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Implementation of Kaizen Approach and Six Sigma Methodology to Improve Organic Eggs Productivity

Maribel Torres
Grupo de Investigación en Ingeniería, Productividad y Simulación Industrial (GIIPSI), Universidad Politécnica Salesiana, Ecuador
Orcid: https://orcid.org/0009-0002-0457-6392

William Quitiaquez
Grupo de Investigación en Ingeniería, Productividad y Simulación Industrial (GIIPSI), Universidad Politécnica Salesiana, Ecuador
Orcid: https://orcid.org/0000-0001-9430-2082

Isaac Simbaña
Grupo de Investigación en Ingeniería Mecánica y Pedagogía de la Carrera de Electromecánica (GIIMPCEM), Instituto Superior Universitario Sucre, Ecuador
Orcid: https://orcid.org/ 0000-0002-3324-3071

Patricio Quitiaquez
Grupo de Investigación en Ingeniería, Productividad y Simulación Industrial (GIIPSI), Universidad Politécnica Salesiana, Ecuador
Orcid: https://orcid.org/0000-0003-0472-7154

Introduction

The case study was carried out on a farm that has an ecological philosophy and its main income is the production of organic eggs. Those come from hens that are not exposed to stress or confinement and are fed with products without high percentages of hormones and chemicals (Sokołowicz et al., 2019). The monthly production of eggs on the farm is around 13 500 units distributed in Cotacachi, Imbabura. Due to the high production of eggs, it is necessary to implement a methodology that maintains the quality of the eggs. The main objective of *Six Sigma* is to improve production processes, reducing time and eliminating unnecessary processes (Smętkowska and Mrugalska, 2018). The phases during the application of this methodology are Define, Measure, Analyze, Improve, and Control (DMAIC) (De Mast and Lokkerbol, 2012). The methodological approach's importance is reducing operating costs and improving the company's organizational performance (Boon-Sin et al., 2015).

Deeb et al. (2018) implemented the *Six Sigma* methodology in small and medium-sized businesses (SMBs). This methodology was used to improve the performance of the company by reducing the variability of the results of the processes, which is formed by a meta-model, based on studies on *Six Sigma*, its phases, and tools. The main results define the requirements to reach in each of the phases of *Six Sigma* implementation. A list of requirements was created for assessing the obtained results, to validate the objectives and maintain the production improvement.

Ahmad (2011) developed several mathematical and artificial intelligence models to compare egg production forecasts. The study utilized a simple approach with one variable, egg production, thus simulating egg production through neural networks and genetic algorithms, by considering a sample of 240 hens and the daily information on egg production. Afterward, a comparison was developed between the models, obtaining that the general regression neural network provided the best fit of 0.71, determining that the neural models are more efficient in forecasting future egg production.

Valderrama-Mendoza et al. (2019) designed a SCADA-type software to measure, record, and control the involved variables to increase the productivity of poultry farms. For data collection, a sensor system in the sheds was installed, and a graphic description that represents the system code. The software was based on predicting the chicken weight, allowing poultry farmers to make the best decisions, hence, standardizing the parameters for production improvement.

Tirado and Abril (2020) analyzed the 5S methodology in companies in the poultry sector in the Province of Tungurahua. The profitability of a batch of traditionally raised hens was compared with one from organic breeding, applying the 5S method. The results showed activities of organization, cleaning, classification, standardization, and discipline, that reduced the cost of production and increased the profitability of the company. By the 5S methodology application, the company's profitability increased by 12.2 %, equivalent to USD 3 910.74, besides, a saving of 4 % in terms of total costs was confirmed.

Omomule et al. (2020) studied the various challenges on poultry farms that affect the quality of egg production. There was a requirement to establish an optimal fuzzy predictive model for poultry egg production, collected data on chick age, feed quantity, feed quality, and total egg production. To carry out the model, software SPSS and Matlab were used. The performance evaluation of the proposed design yielded a relative error of 0.1174 %. This method is profitable and correct for modeling egg production on a farm, with an increase of 10 % in egg production, according to the model results.

Hammershøj and Steenfeldt (2015) determined the manner in which nutrients and forage material affect the quality of organic eggs with two hen genotypes, *Lohman Silver* and *New Hampshire*. Organic eggs are produced by chickens that have access to outdoor living and are fed traditionally. The applied methodology consisted of a sample of 1 200 hens, fed with three types of diets and an average amount of protein of 203, 199, and 182 $g \cdot kg^{-1}$ and two treatments of forage material in the different genotypes. The results indicated that the hen genotype influences all eggs' quality parameters, such as size, weight, yolk color, and shell hardness. Then, for the egg weight, the *Lohman* genotype's eggs were 2.8 g heavier than the *Hampshire* genotype.

Filipiak-Florkiewicz et al. (2017) carried out a comparative analysis between organic eggs and conventional eggs to determine their quality. The evaluation consisted of the basic chemical composition of the egg and the mineral content to determine the fatty acid profiles. Then, the eggs' ability to make mayonnaise was evaluated and the obtained results indicated that the conventional eggs contained the highest number of fatty acids, while the organic eggs contained the highest level of protein, 17.7 g per 100 g. For mayonnaise prepared with organic eggs, there was greater stability. There are significant differences between eggs from organic hens and conventional hens, organic eggs are characterized by a more beneficial chemical composition than conventional ones, including moisture, protein, fat, and ash.

Philippe et al. (2020) compared the performance of egg production associated with three types of housing, battery cages, enriched cages, and aviaries. The study considered 12 scale chambers that were equipped with each of three types of housing, with 30 laying hens in each chamber. The laying rate was significantly influenced by the type of housing. Alternative hen housing methods, such as enriched cages and aviaries, were the best option in egg production.

This investigation aims to improve the production of organic eggs on a farm, applying the *Six Sigma* methodology, with the objective of a continuous improvement of production processes, focused on customer satisfaction (Pérez-Vergara and Rojas-López, 2019). This document is distributed as follows, Methodology describes the steps to carry out this investigation, besides the required equations. Results present the obtained information from the software to analyze it and Conclusions summarize the document data, explaining the authors' perspective.

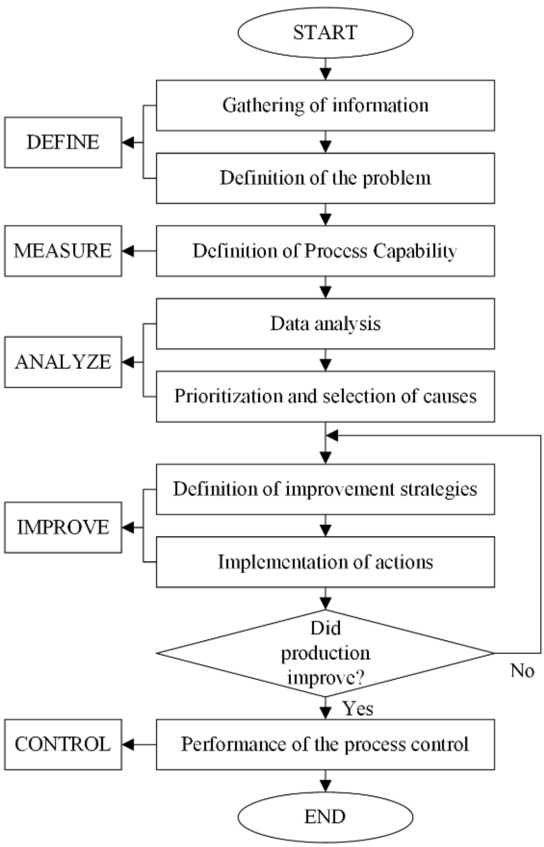
Materials and Methods

The *Six Sigma* methodology was utilized for the development of this study to improve productivity, reduce time, and eliminate unnecessary processes (Navarro-Albert et al., 2017). In the first instance, a statistical analysis of the production data from the previous semester when the investigation started was carried out to obtain more information about the current situation of the farm. Then, a sequence of processes considered within the DMAIC methodological tool was applied, as shown in Figure 1.

The field where the method was applied and the improvement objectives were defined, according to the results of the statistical analysis. Data was measured to determine the behavior of the process, besides, the causes and effects of the detected problems in the production process were analyzed by using an Ishikawa diagram. Finally, improvements were implemented throughout the production chain by integrating the *Kaizen* methodology, responsible for continuous improvement, and complementing it with a control phase to maintain the new performance.

The farm is dedicated to the production and marketing of organic eggs. The previous six months before the study had a total of 600 *Hy Line Brown* hens, the same breed that is specialized for laying hens. The average monthly production is 13 500 units and the production process is managed empirically, only based on the experience of the owners.

Figure 1
DMAIC process flow diagram



This business started in June 2020 as a response to the economic situation in the world due to the COVID-19 pandemic. In the beginning, a market survey was carried out superficially, because eggs are the cheapest protein source in the world and it is considered a food rich in essential amino acids, providing nutritional value to consumers (Lesnierowski and Stangierski, 2018). Therefore, a business of organic eggs started to produce them naturally by giving the chickens decent treatment, without confinement and stress (Dalle-Zotte et al., 2021). The quality of the eggs is measured by different parameters, such as chemical composition, resistance to breakage, or physical composition. Table 1 shows the comparison of the physical and chemical composition of conventional eggs and organic eggs, evidencing that organic eggs are larger and have a greater nutritional value.

Table 1
Comparative analysis for physical and chemical composition between traditional and organic eggs

Characteristics	Organic Eggs	Traditional Eggs
Weight [g]	60.7	60.7
Diameter [mm]	43.9	43.7
Width [mm]	56.9	56.7
Albumen Weight [g]	38.9	38.4
pH	8.80	9.15
Eggshell weight [g]	6.61	6.74
Thickness [mm]	0.35	0.36
Protein [g]	12.1	12.4
Lipids [g]	9.71	10.1
Cholesterol [g]	194	186

To apply the *Six Sigma* methodology, a dynamic analysis of the processes was carried out, through a graph of the process trend and the calculation of the process capacity. The capacity of the process (C_p) is obtained by relating the difference between the upper control limit (*LCS*) and the lower control limit (*LCI*) between six standard deviations of the process (σ) with eq. (1):

$$C_p = \frac{LCS - LCI}{6\sigma} \qquad (1)$$

The upper process capability index (C_{pks}) is the quotient between, the difference between the upper control limit (*LCS*) and the average ($\bar{x}$) and three standard deviations of the process, obtained by eq. (2):

$$C_{pks} = \frac{LCS - \bar{x}}{3\sigma} \quad (2)$$

The lower process capability index (C_{pki}) is calculated by applying eq. (3) as the quotient between, the difference between the average ($\bar{x}$) and the upper control limit (*LCI*) and three standard deviations of the process:

$$C_{pki} = \frac{\bar{x} - LCI}{3\sigma} \quad (3)$$

The capacity of the process (C_p) is the extension of the natural variation, the optimum is that $C_p > 1$, therefore, it is considered that the process is prepared to comply with the parameters of *Six Sigma*. Therefore, C_{pks} and C_{pki}, if $C_{pks} > C_{pki}$, then there is a greater variation below the average, and if $C_{pks} < C_{pki}$, then there is a greater variation above the average (Ugr & Canatan, 2015). Then, by the C_p value, the *Sigma* level is observed. *Six Sigma* levels measure the number of times that an opportunity for error can be given. After the initial analysis, the DMAIC approach was applied in the Define phase (Kulkarni et al., 2021).

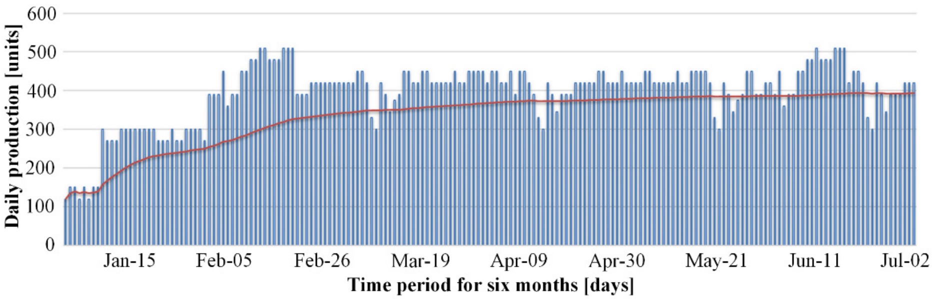
Results

The *Six Sigma* approach is used to improve company productivity by reducing variation in processes. This methodology develops continuous improvement in the production process. For this investigation, a descriptive statistical analysis was carried out on the production of organic eggs in the previous six months of the farm, obtaining the following results. There were 184 production data analyzed, which are equivalent to daily production for six months. The average daily production was 393 eggs, and the median and mode are 420 eggs, and the fact that they are the same indicates that there is no bias. The standard deviation of the process is 80.80, which shows the amplitude of the sample. During the study time, there was a minimum production of 120 eggs per day and a maximum of 510 eggs per day. Then, a dynamic analysis of the processes was carried out to know whether the process is stable. Figure 2 shows the trend of daily production, which has stabilized since March, as indicated by the red curve. However, it is necessary to calculate the capacity of the processes, to assure their stability. By carrying out the calculations, the values for C_p, C_{pks}, and C_{pki} were 0.92, 0,55, and 1.29, respectively.

The C_p value indicates that the process has a *Sigma* level of 2.75, consequently, it is equivalent to a 10 % probability of defects, compared to 100 % of production. By analyzing the values of C_{pks} and C_{pki}, it is defined that $C_{pki} > C_{pks}$, which indicates that there is greater variation above the average, consequently, the process is not symmetric. According to the process capacity data, the analyzed information is not stable.

These values must be greater than or equal to 1, therefore, it is necessary to stabilize the process. The DMAIC approach was used to reduce variation in the production process, through phases [20], Define, Measure, Analyze, Improve, and Control. For the Improve phase, the *Kaizen* approach was used, which is based on the application of a corrective action plan that continuously improves the process (Maarof & Mahmud, 2016).

Figure 2
Daily production trend for six months



In the Define Phase, the current problem and the manner to address it are limited. According to the process capability analysis, the objective was to stabilize the process and for this purpose, it is necessary to know the process in detail. Table 2 shows the SIPOC diagram, through which the process is understood clearly (Nandakumar et al., 2020). Three processes that generate delays in egg production were identified, and these are Collection, egg classification by weight, and egg cleaning.

Table 2
SIPOC diagram

SUPPLIERS	INPUT	PROCESS	OUTPUT	CUSTOMERS
Agroscopio	*Hy Line Brown* laying hens	1. Raise chicks 2. Eggs production 3. Recollection 4. Egg classification per weight 5. Eggs cleaning 6. Place eggs in trays 7. Commercialization	Eggs	Variable customers
agroscopio				

For the Measure Phase, a total of 184 data were collected from January to June 2021. The variation of the process was studied, in this case, by the calculations. A C_p of 0.92 was obtained, which indicates 105 660 defects in 1 000 000 opportunities.

Figure 3 presents the histogram of all the data analyzed, that is, the frequency of the daily production presented in the six months. The graph is biased to the left, where the most repeated production was 420 eggs per day, with an average production of 393 units.

Figure 3
Histogram of the daily production of organic eggs

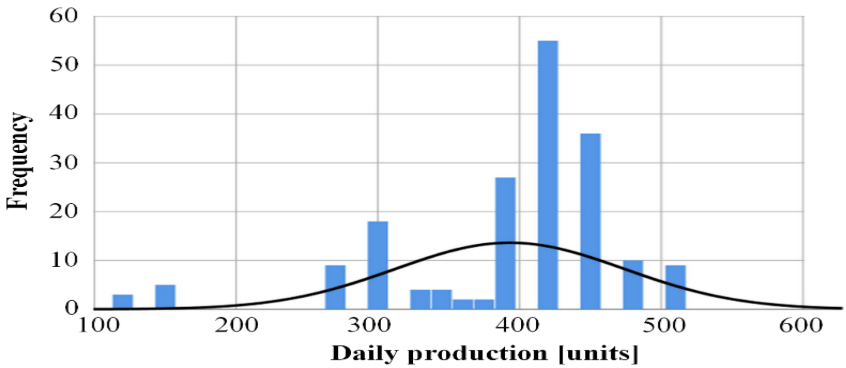
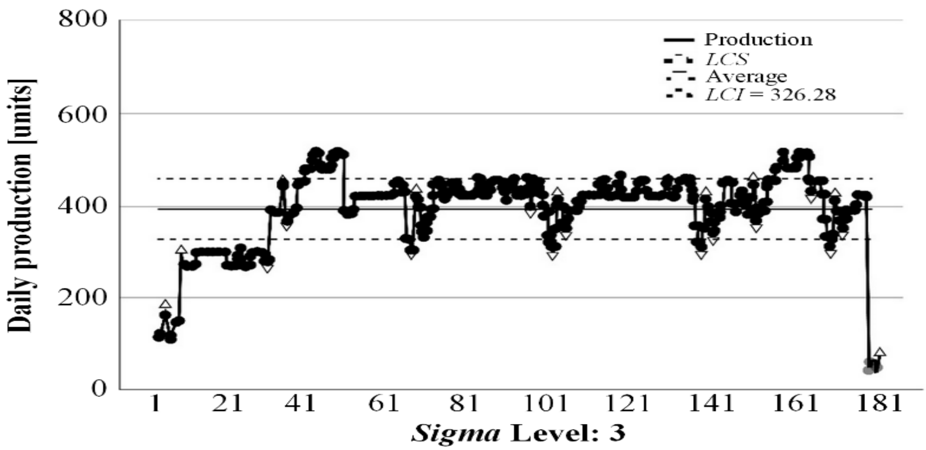


Figure 4 presents the control of the process, indicating variability and several production peaks outside the limits, which confirms that the process is not stable and needs intervention to improve production processes and reduce failures. Besides, the upper (*LCS*) and lower (*LCI*) control limits can be identified, with values of 457.73 and 326.28, respectively.

Figure 4
Daily Production Control Chart



For the Analyze Phase, the root of the variation is studied and causes were selected to define the problem. The Ishikawa diagram was plotted, thus identifying some of the causes for the variability of the process. The factors considered to find the potential causes of the problem were labor, method, machine, material, and environment (Carvalho et al., 2021) as shown in Figure 5. The most important causes according to the analysis were labor and machine.

Figure 5
Ishikawa diagram

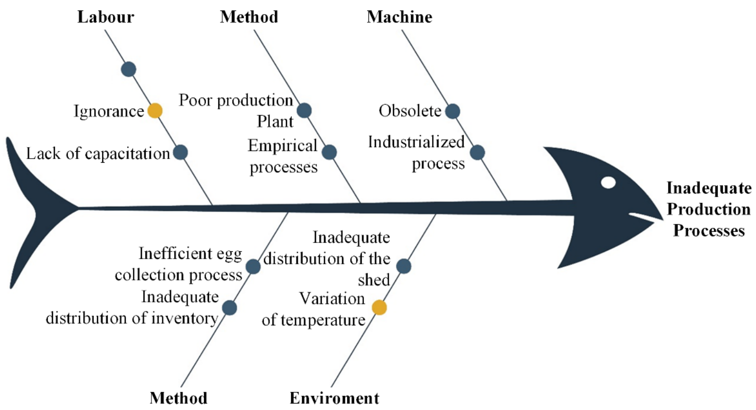
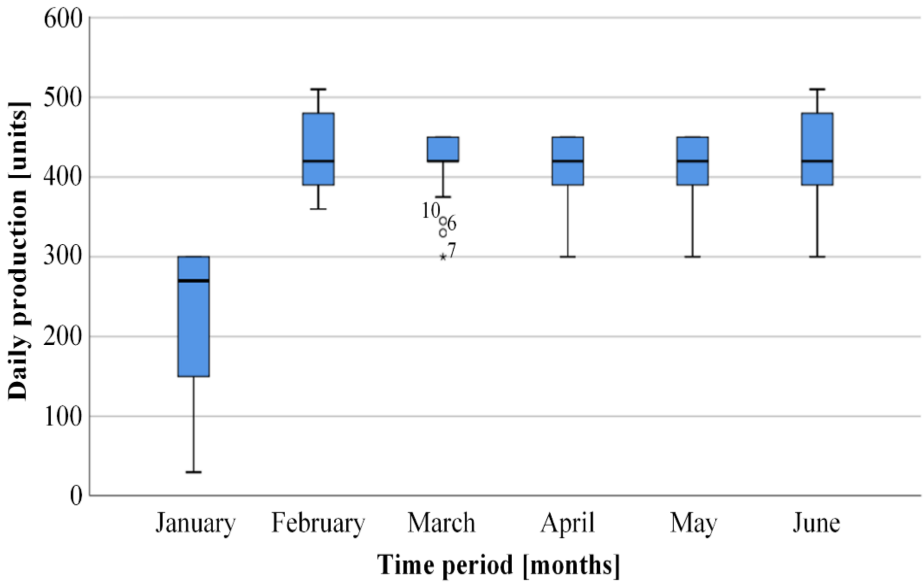


Figure 6 shows a simulation of the current situation of the shed, where the hens and nests are everywhere, slowing down the production process in the egg collection phase, because several hens lay eggs anywhere, losing several units per day.

Figure 6
Current situation of the shed

Figure 7 shows the box plot for the daily production of organic eggs, during the first half of the year. In January, the production is lower and there is a variation in the data. Meanwhile, from February to June the variation reduced and the production stabilized. In addition, in February there was atypical data, but the distribution of the data is skewed towards the production of 300 eggs.

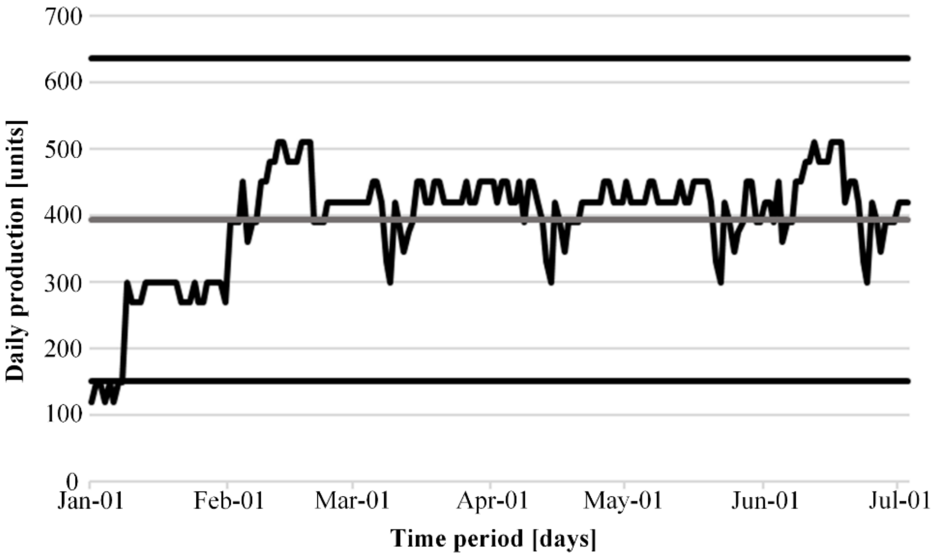
Figure 7
Boxplot of the monthly production for organic eggs



For the Improve Phase, improvement strategies were defined and the *Kaizen* methodology was applied, which focuses on continuous improvement. The first three steps of the methodology coincide with the DMAIC approach, therefore, only processes four and five were applied. According to the analysis of the causes of the problem, deficient planning in the production process of organic eggs and empirical management of production cause high variability in the process. Besides, the egg collection process and inadequate inventory control led to a loss of approximately 10 eggs per day. Poor house layout causes hens to lay their eggs in different places.

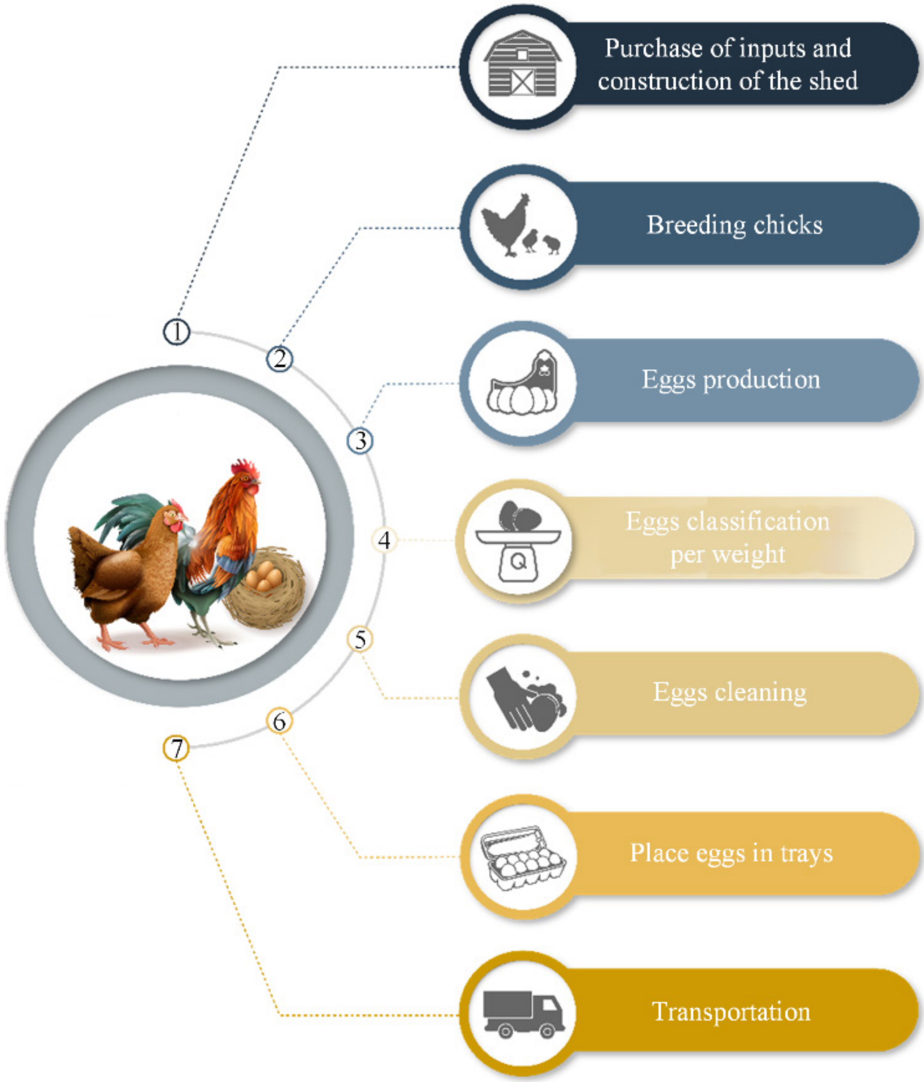
In the Control Phase, the processes were controlled by several tools. In this investigation, controls were carried out through the recording of daily production and by maintaining the upper control limit at 610 eggs and the lower control limit at 178 eggs per day, as seen in Figure 8. Also, sanitary control was necessary, placing lime at the entrance of the shed to protect the hens from various diseases. To control production planning, a checklist was carried out where it was identified that more training is still needed for the people in charge of the farm and the production of organic eggs.

Figure 8
Process control chart after Six Sigma Implementation



The corrective actions to solve each of the root causes are the Production Plan, increasing the batch of laying hens by implementing the process of rearing chicks. Besides, to stabilize the process, it is necessary to increase the control limits. Therefore, the new upper control limit will be 610 eggs per day, and the lower control limit 178 eggs per day. By increasing production, the obtained values of the statistical capacities of processes were 1.02, 1.01, and 1.00 for C_p, C_{pks}, and C_{pki}, respectively, which demonstrate that the process is stable. To solve the inefficient egg collection process and the inadequate inventory control, it was necessary to organize the processes and reduce the time. Figure 9 shows the optimized process of the production system of organic eggs, from the purchase of inputs for the shed to the transportation process. Then, the distribution of the shed was organized in a better manner, increasing the nests and spaces where the hens could remain after grazing.

Figure 9
Production process for organic eggs



Conclusions

The application of the *Six Sigma* methodology, through the DMAIC approach, allowed to identify opportunities for improvement in the production process of organic eggs. It was determined that one of the processes with the greatest variability was egg collection and cleaning. Therefore, the process was redesigned improving the collection process and the egg cleaning to maintain the quality and increase egg production.

In the Measurement phase, a statistical analysis of processes was carried out, obtaining as a result process capacity (C_p) of 0.92, upper process capacity (C_{pks}) of 0.55, and 1.29 for lower process capacity (C_{pki}). These results determined that the process presents a high variability. The DMAIC approach stabilized the process by increasing the values of the upper control limit with 610 eggs and the lower control limit with 178 eggs per day, thus obtaining values of 1.02, 1.01, and 1.00 for C_p, C_{pks}, and C_{pki}, respectively, which indicate stability in the process. Then, fulfilling the objective of the *Six Sigma* methodology is to reduce the variability of the production process.

An improved distribution of the shed was carried out, increasing 10 nests and 10 feeders to do the egg collection faster and more efficiently. The new distribution of the shed improved significantly the organic egg production process and reduced the mortality rates of the hens. It is necessary to change the mentality of the workers for the implementation of the methodology. Quality is a key indicator to position the business in the Ecuadorian organic egg market.

References

Ahmad, H. A. (2011). Egg production forecasting: Determining Efficient Modeling Approaches. Journal of Applied Poultry Research, 20(4), 463-473. https://doi.org/10.3382/japr.2010-00266

Boon Sin, A., Zailani, S., Iranmanesh, M. and Ramayah, T. (2015). Structural Equation Modelling on Knowledge Creation in Six Sigma DMAIC Project and its Impact on Organizational Performance. International Journal of Production Economics, 168, 105-117. https://doi.org/10.1016/j.ijpe.2015.06.007

Carvalho, R., Lobo, M., Oliveira, M., Raquel, A., Alonso, V., Lopes, F. and Souza, J. (2021). Analysis of Root Causes of Problems Affecting the Quality of Hospital Administrative Data: A Systematic Review and Ishikawa Diagram. International Journal of Medical Informatics. 156, 104584. https://doi.org/10.1016/j.ijmedinf.2021.104584

Dalle Zotte, A., Cullere, M., Pellattiero, E., Sartori, A., Marangon, A. and Bondesan, V. (2021). Is the Farming Method (cage, barn, organic) a Relevant Factor for Marketed Egg Quality Traits? Livestock Science, 246, 104453. https://doi.org/10.1016/j.livsci.2021.104453

De Mast, J. and Lokkerbol, J. (2012). An Analysis of the Six Sigma DMAIC Method From the Perspective of Problem Solving. International Journal of Production Economics, 139(2), 604-614. https://doi.org/10.1016/j.ijpe.2012.05.035

Deeb, S., Haouzi, H. B. El, Aubry, A. and Dassisti, M. (2018). A Generic Framework to Support the Implementation of Six Sigma Approach in SMEs. IFAC-PapersOnLine, 51(11), 921-926. https://doi.org/10.1016/j.ifacol.2018.08.490

Filipiak-Florkiewicz, A., Deren, K., Florkiewicz, A., Topolska, K., Juszczak, L. and Cieślik, E. (2017). The Quality of Eggs (organic and nutraceutical vs. conventional) and their Technological Properties. Poultry Science, 96(7), 2480-2490. https://doi.org/10.3382/ps/pew488

Hammershøj, M. and Steenfeldt, S. (2015). Organic Egg Production. II: The Quality of Organic Eggs is Influenced by Hen Genotype, Diet and Forage Material Analyzed by Physical Parameters, Functional Properties and Sensory Evaluation. Animal Feed Science and Technology, 208, 182-197. https://doi.org/10.1016/j.anifeedsci.2015.07.012

Kulkarni, S., Prasanna, N., Mirunalini, S., Akshaya, C., Deekshitha, R., Kousalya, N. and Agalya, A. (2021). Enhancing the Process Capability of Machining Process of Boring Tool Holder by Application of Six Sigma Methodology. Materials Today: Proceedings, 52(3), 329-338. https://doi.org/10.1016/j.matpr.2021.09.043

Lesnierowski, G. and Stangierski, J. (2018). Trends in Food Science & Technology What's New in Chicken Egg Research and Technology for Human Health Promotion? - A Review. Trends in Food Science & Technology, 71, 46-51. https://doi.org/10.1016/j.tifs.2017.10.022

Maarof, M. G. and Mahmud, F. (2016). A Review of Contributing Factors and Challenges in Implementing Kaizen in Small and Medium Enterprises. Procedia Economics and Finance, 35, 522-531. https://doi.org/10.1016/S2212-5671(16)00065-4

Nandakumar, N., Saleeshya, P. G. and Harikumar, P. (2020). Bottleneck Identification and Process Improvement by Lean Six Sigma DMAIC Methodology. Materials Today: Proceedings, 24, 1217-1224. https://doi.org/10.1016/j.matpr.2020.04.436

Navarro Albert, E., Gisbert Soler, V. and Pérez Molina, A. (2017). Metodología e Implementación de Six Sigma. 3C Empresa: Investigación y Pensamiento Crítico, 6(5), 73-80. https://doi.org/10.17993/3cemp.2017.especial.73-80

Omomule, T., Ajayi, O. and Orogun, A. (2020). Fuzzy Prediction and Pattern Analysis of Poultry Egg Production. Computers and Electronics in Agriculture, 171, 105301. https://doi.org/10.1016/j.compag.2020.105301

Pérez-Vergara, I. and Rojas-López, J. (2019). Lean, Six Sigma and Quantitative Tools: A Real Experience in the Productive Improvement of Processes of the Graphic Industry in Colombia. Revista de Métodos Cuantitativos Para La Economáa y La Empresa, 27(27), 259-284. https://ideas.repec.org/a/pab/rmcpee/v27y2019i1p259-284.html

Philippe, F., Mahmoudi, Y., Cinq-Mars, D., Lefrançois, M., Moula, N., Palacios, J., Pelletier, F. and Godbout, S. (2020). Comparison of Egg Production, Quality and Composition in Three Production Systems for Laying Hens. Livestock Science, 232, 103917. https://doi.org/10.1016/j.livsci.2020.103917

Smętkowska, M. and Mrugalska, B. (2018). Using Six Sigma DMAIC to Improve the Quality of the Production Process: A Case Study. Procedia - Social and Behavioral Sciences, 238, 590-596. https://doi.org/10.1016/j.sbspro.2018.04.039

Sokołowicz, Z., Dykiel, M., Krawczyk, J. and Augustyńska-Prejsnar, A. (2019). Effect of Layer Genotype on Physical Characteristics and Nutritive Value of Organic Eggs. CYTA - Journal of Food, 17(1), 11-19. https://doi.org/10.1080/19476337.2018.1541480

Tirado, L. and Abril, J. (2020). Quality and Poultry Sector of the Province of Tungurahua. Revista de Investigación, Formación y Desarrollo: Generando Productividad In-stitucional, 8(2). 15-31.15-31. https://dialnet.unirioja.es/servlet/articulo?codigo=8273677

Ugr, O. L. and Canatan, H. (2015). Literature Search Consisting of the Areas of Six Sigma's Usage. 195(0212), 695-704. https://doi.org/10.1016/j.sbspro.2015.06.160

Valderrama-Mendoza, M., Rodríguez-Urrego, L., Cobo, L. and Martínez, G. (2019). Sistema de Análisis para el Incremento de la Producción de Granjas Avícolas en Colombia. Caso de estudio: Proyecto Proavícola. Avances: Investigación en Ingeniería, 16(1), 1-16. https://doi.org/10.18041/1794-4953/avances.1.5254