry (20 days to calving, 'close-up') period and 140-160 cows (GP6 group) in fresh period; the cows have been fed with PRC for 2 months and 28 days. The dry group was fed 20 days before the calving (Fig. 2).

Cows were fed with PRC with total mixed ration (TMR), from the day of calving till 21st or 28th day. Every Thursday the animals from the fresh group were transferred to the other groups: to the group 1 – cows of 2nd lactation period; to the group 3 – cows of 3rd and 4th lactation periods; to the group 5 – 5th and later lactation periods; to the group 8 – jersey cows only, from all lactation periods; and to group 13 – cows of 1st lactation period (first calving). The group 10 (late in lactation, cows from 200 to 305 days (average 250 days) after calving) was identified as control group and was not fed. The group 2 was identified as control group and was not fed. Then, lactations curves were compared.

From the time of introducing PRC, the milk production in the groups 1, 3, 5, 8, and 13 was monitored. The two control groups (GP10 and GP2) were not fed with PRC.

Results and Discussion

Milk Production on the Farm Using PRC

After using PRC, the number of days till lactation peak significantly decreased: for 1st lactation, from 144 to 98 days; for 2nd lactation, from 81 to 56 days; and for 3rd+ lactations, from 81 to 54 days. All the lactation periods reached the minimum that had never been on the farm before (Fig. 3).

The days for peak of lactation significantly improved: for 1st lactation, from 144 to 98 days; for 2nd lactation, from 81 to 56 days; and for 3rd+ lactations, from 81 to 54 days.

Milk production was improved (based on 'GEA Westfalia') by 3.1% (1.08 kg). By groups: GP6 group had +5.8 kg (17.8%); group 1 +3.7 kg (9.6%); group 3 +3.5 kg (9%); group 5 +1.5 kg (4.2%); group 8 (jersey) +1.5 kg (6.4%); group 13 +1.5 kg (4.2%). Control groups: group 2 decreased milk production by 4.1% (1.5 kg); group 10 had -1.5 kg (4.2%).

Further, the results are presented by a group. Fresh group (GP6) was fed with PRC from 4 May 2020 to 4 Aug 2020. All the animals were fed. The top production of this group was achieved; it increased up to 5.8 kg (from 26.7 kg to 32.5 kg); the results are reflected in Fig. 4. Protein remains high with high milk productivity: 3.35, while the farm average is 3.10.

Despite the decreased milk yield in control groups and heat stress, this led to an increased economic profit for the farm, which was 481 euro per day (43,290 euro per 3 months of testing).

Effect of Applied PRC on Performance Parameters in a Dairy Livestock Farm

Feeding costs were decreased, including the cost for PRC purchase: from 5.49 to 5.47 euro -0.36% feeding per day per cow; TMR was regulated, and the fat (380 gr), wheat (1 kg), and soybean meal (1.72 kg) were excluded. Straw (300 gr), ryegrass (700 gr), clover hey (1300 gr), and corn silage (2500 gr) were included. The expenses for PRC purchase were covered;

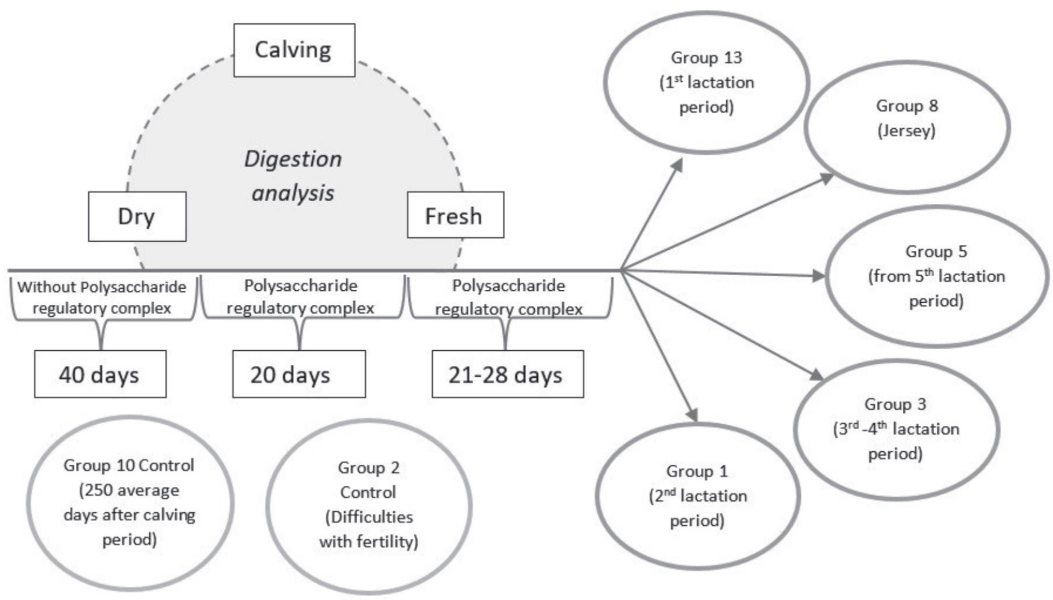


Fig. 2. Testing the study groups on the use of frugal innovation (PRC). Source: generated by the authors.

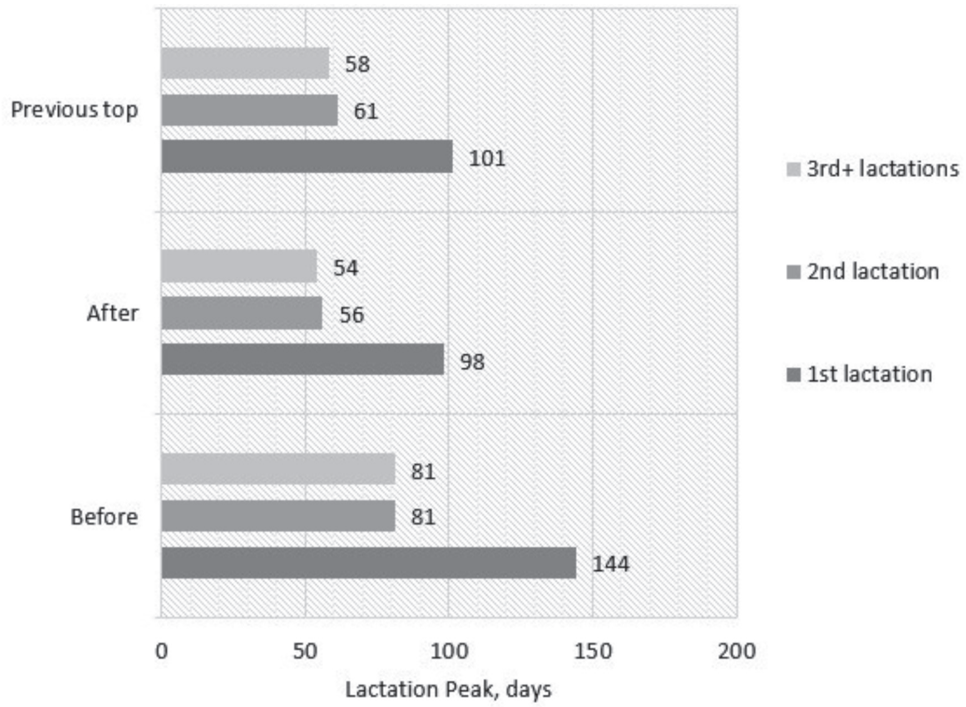


Fig. 3. Lactation peak as a result of PRC use. Source: Formed by the authors.

moreover, the farm had benefit +2 cents per cow per day from feeding savings alone. Healthy ration: NDF (neutral detergent fiber) increased from 35% to 39%; starch in the ration decreased from 24% to 23%; forage/concentrate ratio improved from 42/58 to 53/47.

Total milk production on the farm (13% of the farm cattle were fed with PRC from 4 May 2020 to 4 Aug 2020) increased from 33.86 to 34.94 kg. Due to PRC use, the milk yield increased. This caused an increase of total milk yield on the farm (during the testing it increased by 1.08 kg per head per day) (Fig. 5).

Health parameters. Somatic cell count (SCC) indicates milk quality and food safety, where less than 100,000 cells/mL stands for uninfected cows, and higher than 250,000 – infected cows with significant pathogen levels [16,17]. SCC results for GP6 group were: 570,000 – before testing; 248,000 – on 28th day of testing; and 159,000 – after testing. This result indicates an improvement in animals' immune system functioning, which in the long term could reduce the use of veterinary drugs for the mastitis treatment. Cows of 1st lactation period (GP6) did not have new cases of mastitis.

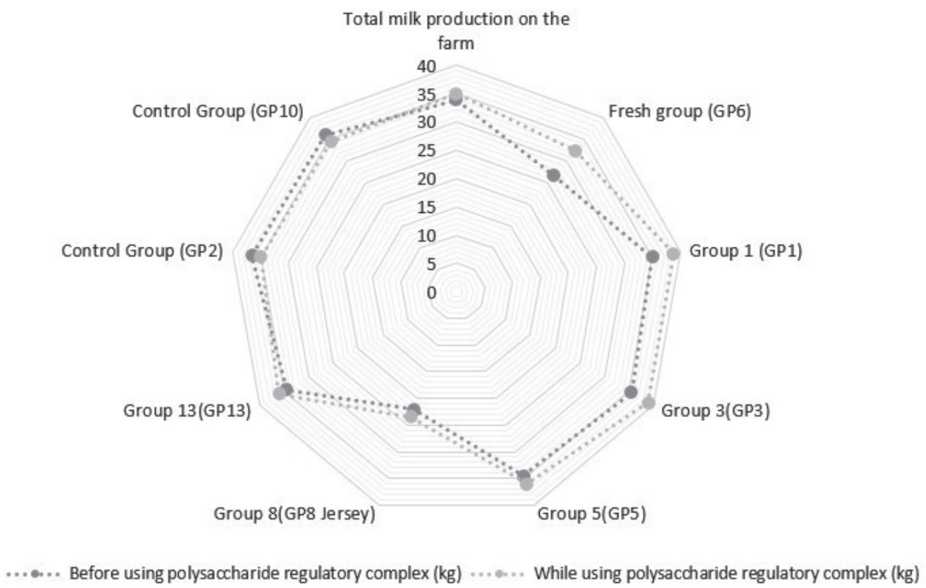


Fig. 4. Milk production on the farm in the studied groups as a result of applying PRC. Source: Formed by the authors.

Heat stress. Despite the heat stress (temperature increase), which negatively influences milk productivity, the animals which received PRC improved their milk yield results [18].

The study presented the robust results that reflect the positive impact on three main indicators: milk production, feeding cost, and animal health. The most common problems faced by the farmers when it comes to high yielding dairy cows are high feeding costs, insufficient milk production, and numerous animal health issues [19, 20]. During the testing, high yielding dairy cows were fed with PRC; TMR was regulated; unnecessary and expensive ingredients were excluded from TMR; the health parameters, digestion of the animals, milk production, and quality of milk were continuously monitored [21].

This study is not free from limitations. Due to the farm's features, it was not possible to feed permanently selected animals, only groups. Some groups were chosen to demonstrate product effects. The testing period was limited to 3 months, and the product might demonstrate all its capabilities in a longer period. The product also affects the decrease of enteric methane emissions; however, this farm does not monitor this indicator [22]. When testing in June, the farm had malfunctions with feed equipment; despite this, milk production was raising in the group fed with PRC, along with somatic cells decrease [23]. The bias (sharp lactation curve, from the 'GEA Westfalia' program) was considered, and the real data were used. Mastitis cases were measured only in 1st lactation period.

Vector Assessment of Frugal Innovation Management on a Dairy Cattle Farm Based on Applying PRC

Based on assessing nine proposed indicators of frugal innovation management effectiveness on a dairy farm, integral indicators were determined for the studied groups for three months, which were normalized and shown in Table 1. Thus, SEI, EEI, and FEI each have three integral indicators. This allowed the authors to consider many determinants of PRC's effectiveness, including lactation peak and animal health parameters.

Using the obtained key indicators, a complex FIMPI was determined, which can be expressed as the length of the frugal innovation management vector of a dairy farm for a certain period (Fig. 6); the results were further compared.

During the three-month study period, the vector of frugal dairy farm innovation management increased by 47%. This is confirmed by the FIMPI indicator. At the same time, its focus was on FEI. The increase in efficiency is quite noticeable compared to the results for the control groups. The results obtained prove that the proposed PRC has a positive effect on the farm's functioning.

The advantage of this study is the proposed methodological approach to assessing the effectiveness of frugal innovation management on a dairy farm based on key indicators: socio-environmental, economic, and farm efficiency [24]. The proposed system of indicators can be supplemented with other indicators that reflect

Table 1. Key frugal innovation management integral indicators of a dairy farm.

Group (month)	SEI (Socio-environmental Efficiency Index)	EEI (Economic Efficiency Index)	FEI (Farm Efficiency Index)	FIMPI (Frugal Innovation Management Performance Index)
gp1 (1m)	0.118	0.262	0.273	0.396
gp3 (1m)	0.397	0.319	0.373	0.631
gp5 (1m)	0.255	0.416	0.490	0.692
gp8 (1m)	0.052	0.256	0.241	0.356
gp13 (1m)	0.331	0.380	0.481	0.697
gp1 (2m)	0.517	0.207	0.354	0.660
gp3 (2m)	0.432	0.127	0.237	0.509
gp5 (2m)	0.343	0.206	0.747	0.848
gp8 (2m)	0.384	0.065	0.749	0.844
gp13 (2m)	0.408	0.419	0.977	1.138
gp1 (3m)	0.204	0.275	0.567	0.662
gp3 (3m)	0.126	0.045	0.446	0.466
gp5 (3m)	0.132	0.376	0.463	0.611
gp8 (3m)	0.127	0.203	0.950	0.980
gp13 (3m)	0.599	1.000	0.696	1.358

Source: Formed by the authors.

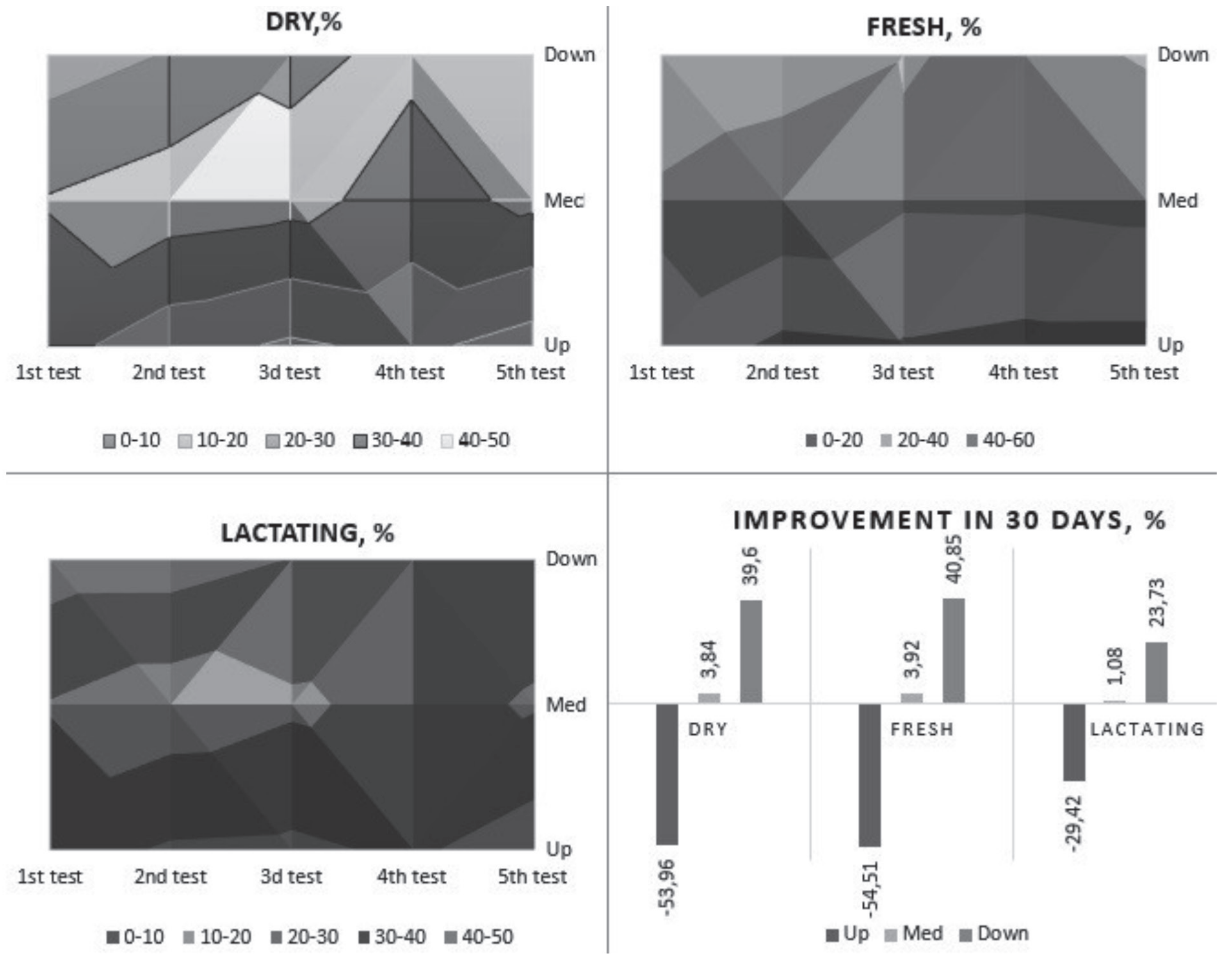
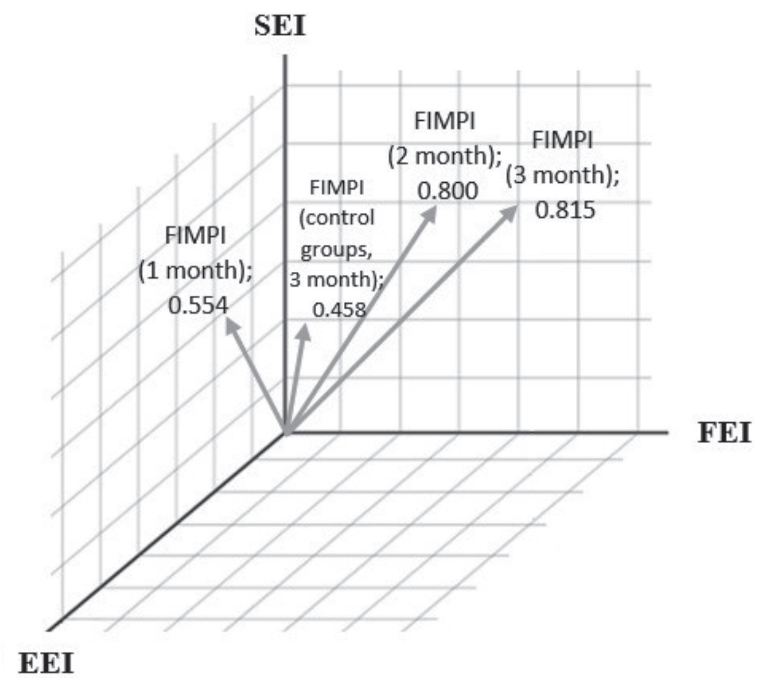


Fig. 5. Total milk production on the farm as a result of applying PRC. Source: Formed by the authors.



Note: $\overrightarrow{FIMPI}$ – the length of the vector Frugal Innovation Management Performance Index; *SEI* – Socio-Environmental Index; *EEI* – Economic Efficiency Index; *FEI* – Farm Efficiency Index.

Fig. 6. Vector of frugal dairy farm innovation management as a result of applying PRC. Source: Formed by the authors.

the specifics of a farm's activities, for example, marketing or sustainable development [25, 26]. Thus, the obtained estimate in the form of an integral FIMPI indicator is complex. This allows for a wider range of indicators and factors to be considered compared to an approach focused on obtaining economic benefits [27, 28]. The proposed approach does not negate the need for economic efficiency. However, at the same time, it is supplemented with social and environmental parameters that are important today and are aimed at satisfying farmer ambitions [29-31]. Of scientific interest is the interpretation of the proposed indicator in the form of a vector length [32], which also helps to identify the strengths and weaknesses of frugal innovation management on a dairy farm.

Modeling the Effective Management of Frugal Innovation (PRC) for a Dairy Livestock Farm

To build a frugal innovation management model for a dairy farm, it is necessary to determine the level of interconnection between the investigated components, presented as indicators. Based on the collected data and calculated indicators for three dimensions of frugal innovation management efficiency, a correlation matrix of the factors under study was formed, which is shown in Fig. 7.

Based on the obtained matrix, it can be argued that there is no strong correlation between the studied variables. This allows them to be used as components of a frugal innovation management model for a dairy farm, since they are not interdependent and contribute to the development of an adequate equation model. At the same time, it should be noted that there is a strong relationship between the factors under study and the main indicator – Frugal Innovation Management Performance Index. The most pronounced correlation is between FIMPI and farm efficiency (FEI), which is 0.824. A sufficient level of interconnection is characteristic of the other two indicators as well. At the same time, they are very close in value: economic efficiency – 0.636 and socio-environmental – 0.594.

This study focused on a comprehensive assessment of the effectiveness of frugal dairy farm innovation management. Taking this into account, it is necessary to conduct a variance analysis of the influence of all three constituent elements on FIMPI based on multiple regression (Table 2). Due to the lack of correlation between the studied variables, the formation of a reliable model is assumed.

Thus, the model of effective frugal innovation management on a dairy farm can be expressed by the following equation:

$$FIMPI = 0.51 \cdot SEI + 0.45 \cdot EEI + 0.79 \cdot FEI$$

The presented results prove a stable relationship for all three studied indicators. At the same time, the parameters of farm efficiency are characterized by the relationship with the FIMPI both in a stand-alone and in an integrated version. This confirms the p-value, which for the variables is less than 0.05. The applicability of the considered regression model is due to such reference points: $R^2 = 0.98$, Ftabl<F (3.59<307.79), and, according

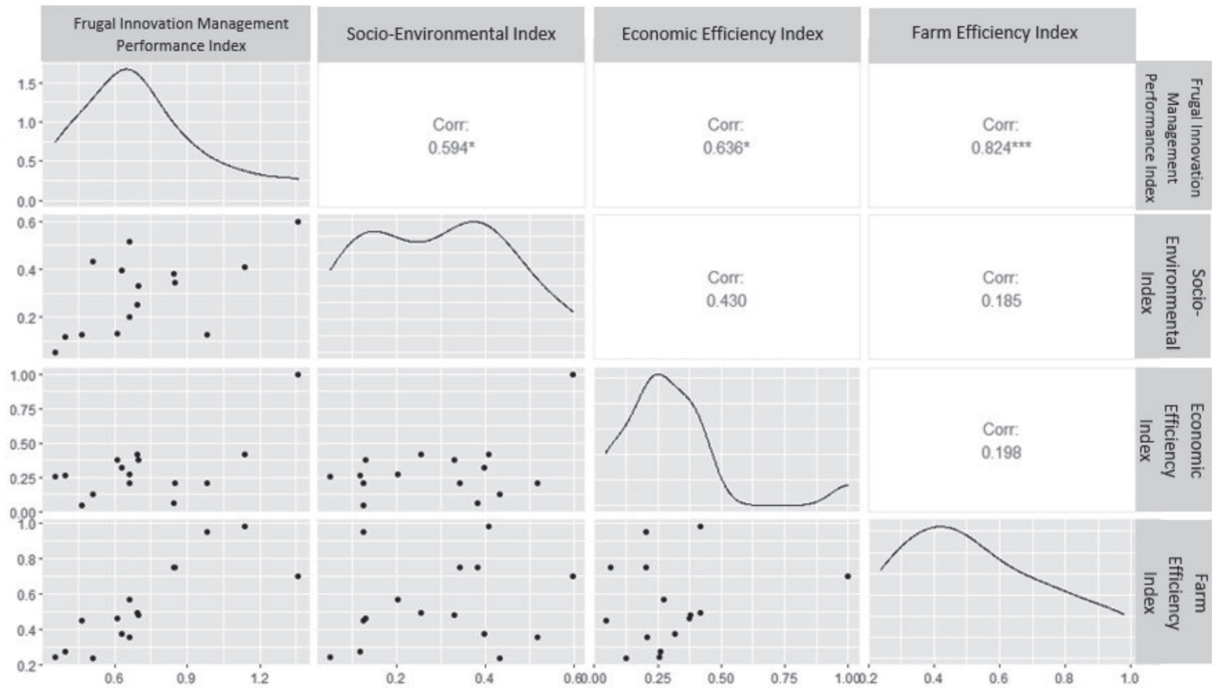


Fig. 7. Correlation matrix of FIMPI constituent indicators for the studied groups according to observations for three months. Source: Formed by the authors.

Table 2. Indicators of modeling the level of frugal innovation management efficiency on a dairy farm in the context of three constituent elements.

	df	SS	MS	F	F Sign	
Regression	3	1.0429	0.3476	307.7875	0.0000	
Residue	11	0.0124	0.0011			
Total	14	1.0553				
Factor	Coefficients	Standard Error	t-stat	p-value	Lower 95%	Higher 95%
Y-intersection	0.0096	0.0255	0.3769	0.7134	-0.0465	0.0657
SEI	0.5135	0.0609	8.4301	0.0000	0.3794	0.6476
EEI	0.4464	0.0446	10.0200	0.0000	0.3483	0.5445
FEI	0.7952	0.0384	20.6920	0.0000	0.7106	0.8798

Source: Formed by the authors.

to Student's criterion, tobs = 30.39 exceeds tcrit = 2.13. It should be noted that hypotheses H1 and H2 have no grounds for acceptance. On the contrary, hypothesis H3 is accepted, since the most significant factor in the effectiveness of frugal innovation management on a livestock farm is farm functionality. At the same time, to increase the effectiveness of the frugal innovation management, a dairy farm should focus not only on economic benefits but also on increasing sustainable development in the context of socio-environmental parameters of a farm as a producer of natural products from healthy animals.

PRC's Effect on the Cows' Rumen

The special activated rumen and intestinal microflora maximizes the efficiency of digesting roughage and concentrated feed rations. This protects against acidosis and ketosis and preserves productivity during forced temporary use of lower quality feed (with low metabolic energy).

It has a powerful stimulating effect on a cow's rumen, eliminates acidosis due to the activation of specific groups of microorganisms, increases propionate production, fights insulin resistance, and changes dietary edibility (increases forage/roughage and decreases concentrated part).

The shift in the equilibrium between lactate-synthesizers and lactate-utilizers in favor of the latter, as has been experimentally shown, stimulates increased production of propionate, the main energy molecule of the cow, and prevents lactic acidosis occurrence. An increase in the concentration of microbial propionate in the blood and liver allows the cow to safely reduce accumulated fat levels and utilize surplus acetyl coenzyme A accumulating as a result of fat assimilation. This phenomenon stays behind of the anti-ketosis action. A combination of the above effects allows for soft removal of insulin-resistance in the cow. It also has an immunizing effect - the stimulation of energy production in sufficient quantities due to the harmonious functioning of rumen and liver leads to the removal of the immuno-depressant effect of energy deficit (decreasing mastitis, endometritis, etc.). It has a hepatoprotective effect, so that liver functions properly and the propionate formed in the rumen is effectively transformed into blood glucose. Endocrine system stimulant (increasing prolactin) also acts as hormones stimulator due to the phytogenics; there is a moderate stimulation of prolactin production that leads to increased milk yields along with increased blood glucose.

In the gastrointestinal tract PRC makes up the complex act as growth factors for lactic acid bacteria, streptococci, and bifidobacteria. It is known that when introducing growth factors, the number of beneficial bacteria increases 5-10 times. Active colonization of the intestine with lactic acid bacteria leads to inhibition of growth and displacement of pathogenic producing toxins microorganisms, and putrefactive bacteria. A decrease in the concentration of endogenous toxins and ammonia has a positive effect on the well-being of the animal.

The construction of an active structure of the intestinal mucosa, which can absorb 20% more calcium, is caused by colonization by lactic acid bacteria and the particular action of polysaccharides. Polysaccharides with a length of 15-22 carbohydrate fragments break down into the short-chain fatty acids acetate, propionate, butyric, and valerianic acids when exposed to the bacteria of the large intestine. These acids are well-known for their importance in mammalian and avian metabolism. In ruminants, for example, they are the primary source of glucose in the blood during calorie deprivation.

By utilizing hydrogen (generated by fermentation of feed ingredients) into the propionate path, pH in the rumen is kept high enough to allow bacteria to stay active and grow enough for optimal fermentation of feed ingredients. Normally hydrogen is utilized by methane generating archaea, resulting in enteric methane production. PRC redirects the process of hydrogen utilization to propionic SCFA production. Thus, the enteric methane production per unit of milk decreases in reverse proportion to the increased production of propionate. Propionate is a precursor of blood glucose in gluconeogenesis taking place in the liver. This increase in propionate synthesis at low starch concentrate levels leads to higher milk yields, decreased feed costs, and lower methane emission. These are the benefits that directly impact profitability at the farm.

Conclusion

The results of using PRC as a frugal innovation show an increase in livestock farm efficiency. Comparative characterization showed that the lactation curves of the groups that received feed with PRC increased. In the control groups, the lactation curves decreased. In general, applying the frugal innovation (PRC) on a dairy farm led to a reduction in feeding costs, and milk yields increased by 1.08 kg per head per day. Despite lower milk yields in the control groups and heat stress, this resulted in increased economic profits for the farm. At the same time, the diet became healthier, animals' immune system improved, which in the long run will reduce the use of veterinary drugs for mastitis treatment. There were no new mastitis cases in cows of the first lactation period.

Acknowledgments

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Conflict of Interest

The authors declare no conflict of interest.

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