Zagazig Veterinary Journal, ©Faculty of Veterinary Medicine,
Zagazig University, 44511, Egypt.
Volume 52, Number 1, p25-34 March 2024
DOI: 10.21608/zvjz.2024.264161.1231

RESEARCH ARTICLE

Statistical Metrics to Assess the Impact of Reproductive Efficiency Measures on Dairy Farm Productivity.

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Abstract

The purpose of this study was to evaluate the significance of the effect of some reproductive traits (Days open, calving interval, and dry period) on the productivity of some dairy farms by applying some statistical measures. From the period extended from the summer of 2017 to the winter of 2020, a field survey was conducted on random samples of dairy-producing sectors in several locations in Egypt, Including Menofia, Al-Qalyubia, Beheira, and Giza governorates. There were three sectors: agricultural, private, and government. This study included dairy breeds: crossbred (Balady X Friesian), exotic Holstein-Friesian, Brown Swiss and native Balady. A longitudinal and cross-sectional field survey yielded the results. During data collection, the researcher maintained close touch with dairy owners and management. The dairy farms were visited at least twice, once in the summer and again in the winter. The researcher collected the data by two methods: Based on accurate records obtained from dairy farms in the research locations, and the researcher developed a structured questionnaire procedure based on the study's goals and administered it to dairy owners and managers during the interview. The acquired data was analyzed using correlation and regression techniques. The results indicated that the longest days open value was observed in Holstein Friesian cattle as it reached 200.96 days, followed by Brown Swiss as it reached 190.44 days and the higher dry period length was observed in Balady breed cattle as it reached (131.07 days), followed by crossbred cattle (Balady X Friesian) as it reached (115.70 days). Our results concerned with the calving interval period length showed that the longest calving interval period level was observed for Holstein Friesian (474.11 days), followed by Brown Swiss cattle as it reached 460.30 days. The regression equations results indicated that the changes in the calving interval by about 10% increased milk production by 5.50%. An augmentation of approximately 10% in the duration of days open led to a corresponding rise in milk yield of 2.1%. Additionally, extending the length of the dry period by around 10% resulted in an increased milk production of 3.1%. Our results concluded that the calving interval, days open and dry period are the main reproductive efficiency parameters that affecting positively milk production yield and efficiency and the statistical measures that include regression analysis, correlation analysis with the help of t-test, analysis of variance test is the main statistical a parameter that can be used for determining the factors affecting milk yields and production efficiency.

Keywords: Statistics, Reproductive Efficiency, Production, Dairy Farms.

Introduction

Biostatistics is the discipline of statistics dealing with the planning and analysis of biomedical research data. It is a set of ideas and methods for producing and applying quantitative evidence to scientific problems [1]. Biostatistics is the study of biological processes using statistical theory and methodology. Biostatisticians encounter challenges not only in the realms of health and medicine, but also in agriculture, biology, genetics, biochemistry, biophysics, demography, and epidemiology, among other disciplines. Any probabilistic or statistical advancement within these domains may be categorized as biostatistics [2].

Inferential statistical approaches are divided into two categories: parametric and nonparametric. All methods for comparing means are considered parametric, while methods for comparing non-means, such as medians, mean ranks, and proportions, are classified as nonparametric. Parametric tests assume that the variable is continuous and distributed somewhat evenly. Nonparametric techniques are utilized when the data is continuous but non-normally distributed, or when it is not continuous. Fortunately, the most common parametric techniques have nonparametric alternatives, which can be beneficial when the assumptions of a parametric test are not met, allowing for the use of nonparametric alternatives as a fallback [3]. The application of biological statistics and biostatistics contributes significantly to thriving and advancing research issues, experimental design, measurement refining, data processing, and the interpretation of output results. Biostatistics is constantly evolving to improve data analysis with properly designed methods to accommodate the research question, resulting in more powerful results [4].

In various fields, such as biology, farming, economics, trade, medicine, industry, planning, education, etc., the role of statistics has grown and evolved from a single-state science to an important one. The big progress and the increased dependence on computer science and technology have revealed this role. As individuals appreciate contemporary society's successes, safety and health concerns in industries, farms, communities, and so on are a major worry. As a result, safety and health research have become increasingly crucial. To properly assess the safety and health data generated, an increasing number of statistical analysis methods are being employed in a variety of study domains, and numerous statistical models have been established to characterise research aims and findings. In 1999, the American Statistical Association (ASA) (n.d.) said that statistical analysis is a crucial instrument in examining practically all elements of society and that current research breakthroughs in areas of safety, health, and medicine have significantly benefited from this technique [5]. Milk Production Efficiency: Productive variables such as the genetic potential of dairy cows, feed quality, and management practices directly impact milk production per cow. High-quality genetics and optimal nutrition can enhance milk yield, increasing dairy farmers' profitability [6]. Reproductive Performance: Reproductive variables, including fertility rates, calving intervals, and conception rates, influence the frequency and timing of calving. Efficient reproductive performance ensures a steady supply of replacement heifers and maintains the milking herd size, contributing to consistent milk production levels [7]. Shorter calving intervals lead to more frequent lactations and increased lifetime milk production per cow. Efficient reproductive management practices aim to minimize calving intervals while ensuring cow health and fertility [8]. Multilevel models allow us to assess contextual effects by including a higher-level predictor that represents the effect of the context or group to which individuals belong. We can use this analysis to separately estimate the relationship between milk yield and reproductive performance at cow and herd levels. The relationship at the herd level (the herd contextual effect) may differ in magnitude and even direction from the relationship at the cow level [9]. This study attempted to evaluate the effect of some reproductive traits (days open, calving interval, and dry period) on the productivity of some dairy farms by applying some statistical measures.

Materials and Methods

Source of data

This investigation was conducted via a comprehensive field survey across diverse regions of Egypt, including Menofia, Al-Qalyubia, Beheira, and Giza governorates. The study spanned from the summer of 2017 to the winter of 2020 and involved random sampling within the dairy production sector. The targeted sectors encompassed farmers, private enterprises, and government entities. The study specifically examined distinct dairy breeds: Balady (local breed), Brown Swiss, Holstein-Friesian (exotic breed), and Cross-bred (Balady X Friesian).

Methods of data collection

Data for this study was gathered through a cross-sectional and longitudinal field survey, with the researcher maintaining close communication with dairy holders and managers throughout the data collection process. Each dairy farm was visited on a minimum of two occasions, once during the summer and once during the winter. As outlined by Omar [10], data collection utilized two methods: a. Retrieval from precise records maintained in the dairy farms within the designated study areas. b. Implementation of a structured questionnaire method devised by the researcher, aligning with the study's objectives. These questionnaires were administered to dairy holders and managers during interviews.

Types of collected data

The acquired data, in its raw form, comprised milk production records and associated reproductive records, according to Ajili *et al.* [11]. This dataset underwent categorization into distinct parameters to assess the economic, productive, and reproductive efficiencies of dairy cattle. The data was organized as follows:

Productive and Management data

- Herd size: Number of animals in the herd.
- Types of reared breeds: Breeds of cattle raised (Balady, Cross, Holstein-Friesian)
- Parity "lactation number": Lactation order (1st, 2nd, 3rd, 4th, 5th, 6th, 7th, etc.)
- Production sectors: Farming sectors (Farmer, Private, and Government)
- Calving season: Period of calving (summer and winter)
- Daily milk yield/kg: Milk yield per day per kilogram
- Annual milk yield/ton: Total milk yield per year per ton
- Lactation period/day: Duration of lactation per day
- Types of feedstuffs consumed: Varieties of feedstuffs ingested (berseem, silage, concentrates, bran, derris, dry matter intake, and annual feed consumption)

Reproductive data

- Calving interval
- Days open
- Dry period
- Date of calving
- Date of insemination
- Dry-off date.
- Types of insemination (artificial or natural) [11].

Economic (Financial) data

- Costs of dairy production
- Fixed costs: This encompasses the depreciation of assets such as buildings, animals, equipment, and parlors. Depreciation rates were determined by dividing the value of buildings by 25 years, equipment by 5 years, and parlours by 15 years. Animal depreciation was

calculated using the fixed-line method [10, 12].

- Variable costs: consist of expenses in Egyptian Pounds (LE) for drugs, vaccines, disinfectants, veterinary supervision, and feed costs, encompassing berseem (Fadden/dairy animal), berseem hay (ton/dairy animal), silage (ton/dairy animal), concentrates (ton/dairy animal), and other feed costs. Additionally, it includes labor costs, electricity expenses, and miscellaneous costs [13]. Returns from dairy production include earnings in Egyptian Pounds (LE) derived from milk sales, the value or sales of calves added to the herd, animal sales, and manure sales.
- The return from milk sales is calculated by multiplying the total annual milk production by its respective price, as per the prevailing prices during the study period [13].

Statistical analysis (different statistical methods according to the type of data)

The data underwent collection, organization, summarization, and subsequent statistical analysis utilizing the SPSS/PC+ software, version 25 (SPSS, 2018). The researcher inputted the collected data into the SPSS/PC+ program. Productive and reproductive parameters impacting dairy products, along with associated costs and returns, were computed, and subjected to statistical analysis for each animal based on fixed factors such as breed, calving interval, dry period, and days open. The correlation matrix was computed through multiple correlation analysis and categorized into different levels: high positive correlation (r = 0.33–1.00), medium positive correlation (r = 0.17–0.33), low positive correlation (r = 0.00–0.16), high negative correlation (r = -0.33–-1.00), medium negative correlation (r = -0.17–-0.33), and low negative correlation (r = 0.00–-0.16). In terms of regression analysis, A stepwise regression approach was employed to identify the most suitable regression model that explains the relationship between milk production (a dependent variable) and the variables influencing milk production (independent variables).

Results and Discussions

Kim and Jeong [14] reported that reproductive performance holds significant importance in the contemporary global dairy industry, serving as a crucial factor in evaluating the overall profitability of a dairy farm. In dairy herds, inadequate reproductive performance stands out as a prevalent reason for culling [15]. This issue impacts the daily milk production per cow, and the cow's longevity within the herd, and consequently, it indirectly influences costs associated with herd replacement, breeding, and expenditures on veterinary treatment and medications by Yusuf [16]. Temesgen et al [7] noted that to comprehensively understand the factors influencing milk yields, particularly the days open, dry period, and calving interval, statistical analysis methods such as regression and correlation analysis, aided by the F-test and t-test, prove to be effective tools.

Days open among different dairy breeds.

The calving-to-conception interval, commonly referred to as days open, serves as a crucial parameter in evaluating reproductive performance and making economically informed decisions in dairy herds [13]. The economic advantage lies in the reduction of days open, leading to increased milk yield relative to labor and feed costs [17]. This reduction also contributes to an augmentation in the number of calves [18] and the overall productive days of the dairy cow. Moreover, minimizing days open has the potential to lower breeding costs and culling rates, making it a financially advantageous practice for dairy operations [19].

Table (1) illustrates that the days open revealed variations among different cattle breeds. Holstein Friesian cattle exhibited the longest open level at 200.96 days, followed by Brown Swiss at 190.44 days. Crossbred cattle (Balady X Friesian) had an intermediate level with a value of 104.07 days, while Balady cattle demonstrated the shortest days open level at 78.54 days. These outcomes align with the findings of Sanad *et al.* [20], who reported a significant difference ($P < 0.01$) in days open among dairy breeds. In their study, the days open values ranged from 90.88 days/cow to 107.14 days/cow for crossbreds in the winter season and Frisian breeds in the summer season. The highest values were observed for crossbred and Frisian breeds, ranging from 91.04 days/cow to 107.06 days/cow. Consistent with our results, it is emphasized that days open should not exceed 113 days to achieve an optimal calving interval of 13 months, as reported by Sanad *et al.* [20]. Additionally, Cilek and Bakir [21] noted that cows calving in the summer exhibited a greater number of days open compared to those calving in the winter months (January to March), where the fewest days open were observed.

Table 1. The average number of days open among different dairy breeds.

Breed	No of records	Mean ± Std. Error
Balady	217	$78.54^{d} \pm 6.44$
Crossbred (Balady X Holstein Friesian)	666	$104.07^{c} \pm 3.68$
Holstein Friesian	554	$200.96^{a} \pm 4.03$
Brown Swiss	1551	$190.44^{b} \pm 2.41$

*This means within the same column different letters are significantly different at ($P < 0.01$)

Dry period among different dairy breeds

The transition period, a crucial time for the well-being, productivity, and profitability of dairy cows, is commonly defined as the period spanning from three weeks before to three weeks after calving. During this critical time, the health, productivity, and profitability of dairy cows are greatly impacted. During the three weeks preceding calving, the nutrient requirements of the fetus reach their peak, while dry matter intake (DMI) experiences a slight decline of 10% to 30%. Following this, in the first two to three months of early lactation, the energy demands for milk production escalate rapidly, surpassing energy intake levels [22, 23].

Table (2) illustrates that the length of the dry period demonstrates that the longest duration was observed in Balady breed cattle, clocking in at an impressive 131.07 days. This was followed by crossbred cattle (Balady X Friesian) with a duration of 115.70 days. Holstein Friesian cattle had a dry period length of 100 days, while Brown Swiss cattle exhibited the shortest duration of 62.18 days.

These results may attributed to that the most of the records of balady breeds were obtained from farmers who did not synchronize the parturition or adjust the dry period compared to the private farms that bred the Holstein cows and their crossbreds with an adjusted and reduced dry period [20]. In this context, Omar [10] reported that, the private farms bred cattle of lower dry period than those bred by the farmers or those in rural areas.

Table 2. Averages of dry days among different dairy breeds.

Breed	No of records	Mean ± Std. Error
Balady	217	$131.07^{a} \pm 2.47$
Crossbred (Balady X Holstein Friesian)	666	$115.70^{b} \pm 1.41$
Holstein Friesian	555	$100.00^{c} \pm 1.54$
Brown Swiss	1551	$62.18^{d} \pm 0.92$

*This means within the same column different letters are significantly different at ($P < 0.01$).

Calving interval among different dairy breeds

It is widely acknowledged that achieving a calving interval of approximately one year is a pivotal factor that determines both the fertility and profitability of dairy herds. To attain this optimal calving interval, a postpartum cow must swiftly resume ovarian activity, exhibit clear signs of heat, successfully mate, and conceive within a maximum of 85 days following calving, all while consistently producing substantial quantities of milk. These results attributed to the increasing calving interval associated with increasing the costs of production especially the variable costs and losses in return through reduction of obtained calves, as well as a reduction of the milk yield on the long run period [24]. These results agreed with those of Omar [10] who reported that increasing the calving interval than one year associated with economic losses through reduction of milk return and losses in newborn calves.

Table (3) revealed that the duration of the calving interval period unequivocally demonstrates that the longest calving interval period was observed in Holstein Friesian cattle, reaching an impressive 474.11 days. Following closely behind are the Brown Swiss cattle, with a notable calving interval period of 460.30 days. Additionally, the crossbred cattle (Balady X Friesian) also exhibited a relatively extended calving interval period, averaging 388.97 days. Conversely, the Balady cattle recorded the lowest calving interval period at 364.39 days. These results may be attributed to that farmers tend to bred balady cows directly after parturition within two months, without giving a resting period to the cows after parturition that causes reduction of calving interval period [20].

Table 3. Average of the calving interval among the different dairy breed

Breed	N	Mean ±Std. Error
Balady	217	364.39^{d} ±6.39
Crossbred (Balady X Holstein Friesian)	666	388.97^{c} ±3.64
Holstein Friesian	555	474.11^{a} ±3.99
Brown Swiss	1551	460.31^{b} ±2.39

*This means within the same column different letters are significantly different at (P < 0.01).

Correlation analysis

Correlation matrix of milk production resources

The correlation matrix was made to measure the level of correlation to avoid autocorrelation or multi-correlation. Table (4) illustrates, correlations between variables affecting milk production (1- Calving interval 2-days open 3- dry period 4- total cost 5- feed cost 6- total return 7- profit of milk (305day), The following results can be categorized as in the following, High positive correlation (r= 0.33-1.00) observed between calving interval with days dry (0.81), Calving interval with days open (0.92), Milk yield (0.94) with total return, Total fixed cost (0.35) with days open, Profit (0.41) with a total return

Medium positive correlation (r =0.17 to 0.33)

Total return (0.22) with days open, Milk yield (0.22) with days open, Milk 305 days yield (0.19) with calving interval, Milk yield (0.22) with days open, total return (0.17) with total cost, Total return (0.19) with calving interval. A low positive correlation (r = 0.00 to 0.16) observed between, Total cost (0.05) with calving interval, Profit (0.06) with calving interval, Total variable cost (0.05) with days open, Total cost (0.06) with days open, Feed cost (0.05) with days open, While, the low negative correlation (r = 0.00 to -0.16) observed between total cost (-0.08) with dry period, Feed cost (-0.08) with dry period, and Medium negative correlation (r = 0.17-to 0.33-) observed between Total return (-0.31) with dry period, Milk (-0.25) with dry period). The negative correlation between feed costs with days open, days dry and calving interval may be attributed to that the increased days open, days dry and calving interval are commonly associated with increasing the feed consumption by the cows and the losses in milk production and calves born [24].

Table 4. The correlation coefficient between studied productive with economic variables.

	1	2	3	4	5	6	7
1	1.00						
2	0.92***	1.00					
3	0.81***	0.64***	1.00				
4	-0.78***	-0.59***	-0.62***	1.00			
5	0.19***	0.22***	-0.43***	-0.31***	1.00		
6	0.06***	0.07***	-0.14***	-0.10***	0.41***	1.00	
7	0.19***	0.22***	-0.40***	-0.25***	0.94***	0.39***	1.00

*Significant at (P<0.05) **significant at (P<0.01) ***significant at (P<0.001)

*1: Calving interval, 2: days open, 3: dry period, 4: total cost, 5: feed cost, 6: total return, 7: profit of milk (305day)

Regression analysis

Production functions of dairy cow

Comparison between outputs of linear production functions was done to determine the best function which describes the relationship between milk production and production resources (calving interval, days open, dry period,). So, the best logarithmic function was as follows:

Function	Log TMY = 0.88+ 0.55 Logci + 0.21 Log do + 0.31 Log dp
t	(1.56) ** (0.06) ** (0.28) ** (1.36)
F	(645.58) ***
R-2	0.61

**significant at (P<0.01) ***significant at (P<0.001)

The findings revealed that the logarithmic production function held immense significance (P<0.01), with a remarkable 55% of the variations in milk production being attributed to alterations in production resources. As indicated in the table, the average elasticity of the calving interval stood at approximately +0.55, signifying that about 10% modification in the calving interval led to a substantial 5.50% surge in milk production. These results may attributed to that the adjusting of CI in the level of one year, DO in the level of 100 to 120 days and dry period in the level of 2 months improve the milk yield due to optimizing of body condition and renew of the udder tissue of adult cows [10].

Table (5) revealed the average elasticity of days open reached about +0.21, demonstrating that a minor 10% adjustment in days open resulted in a commendable 2.1% elevation in milk production. Moreover, the average elasticity of the dry period hovered around +0.31, clarifying that a mere 10% shift in the dry period translated into a noteworthy 3.1% augmentation in milk production.

Table 5. The different elasticity for the independent variables affecting milk production.

Variables	Elasticity
Calving interval	+0.55
Days open	+0.21
Dry period	+0.31

These outcomes concur with the findings of Sanad *et al.* [20]. which highlighted that the key factors influencing the reproductive and productive efficiency of milk production farms encompass the calving interval, days open, and dry period. Additionally, Tadesse et al. [25] affirmed that the calving interval, dry period, and days open serve as the principal indicators of milk production efficiency. The outcomes of our study have unequivocally demonstrated that the calving interval, days open, and dry period are indisputably the pivotal factors that remarkably enhance milk production yield and efficiency. The statistical indices, comprising regression analysis and correlation analysis, facilitated by the t-test, along with the analysis of variance test, undoubtedly constitute the paramount statistical parameters that can be effectively employed to ascertain the determinants that influence milk yields and production efficiency.

This study **concluded** that, the using of statistical metrics and measures may be helpful to improve dairy farm productivity through assessing and improving the reproductive efficiency measures, including calving interval, days open and days dry.

Acknowledgement

I extend my profound appreciation to my supervisor, Prof. Dr. Mahmoud S. El-Tarabany, for his diligent efforts and unwavering guidance, which have played a pivotal role in the completion of this work. Furthermore, I would like to express my sincere gratitude to all the dedicated staff members of the Animal Wealth Development Department, Faculty of Veterinary Medicine, Zagazig University, whose contributions have been invaluable to this research project.

Conflicts of interest It is with utmost sincerity that I declare the absence of any conflicts of interest within the context of my manuscript.

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الملخص العربي

تقييم القياسات الإحصائية لتحديد أهمية مؤشرات كفاءة التناسل علي زيادة إنتاجية مزارع الألبان.

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تهدف هذه الدراسة إلى تطبيق مقاييس إحصائية في تقييم أهمية معايير كفاءة التناسل (أيام مفتوحة، فترة بين كل ولادة والتي تليها، وفترة الجفاف) علي إنتاجية مزارع الألبان.تمت هذه الدراسة عن طريق مسح ميداني في مناطق مختلفة من مصر تشمل محافظات (المنوفية، القليوبية، البحيرة، والجيزة) خلال الفترة الممتدة من صيف عام 2017 إلى شتاء عام 2020 على عينات عشوائية من قطاعات إنتاج الألبان. تضمنت هذه القطاعات المزارعين والقطاعات الخاصة والحكومية. وشملت سلالات الألبان المشمولة في هذه الدراسة البلدي (السلالة المحلية) والهولشتين-فريزيان (السلالة الأجنبية) والمهجنة. (بلدي X فريزيان)ايضا سلالة ابقار السويسرية البنية أو البراون سويس.تم جمع البيانات من خلال مسح ميداني عرضي وطولي. خلال جمع البيانات، كان الباحث على اتصال وثيق مع أصحاب ومديري المزارع الألبان. تم زيارة المزارع الألبان مرتين على الأقل، مرة في الصيف والأخرى في الشتاء. قام الباحث بجمع البيانات بواسطة طريقتين: من السجلات الدقيقة المتاحة في مزارع الألبان في مناطق الدراسة وطريقة الاستبيان المنظمة التي أنشأها الباحث وفقًا لأهداف هذه الدراسة وأذن بها أصحاب ومديرو المزارع الألبان أثناء وقت المقابلة. تم إجراء تحليل الارتباط وتحليل الانحدار على البيانات المجمعة. أشارت النتائج إلى أن مستوى "الايام المفتوحة" الأعلى لوحظت في أبقار هولشتاين فريزيان حيث بلغ (200.96 يوم)، تليها براون سويس حيث بلغت (190.44 يوم). أما بالنسبة لمدة الفترة الجافة، فقد واضح أن أعلى مستوى لهذه الفترة يوجد في أبقار البلدي حيث بلغت (131.07 يوم)، تليها الأبقار المهجنة بلدي X فريزيان حيث بلغت (115.70 يوم) أما بالنسبة لفترة فاصل الولادة، فقد واضح أن أعلى مستوى لهذه الفترة يوجد في أبقار هولشتاين فريزيان حيث بلغت (474.11 يوم) ، تليها براون سويس حيث بلغت (460.30 يوم). أشارت المعادلة الخطية إلى أن التغير في فترة مابين كل ولادة والاخري بنسبة 10٪ يؤدي إلى زيادة في إنتاج الحليب بنسبة (5.50٪). أيضًا، يؤدي التغير في " الايام المفتوحة " بنسبة 10٪ إلى زيادة في إنتاج الحليب بنسبة (2.1٪). أيضًا، يؤدي التغير في مدة الفترة الجفاف بنسبة 10٪ إلى زيادة في إنتاج الحليب بنسبة (3.1٪). توصلت نتائجنا إلى أن فترة بين الولادة والاخري، وفترة الانتظار، وفترة الجفاف هي المعايير الرئيسية لكفاءة التكاثر التي تؤثر إيجابيًا على إنتاج الحليب وكفاءته، وأن التحليل الإحصائي الذي يتضمن تحليل الانحدار، وتحليل الارتباط بمساعدة اختبارt ، واختبار تحليل الاختلاف هي المعايير الإحصائية الرئيسية التي يمكن استخدامها لتحديد العوامل التي تؤثر على إنتاج الحليب وكفاءته.