Improving the production process of consumption eggs by means of quality control charts

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The quality of consumption eggs is a result of the interaction between many factors that influence the functioning of the laying hen as an egg producing domestic animal. Amongst them are factors proper to the animal (strain, age,...) on the one hand, and factors such as feed, climate, housing system and management on the other hand. The resulting egg quality is defined by egg weight, shell strength and internal and external quality. This final quality has to meet up with customer's demands. As a result the production process is focused on a produce that answers these demands. Therefore, it is of great importance to detect a quality decrease as soon as possible, track the cause and take measures. However, in practice there is often a large time span between the origination and the detection of quality loss resulting in economical damage.
Wanting to monitor a production process inquires regular monitoring of the different parameters. Through the years techniques and devices have been developed to define many of the production parameters on a regular basis. On the other hand, measurement techniques for the egg quality parameters remained slow, often inaccurate, subject to human subjectivity and usually destructive.
Considering the production of consumption eggs as a process in combination with the availability of all information of the different parameters, enables one to use the technique of statistical quality control charts to follow up the process and monitor the evolution of the different parameters and their mutual relation. The concept of statistical quality control was applied to data originating from two experiments. The first experiment was a small scale heat stress experiment of 3 weeks, while the second experiment was a large scale experiment of a total laying period of a flock of laying hens housed in furnished cages. For these experiments control charts were developed and occurrences of limit exceeding changes of parameters were investigated. The results show the usefulness of the control charts in contributing to improvement of the egg quality.

Keywords: egg quality; monitoring; statistical process control; control charts

Introduction

The quality of consumption eggs is a result of the interaction between many factors that influence the functioning of the laying hen as an egg producing domestic animal. Amongst them are factors proper to the animal (strain, age, health...) on the one hand, and factors like feed, water, climate, housing system and management on the other hand. The values and characteristics of all these input factors, and more

importantly their interaction, will result in an output, the production of eggs. The final quality of the produced eggs has to meet up with customer's demands. As a result the production process is focused on a produce that answers to these changing demands. Therefore it is of great importance to detect a quality decrease as soon as possible, track the cause and take measures. Nowadays in practice, performances of a flock of hens are monitored either by the farmer itself by looking at the absolute daily production numbers, or by management supporting services, sometimes with software packages, of breeder or feed companies who consider results on a weekly basis. Performing process monitoring on this basis makes it difficult to detect quality decreases resulting in economical damage. Therefore it would be of interest to have a technique which is capable of quickly detecting possible changes.

In industry, where uniformity of the quality of products is of the utmost importance, the concepts of Statistical Process Control (SPC) became established years ago to perform quality assurance. The basic principle of SPC is to formulate quality limits based on the natural process variability or the *common cause variation*. Occasionally other kinds of variability, not proper to the considered process, may occur. In this case of *special cause variation* the quality of the products will fall outside the formulated limits. (Montgomery, 2005; DeVor *et al.*, 1992). Yet, this methodology is not often used in biological production processes. Furthermore, few references are available that it is used in agricultural processes. The reason for this is twofold: first, production parameters of agricultural processes are seldomly stationary complicating the classical SPC, and second, few measurement techniques are available to define quality on a regular basis.

In this contribution, the laying of eggs is taken as an example of an agricultural process to investigate the possibilities of SPC. Through the years techniques and devices have been developed to define many of the production parameters on a regular basis and record them automatically on computers (Belyavin, 1988). Furthermore, recently fast and non-destructive measurement techniques for the assessment of egg quality were developed. Coucke (1998) presented a technique to assess the egg shell quality by means of the acoustic resonance technique. Besides Kemps *et al.* (2006) developed a method to evaluate the internal egg quality using VIS/NIR light transmission spectroscopy. The availability of all these data on both input and output parameters creates the opportunity to use the technique of SPC on the observance and monitoring of the evolution of these parameters and their mutual relation.

In the past, other methods of process monitoring of egg production have been proposed. For instance, breeding and feeding companies develop standards based on their own experience which could be used by the farmer. Unfortunately, these standards usually only comprise of weekly data on a limited number of variables (Lokhorst, 1996). Besides, Goedeke (1989) and Schmisseur & Pankratz (1989) developed expert systems for poultry production based on the monitoring of the process in longer periods. However, the laying process implies a wide range of parameters which are object to variation on a daily basis. Lokhorst (1996) presented an expert system to detect shifts of the laying process in an aviary system. He developed mathematical curves for all important input and output variables and used them as a standard. A process shift was then signaled when variables displayed aberrations from these mathematical standards.

In this paper the use of SPC by means of quality control charts for detecting shifts of quality parameters of consumption eggs is demonstrated. Data of two experiments were used to investigate the applicability of SPC.

Materials and Methods

Experiments

For the application of the concept of statistical process control, data originating from two experiments were used. The first experiment was a small scale heat stress experiment of 3 weeks. 24 Isa Brown® laying hens were individually housed in a test setup of cages. At the time of the experiment, the birds were 42 weeks of age. In the first week, the animals were kept under normal temperature (21°C). In the second week the hens were subjected to 8 days of heat stress (32°C) and the third week temperature was reset to 21°C. Each day the individual egg weight was measured, all the eggs were tested with the crack detector

(De Ketelaere *et al.* 2000) and finally, from the intact eggs, the egg shell strength, denoted by the dynamical stiffness (K_{dyn}) was assessed as described by Coucke (1998) and Coucke *et al.* (1999). Data from this small-scale experiment were used to detect shifts of the egg weight and K_{dyn} on a short-term base. On a short term it is not necessary to take the age-effect of the hens into account, because it can be assumed that there will be no significant changes, providing no special events happen. Since the laying of eggs is a dynamical process in which certain parameters evolve as the hens age (e.g. increasing egg weight), it had to be investigated whether existing SPC techniques could be used on data of the long-term experiment. For this, data from the observation of a group of 500 Isa Warren® chickens in an aviary housing system were used. From these data recordings of the average egg weight was used for designing control charts.

Statistical Process Control – Control Charts

The choice of the control chart depends on the numerical characteristics of the parameter that has to be monitored e.g. proportions, continuous variables or counts. For the first experiment, the objective was to monitor two continuous parameters, namely egg weight and K_{dyn}. For the second experiment the egg weight was observed. When monitoring the egg weight on a short-term basis like in the first experiment, it can be assumed that the average egg weight will remain relatively constant, that is when the short-term experiment is done after the laying peak of the hens. This implies that a shift of the egg weight can be detected as an aberration of a fixed mean value, estimated by calculating the average egg weight over a reference period. On the other hand, when monitoring on a long-term basis, it has to be taken into account that the egg weight is a dynamical parameter which, on average, increases during lay (fast increase in the beginning of lay and slow increase after the laying peak).

For monitoring these parameters, a *cumulative sum (Cusum) control chart* was used. The Cusum chart directly incorporates all the information in the sequence of sample values by plotting the cumulative sums of the deviations of the sample values from a target value. This makes the chart sensitive to small process shifts ($\leq 1.5\sigma$). A Cusum chart is governed by the standard deviation, and factors *k* and *h*. These values for these factors will define the shift that can be detected in a certain time span. For the used data, *k* was chosen 0.50 and *h* 2.0, which makes it possible to observe a shift of mean of $1\cdot\sigma$ within 3 days after occurrence. At the same time, with this choice of these parameters a false alarm can be expected every 38 days. For more details on this matter, see Montgomery (2005) and Devor *et al.* (1992).

For construction of the charts for data of the first experiment, the averages of the first 7 samples were taken as reference to calculate the target value or process mean (μ) and the standard deviation (σ). The Cusum control charts were designed to detect shifts in mean from the target value.

To construct control charts for the second experiment, a different methodology had to be applied due to the dynamical properties of the egg weight. Here a local first order linear model was plotted based on 20 measurements (t_1 - t_{20}) that were in control. Using this model the next point (t_{21}) of the egg weight sequence was predicted. Then the difference between the predicted and the measured value at this point (t_{21}) was calculated. Next, a new model was developed using measurements t_2 to t_{21}, the value for t_{22} was predicted and the residual between prediction and measurement was defined. This procedure was continued for the other measurement points. A shift in mean was detected by processing these residual values using a *Cusum control chart*.

Results

From the small scale experiment no graphical output is shown. Results for the egg weight showed an in-control average of 63.15g and a standard deviation of 0.69g. Using SPC a decrease of ± 1 gram (= $\pm 1.5\cdot\sigma$) of egg weight was signaled within two days after the start of the heat stress. For Kdyn, which showed an average of 12 647 kN/m and a standard deviation of 605 kN/m, a decrease of ± 1000 kN/m (= $\pm 1.5\cdot\sigma$) was detected 3 days after heat stress started.

From the data of the monitoring of a large group of laying hens in an aviary system, the egg weight was used because of its most extreme dynamical character compared to other parameters. It was assumed that the laying period starts at an age of 141 days (Siplu, 1990) with start of the monitoring at the first day of lay. Figure 1 shows the course of the egg weight during the whole lay. Evaluating this graph, two major critical points at which a large drop in egg weight occurs, can clearly be discerned (as is marked in the figure by I & II). It would be of interest to signal a decreasing sequence of average egg weight before this trend results in a large shift which could also be signaled by normal plotting. For this purpose, Cusum charts were designed from the residuals between the measured average egg weight and the predicted weight based on a proceeding general first order linear model fitted on 20 previous measurements. To clarify the usage of this technique, the shift of average egg weight at these points is discussed. It was not the purpose of this paper to investigate the special cause for the shifts.

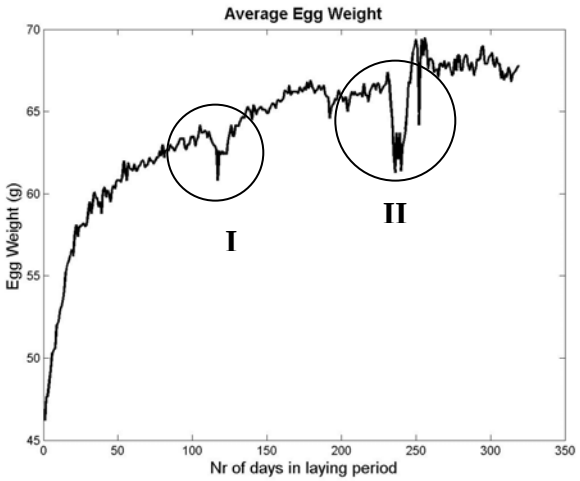

Figure 1: Graphical representation of the evolution of the average egg weight during the whole laying period. Two major critical points (I & II) are highlighted.

In figure 2, a detail of the measured values (2.a) combined with the Cusum chart (2.b) of the residuals from the first large drop is presented. From this picture it is clearly seen that from point 111 till the low value at point 117 there is a sequence of 7 decreasing points. From normal observation, this would probably be noticed at point 115 or earliest at 114. The Cusum chart generates its first alarm at point 112. This alarm is then confirmed in point 113 and further. The Cusum chart also generates 2 false alarms at point 105 of a strong increasing egg weight, and at points 96 for a larger decrease than expected. Next, figure 3 shows the detail of the plot of measured values (3.a) combined with its Cusum chart (3.b) for the second drop. In figure 3.a it can be seen that a decreasing sequence of points starts at point 231 to point 236. When looking at the observations plotted in the whole laying period, this would probably be signaled at point 234 while the Cusum reports a shift from point 233 onwards.

Discussion

From the results of the small scale experiment, it was shown that the decrease in both egg weight and K_{dyn} was detected fairly quickly: a shift of $1.5\cdot\sigma$ or 1 gram was signaled after 2 days for the egg weight and after 3 days for K_{dyn}. It may seem that the chart generates an alarm a bit late, but this is due to the choice and/or values of the design parameters of the cusum chart (k and h). Since the control limits are designed based on the standard deviation of the average in-control egg weights of the 7 first measurements, the limits of the designed chart are not so tight. When monitoring larger groups of chickens, this standard deviation will decrease and the control limits will tighten. The drop in K_{dyn} after applying heat stress is signaled after 3 days. This is later than for egg weight, but could be explained by the larger variation for this parameter. Designing a Cusum chart for a certain variable when looking for deviations of a fixed average value could not be used for the egg weight under long-term conditions, but it will be applicable for other parameters that show a more or less steady mean value under normal conditions like feed consumption, water consumption,…

From the results of the large scale experiment, it can be said that supporting the monitoring of the egg weight by the Cusum chart of the residuals between the measured values and the predicted values of a local fitted linear model, can be very useful for early detection of an occurring shift due to a special cause.

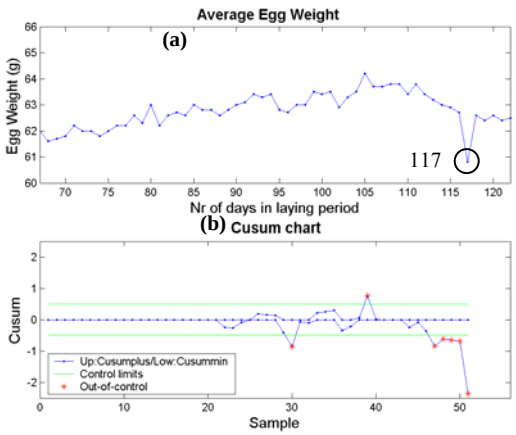

Figure 2: (a) Detail (point 67-122) of the evolution of the egg weight prior to critical point I = point 117. (b) Cusum chart of the residuals between the predicted and the actual value. The X-scale of the Cusum is based on the fact that 40 focused points were taken out. The graphs are ordered that the measurement points match.

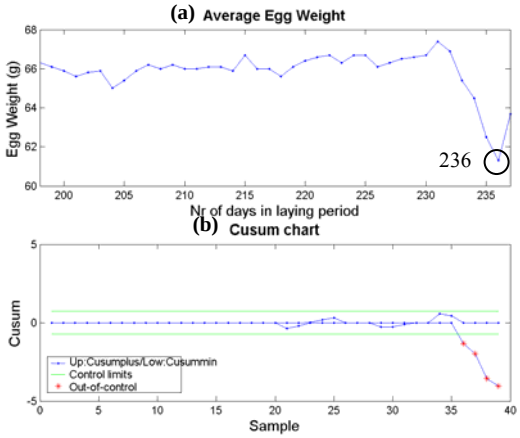

Figure 3: (a) Detail (point 198-237) of the evolution of the egg weight prior to critical point II = point 236. (b) Cusum chart of the residuals between the predicted and the actual value. The X-scale of the Cusum is based on the fact that 40 focused points were taken out. The graphs are ordered that the measurement points match.

For the first critical point discussed, a decreasing egg weight was signaled two days earlier then would have probably been by using normal observational monitoring. For the second critical point the Cusum generated an alarm at least 1 day earlier. Although the Cusum technique might produce some false alarms, as can be seen in figure 4.b., these false alarms are usually invalidated relatively quickly by the in-control status of the following points. Furthermore, it's a normal phenomenon that a control chart generates a false alarm at certain time intervals. The length of this interval depends on the choice of the parameters k and h. For our choice (k = 0.5 & h = 2.0) a false alarm can be expected every 38.5 measurements (38.5 days) (Hawkins & Olwell, 1998). Changing these parameters will increase the interval between two false alarms on the one hand, but will decrease the capability of the Cusum chart to signalize small shifts.

Wanting to design an expert system for the management of a flock of laying hens in an aviary, Lokhorst (1996) developed mathematical curves for different production parameters. Aberrations of the actual parameter measurements from these curves would indicate an out-of-control situation. However, for a general system of monitoring a flock of birds in a certain housing system, it is very difficult to approximate the actual course of a certain dynamic parameter (e.g. egg weight). This system might work for one flock, but will probably fail for another since results of a certain strain of birds on one farm (with a certain feed, management, etc.) can vary greatly from the same strain on another farm. The philosophy that this paper is suggesting, is that a certain flock (on a certain farm, in a certain housing system and managed by a certain farmer) acts as its own reference during the laying period. By using in-control measurement points to predict a next observation, aberrations will be detected compared to the actual average and variation of the flock.

Another possibility to look for deviated values of a flock performance could be using feeder and breeder company standards. These standards cannot take into account the various housing, feeding and management variables. Furthermore, if a flock performance is already beneath these norms in the beginning of lay, it will be very difficult to catch up for the rest of the productive period. When looking at deviations from this norm, in that case a farmer would constantly be alarmed. Therefore, it would be better for the poultry farmer to aim for the best possible performance based on the performance of the flock.

This paper attempted to indicate the benefit of SPC for monitoring parameters of the production process and the quality of consumption eggs. To illustrate this, some examples were given on some egg quality parameters, namely egg weight and egg shell strength. Besides these parameters, it is possible to design control charts for every parameter involved in the production process like temperature, feed consumption, water consumption, mortality etc. Designing control charts for these parameters will be

more straightforward as they lack the dynamical characteristic. They should oscillate around a fixed mean and large aberrations from this value can be easily signalled.

When monitoring a production process, with its specific input and output parameters, it is insufficient to look at the individual course of the parameters. The laying process is a complex system with coherent input parameters on the one side and a resulting egg quality on the other side. To interpret process changes for management matters, it is important to understand the correlation between all parameters and the magnitude of the effect towards final egg quality. Therefore, univariate SPC for monitoring every single parameter and investigating the possibility to detect parameter shifts is the first and important step towards a multi-parametric monitoring of the process which could be obtained by multivariate SPC.

In conclusion, it was shown that SPC (Cusum charts) can be a useful tool for the monitoring of the egg laying process. In particular it was proven that it is possible to monitor the egg weight, with inclusion of its dynamic character in the design of the control chart, and the non-destructively assessed egg shell strength K_{dyn}.

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