Control of food products' quality

Řízení kvality potravinových produktů

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Abstract: The paper deals with one of the significant parts of the concept related to controlling production quality, which is the analysis of production quality stability done for the following production procedure regulation aimed at the food manufacturing industry. The proposed methodology (respecting the change of location and variability of the food quality characteristics) will be introduced on the milk quality regulation. Also, there is the frequent problem solved out here in the report that relates to food quality measuring – their self-regulation by using the statistical calculation of self-regulation higher classes' coefficients and also using the functional statement taken from the differential description.

Key words: quality management, control of food quality, character of food quality

Abstrakt: Příspěvek se zabývá jednou z významných součástí koncepce řízení kvality produkce, kterou je analýza stability kvality produkce pro následnou regulaci produkčního procesu, zaměřená do oblasti potravinovo-zpracovatelského průmyslu. Navržená metodika (respektující změnu polohy a variability kvalitativních znaků potravin) bude představena na regulaci kvality mléka. Dále je vyřešen častý problém měření kvality potraviny – jejich autoregulace s využitím statistického výpočtu autoregulačních koeficientů vyšších řádů a pomocí funkčního vyjádření z diferenciálního popisu.

Klíčová slova: management kvality, řízení kvality potravin, znak jakosti potravin

The answer to question "What does quality actually mean?" is generally vague, as is obvious in the following three concept's definitions. It is not possible to automatically reach the compliance with the standards that specify the user's features, operating characteristics and external parameters of the product (Heelwright 1998). Those are nowadays regarded as the necessary conditions (but not the sufficient ones) which must be followed for the product quality classification. Viewed from a business perspective which is currently the most preferred, the product classification sign is decided neither by a producer nor by an independent evaluator (e.g. prototype testing premises, certificating institutions) but directly by a customer. Therefore, in the business concept the quality is very difficult to be absolutely measurable, but on the other hand, the quality can be anyway evaluated (e.g. using the ordinal or nominal ways to do it), and above all, such quality control in business companies is necessary to be established and developed. The following examples of quality definitions illustrate the above-mentioned fact that on one hand quality may not be clearly defined, but on the other hand, it cannot be ignored. The possible concepts of quality classification are:

– Satisfying the needs and requirements as well as any specific demands of customers at any time and immediately.
– Providing the costumers with such products and services that consistently satisfy them or surpass their expectations (Heelwright 1998).
– Immediate doing the right things in the right ways, the consistent struggle for improvements and above

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all doing it for the costumer's full satisfaction (Hron et al. 2009).

As considering what is common to these definitions, there are three principles on which the quality management stands:
(1) Quality relates to procedures, products, personnel and working environment.
(2) Quality means to at least meet (optimally to surpass) the costumer's expectation related to the value that he/she gained while having purchased the offered product.
(3) Quality is a permanently variable aspect.

In accordance with the three above-mentioned principles, quality represents the dynamic aspect that characterizes the value of the costumer expectations' fulfilment expressed on the offered product, the products' manufacture procedure and also considering the behaviour of workmen who are involved in such procedures. This dynamic concept can be basically understood in two views that influence each other:
– Either it is, as soon as possible, necessary to modify the products as a reaction to the costumer's preferences change.
– Or it is possible to keep the costumer's preferences on the current values by satisfying him/her with the constant quality of output products.

This paper is aimed at solving the second alternative – it proposes a methodology for keeping the production process in food-processing industry steady and also considers the specific nature of controlling such kind of business sector (e.g. output-way autocorrelation and input-way variability).

MATERIAL AND METHODS

Back in 2000, there were production procedures published (Kaiser, Nowack 2000) to which it is not possible to apply the conventional methods of quality regulation designed by Shewhart (Heelwright 1998; Hron et al. 2009). In particular, it is possible to apply the conventional methods to only 15–25% of the food industry procedures (see the study mentioned in Kaiser, Nowack 2000). This restriction in the use of the conventional statistical regulation methodology for food production has mainly been caused by the following specific factors in which the food production features:
– Factor A: Food production procedures do not comply with the normal quality character division quite often.
– Factor B: Food production procedures show some natural changes in the dispersion (or in the variation range) of the quality character (that is observed).
– Factor C: Food production procedures show the natural (or possible) changes in the mid values.
– Factor D: Procedures show possible changes in the dispersion size as well as mid value position.

AD C: Moving the mid value may be (for instance in milk production) caused by the cattle mastitis (mammary inflammation disease). This may consequently lead to the reduction in the biological and nutritional values of milk quality, thereby reducing the possibility of the technological workability.

AD B: Natural changes in the observed character dispersion may be (for example in milk) caused by the temperature rising when the cooled and non-cooled milk necessarily mix together. On the basis of the extensive studies, referred to in Kaiser, Nowack (2000) which include 825 time series, it can be concluded that the procedure types C and D have most frequently been appearing in the food-processing industry. This fact also changes the possibility to use the classical regulation charts (by Shewhart) and in such way, the priority is being given to the so- called regulation charts with extended the regulation limits, such charts include the function to change the mid value and, where applicable, also dispersion of the process.

In food production, the quality of the entry material often varies depending on the year season conditions, geographic location, etc., therefore in addition to the changes in the location and the variability of processes, also the changes in the probability division of the observed quality character should be considered.

Another problem the management for quality of the food-processing industry has also to deal with is the frequently appearing autocorrelation of the observed character (mutual relation of the particular observation to the observations which were held before). The data autocorrelation means another failure to the basic condition that must be followed as using the standard regulation charts. If using the auto-correlated data for the Shewart's chart, it will cause an excessive narrowing of the regulation limits and many unnecessary signals.

The risk of the unnecessary signal represents the first class errors which occur when the process is statistically stable and the value of selection characteristics randomly deviates outside the regulation limits. This practically calls up wrongful concerns of poor quality of food production. Such unnecessary intervention to the newly adjusted regulation of the otherwise overmasterable process may cause an unnecessary increase of expenses.

As a possible solving point of the mentioned problems, it is advised to make some modification of the classical method (for the analysis of the production process stability and quality regulation) to set a new one, which will better respect the particularities of the food production process management ways.

RESULT AND DISCUSSION

The proposed method which respects the change of location and variability of the qualitative characters of foodstuff will be introduced in milk quality regulation.

Currently, the dairy companies legislation is being harmonized with the European Union legislation. The harmonization begins with milk materials rated in the Czech Republic by the ČSN 570529 Standard. The standard is harmonized with European Union Directive No. 92/46. The standard CSN 570529 is legally binding and thus the parties which conclude the supply-costumer contracts should respect it due to its conformity with the Directive 92/46, the directive which is required when exporting dairy products to the EU countries. A supplier-customer relationship between the primary milk production bodies and dairies is always based on the hygiene limits contained in the CSN 570529 standard. In the frame of the correct manufacture documentation and the total system of the error-free milk production, there is currently a base of the raw cow's milk to be followed. The basic quality characters of this milk are subject to be evaluated (Cooper 2007).

– CPM – the total number of mesophilic microorganisms[1],
– number of somatic cells,
– presence of inhibitory substances

The listed basic characteristics of milk quality have a key significance for achieving the required hygienic quality of dairy foods; they are evaluated as binding characteristics. Other features that in main terms determine the technological quality of milk raw materials and also yield and thus also the economic result of production are known as the basic non-binding characteristics. It regards the milk composition, the quantity of fat, protein, the quantity of fat-less dry mass (TPS). For some of producers (farmers), in supply-costumer contracts there are included additional characteristics like for instance the limits of CPM and PSB related to milk quality. Also some more microbiological criteria can appear among such additional quality characteristics: the number of the psychrophilic microorganisms (up to 50 000 per ml), the number of the coliform bacteria (up to 2 000 ml), the number of the thermoresistant micro-organisms (up to 2 000 per ml), the number of the spore-forming anaerobic bacteria (Cooper 2007). Our 570529 CSN Standard also provides additional quality characteristics like for instance the minimum presence of calcium, vitamins A, B and B2.

First, the problem of milk quality variability should be solved. Since the food-processing procedures (mainly in livestock production) have a wider variability of entries (which is caused by the uniqueness of every single domesticated animal), it will be quite reasonable to extend the variability of the output food products. It is necessary that this extension does not exceed the mandatory hygienic limits. The question of stability (a more detailed explanation is given in the booklet [Hron et al. 2009]) can be solved by extending the regulation limits. If an average value $\bar{x}$ and dispersion R are used for statistical regulation, then the process can be considered as stable only if the number of values $\bar{x}$ and R is lying out of the regulation limits (calculated from natural variability) does not exceed a previously stated value. Usually, the need to extend the regulation limits is also associated with the time factor. If we (in short-term) observe the food quality character (up to approx. 200–300 measurements), it is very realistic to describe this process using the Gaussian distribution and then it is also realistic to regulate it by using the Shewhart control chart. But, if we observe the process in the longer time term, then the output values will not be stable, they will be just locally stable due to the large variability of inputs into the production process, due to the inherent variability.

The problem of position (and variability) of the food product qualitative character, depending on the time factor, is shown in the following experiment. The quality of milk in terms of one of the mandatory criteria is defined by using the total number of the mesophilic microorganisms CPM. The standard sets a limit CPM = 100.000 per 1 ml as the tolerable maximum. Doing so, the reproduction of the mesophilic microorganisms just slows down a little bit when being radically cooled, which means that the qualitative factor is considered as a function of time. The subsequent heat treatment (pasteurisation) will significantly reduce the number of micro-organisms. Now let us consider the problem of the micro-organisms concentration in milk from the view of time. The reservoir (tank) of milk can be defined as the internal

[1]Mesophyl – the organism that prefers humid environment.

tank that has its volume V (m^3) and the input flow of the newly produced milk which has an average flow value v (m^3/s) (derived from discrete infusion). If we define v_t (n/m^3) as the concentration of the mesophilic microorganisms in the milk input flow to the reservoir and x_t (n/m^3) as the microorganisms' concentration in the milk output collection from the tank for further processing, we can describe this system with a linear differential formula (first degree formula). Within this system, we will assume homogeneity in the microorganisms concentration, which we can practically achieve by stirring the milk. The description of the system is as follows:

$$x_t = w_t + T \times \frac{dx_t}{d} \quad (n/s) \tag{1}$$

where T means the system constant defined as the time for which the milk reservoir volume V would be filled up with steady inflow v. T is mathematically defined as:

$$T = \frac{V}{v} \quad (s) \tag{2}$$

Since this is an inhomogeneous formula, it will be necessary to determine the initial conditions and then to find out the particular solution. To obtain the solution, we can use the method of variation of constants. The homogeneous part of formula is to be solved by separation of variables. If the initial condition is $w_0 = w_t$ within the time $t = 0$, then the concentration of microorganisms in the milk collection out of the tank x_t is expressed as:

$$x_t = w_0 \times \left(1 + e^{\frac{-t}{T}}\right) \quad (n/s) \tag{3}$$

In the practical situation, it is not possible to measure the output microorganisms concentration x_t continuously; it should be measured discreetly in the particular time intervals. So in reality the following recurrent formula which is valid for the output concentration of microorganisms x_t should be used:

$$x_t = w_0 \times \left(1 + e^{\frac{-t}{T}}\right) \quad (n/s) \tag{4}$$

$$x_{t-1} = w_0 \times \left(1 + e^{\frac{-t+1}{T}}\right) \quad (n/s) \tag{5}$$

And using substitution (5) to (4), we will get:

$$x_t = x_{t-1} + \left(w_0 + x_{t-1}\right) \times \left(1 + e^{\frac{-\Delta t}{T}}\right) \quad (n/s) \tag{6}$$

It is obvious from the relation in (6) that the output mesophilic micro-organisms concentration is dependent on both the concentration of microorganisms in milk detected at the input flow w_t as well as the concentration of micro-organisms found in the milk capacity from the previous withdrawal out of the tank x_{t-1}. If we mark a parameter of microorganisms exponential growth number such as:

$$a = 1 + e^{\frac{-\Delta t}{T}} \tag{7}$$

then the formula (6) turns into the following form:

$$x_t = a \times w_t + (1 + a) \times x_{t-1} \quad (n/s) \tag{8}$$

In the field of practice, it is easy to satisfy the requirement that the microorganisms concentration in milk should not be a non-correlated quantity (in terms of microorganisms concentration in milk tank – for example in such events when the tank is not connected to another reservoir performing the same purpose). But then there may occur the autocorrelation between the microorganisms concentrations measured in each collection from tanks (in our time interval between x_t and x_{t-1}). This autocorrelation functionally[2] expressed with an addition to figure one taken from the coefficient of exponential growth:

$$Rxx\ (t) = 1 - a = 1 - \left(1 + e^{\frac{-\Delta t}{T}}\right) = -e^{\frac{-\Delta t}{T}} \tag{9}$$

According to Table 1, it is obvious that to ensure a low impact of previous milk collection at microorganisms concentration, it is important to keep a sufficiently long time interval between each sample taking.

The ***Rxx*(*t*)** values in Table 1 are calculated by adding the values from the table's left column into the formula (9). Negative values of the autocorrelation coefficient show us that if we measure the higher level in the output concentration of mesophilic microorganisms within the time period of x_{t-1}, it will have 'blunting' effect on the output concentration in the time of x_t. If we admitted a weak relation between the output values of concentrations, we would have

[2]As for the field of practice, the auto-correlation coefficient is being estimated statistically.

Table 1. Values of autocorrelation coefficient $Rxx(t)$ in dependence on ratio between sample taking intervals and reservoir filling up

Time ratio $\Delta t/T$	Autocorrelation coefficient $Rxx(t)$
1	−0.368
0.75	−0.472
0.5	−0.607
0.25	−0.779
0.05	−0.951

to extend the interval between the sampling at least to a half of the time that is needed for full filling of the milk reservoir.

Now, after describing the impact of autocorrelation on the course of measuring the quality of the food product, we can proceed to make own quality regulation. Regulating of the quality will be presented by using the process of milk production control. References Cooper (2007) state the main precautions which should be followed when handling and the subsequent processing of the milk products:

– Filtering process should immediately follow after milking in order to remove the foreign impurity matters that may be present in milk.
– Milk should be immediately cooled (preferably to 4 degrees of Celsius) to maintain its quality. Low temperatures prevent from expansion of the microorganisms living in the milk. Such microorganisms cause milk quality deterioration. If these organisms are present in milk in their high concentrations and also due to the fact that they are pathogenic, they may represent a danger to the consumer health.

It is also necessary that the EU legislation administering production rules for hygienically clean milk is taken into account. This legislation describes biological limits of concentrations before and after the heat treatment:

– Pasteurisation should be performed in its adequate way and should comply with the requirements of

Table 2. Values of mesophilic organisms in pasteurized milk measured in samples during the period of 60 days

Time rank of the sample (day)	Number of mesophilic organisms (in thousands CPM)	Time rank of the sample (day)	Number of mesophilic organisms (in thousands CPM)	Time rank of the sample (day)	Number of mesophilic organisms (in thousands CPM)
1	33.9	*21*	32.3	*41*	32.9
2	35.8	*22*	33.4	*42*	35.7
3	31.3	*23*	31.5	*43*	31.7
4	33.8	*24*	33.7	*44*	31.9
5	30.9	*25*	33.4	*45*	34.4
6	31.8	*26*	31.2	*46*	33.2
7	32.7	*27*	35.8	*47*	32.4
8	31.3	*28*	31.5	*48*	33.2
9	35.6	*29*	33.9	*49*	34.8
10	36.1	*30*	32.6	*50*	31.5
11	36.0	*31*	40.5	*51*	33.4
12	35.4	*32*	40.7	*52*	31.8
13	37.9	*33*	32.0	*53*	35.6
14	34.4	*34*	31.5	*54*	31.6
15	32.1	*35*	31.6	*55*	37.1
16	31.1	*36*	34.3	*56*	34.0
17	30.9	*37*	32.9	*57*	35.6
18	37.8	*38*	39.1	*58*	33.5
19	33.4	*39*	33.6	*59*	35.1
20	31.8	*40*	34.4	*60*	33.7

Directive 852/2004 concerning hygienic rules for foodstuff.
– The total number of micro-organisms in raw milk (specified in the incubation temperature of 30°C) should not exceed 300 000 per 1 ml; the same number in processed milk should not exceed 100 000 per 1 ml.

A dairy producer (farmer) may have the criteria which are stricter than those of the hygienic limits, particularly if having progressive technologies available to the processing of raw milk. The following Table 2 shows the numbers of the mesophilic microorganisms in the pasteurized milk samples taken during the period of 60 days.

As applying the methods of descriptive statistics to these data, we will find the following information about the measured collection:
Arithmetic average $\bar{n}$ = 33.73 thousand CPM
95% confidence interval: $\bar{n}$ (min. 95) = 33.1 and $\bar{n}$ (max. 95) = 34.3 thousand CPM
Standard deviation: σ_n = 2.16 thousand CPM
Inclination coefficient = 0.908 (inclination from zero point is not significant);
Acuteness coefficient = 0.597 (inclination from zero point is not significant);

Furthermore, we will determine the autocorrelation coefficient ρk of the first, second and third class[3] according to the relation as follows:

$$\rho_k = \frac{\sum_{t=1}^{n-k}\left(x_t - \bar{x}\right)\times\left(x_{t-1} - \bar{x}\right)}{\sum_{i=1}^{n}\left(x_t - \bar{x}\right)^2} \qquad (10)$$

First class autocorrelation coefficient:
ρ_{kl} = –0.087 – is not significant;
Second class autocorrelation coefficient:
ρ_{k2} = +0.141 – is not significant;
Third class autocorrelation coefficient:
ρ_{k3} = +0.006 – is not significant;

According to these three classes, we can see that the autocorrelation measurement is correct because we have been taking the samples just once a day and thus we have found out a very small value of $\Delta t/T$ (see Table 1). Data from this table comply with the regulation requirements of the Shewhart's charts except for the values of normality (data distribution is sinistrally asymmetrical). Now we will determine the regulation limits for the individual values of quality characteristics. Specifically, these regulatory limits are: The upper control limit (UCL), lower control limit (LCL) and the central line (CL). For the known values of both parameters $\bar{n}$ and σ_n, the central line equals to the average value:

$$CL = \bar{n} = 33.73 \text{ (thousand CPM)} \qquad (11)$$

We will determine the upper and lower control limit in accordance with the tolerable risk of the qualitatively different products. In practice and with regard to expenses connected to technologies by which the defectless products are made, the usual risk level equals $\alpha = 0.00135$ ($u_{1-\alpha} = 3$) (which corresponds with zone $6 \times \sigma_n$. And therefore, the values of the lower and upper control limits are as follows:

$$LCL = \bar{n} - u_{1-\alpha} \times \sigma_n = 33{,}73 - 3 \times 2.16 = = 27.25 \text{ (thousand CPM)} \qquad (12)$$

$$LCL = \bar{n} + u_{1-\alpha} \times \sigma_n = 33.73 + 3 \times 2.16 = = 40.21 \text{ (thousand CPM)} \qquad (13)$$

Figure 1 (devised from Table 2 and from the values obtained from formulas (1), (12) and (13)) shows the regulation chart for the individual values. It is obvious from the chart that most values are closer to the LCL point; therefore the sample distribution is left-side asymmetrical. The mesophilic microorganisms´ values exceeded the LCL level in the 31st and 32nd sample. In terms of practical matters, it is disputable to use the LCL for qualitative characters with decreasing preference of higher values. In terms of milk product quality, it will not be a problem if the qualitative character moved above its optimal standard limit point (in our case this would be under the LCL). However, if it is difficult to achieve values over the optimal standard limits of the qualitative

[3]There can occur not only the first class dependence, but also that one of the higher class – e.g. such the process periodicity. The autocorrelation rate always moves within the range of <–1, 1> and the values at both ends of this interval represent the strongest correlation (dependence) while the zero value on the contrary represents the state of independence. For example, if the value of the autocorrelation coefficient No. 2 reaches a too high level, it means that the process has got the periodicity of two cycles. This is useful when we want to verify whether there are periodical dependences between two observed processes. If the periodicity in milk production reaches values higher than those of the first class, it would signalize some error occurred in the applied technology of milk retrieving and processing (for example a butt end of the milking device was insufficiently disinfected, the milk came from an animal showing clinical signs of mastitis, etc.).

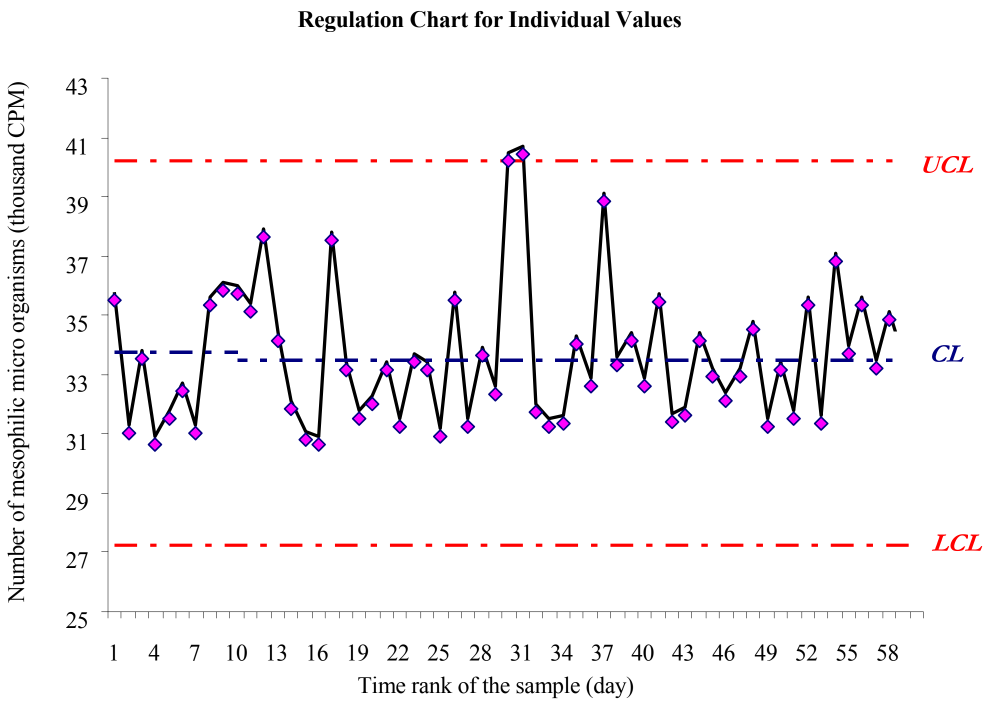

Figure 1. Violation of normality in the distribution of the qualitative milk character and the violation of stability limits in two cases

character during the normal state of operation, such level limit can be very useful. A long term crossing of this limit may represent a warning signal which is indicating that there occurred a systematic error during the qualitative character measurement and such measuring method does not provide the real data.

The mentioned regulation limit LCL (in some free generalisation) may be considered as a signal threshold which indicates that either there was a radical improvement of the process technology efficiency or the supply of the input raw material rapidly increased its quality. If neither of the mentioned factors caused such exceeding of the LCL, then it could mean a serious inaccuracy in the measuring or in the diagnostically method which was used to measure the qualitative character. On the other hand, the UCL regulation limit[4] can be considered as a preliminary warning signal which indicates that the hygienic limit stated in the Directive may not be observed in the close future. The practice of the food-processing industry often requires (beside hygienic regulations that are often understood as emergency limits) other additional limits that can in advance signalize the possibility of emerging of some special cause of variability of the qualitative product criteria.

RESULTS AND DISCUSSION

The traditional approach to the manufacturing of food products is based on the dependences of production that create a product and quality control in which the final product should be checked. The units that do not comply with the specifications (stated in the mandatory Hygienic Directive) should be sorted out. Such strategy based on different units detection is often too expensive because it assumes that the control is performed not sooner than the expensive production of food product has been performed. Instead, it is much more effective to set a prevention strategy and so to avoid losses on production of an unusable product. This can be achieved through obtaining the information about the production process and its subsequent analysis in order to get possibility to affect the own production process.

The aim of this report lies in introducing such kind of procedure which would allow reflecting the special nature of the production process control in the food-processing industry which disposes of the second class variability. For example, this second type of variability is caused by the insufficient homogeneity of the input (animal, vegetable) raw material, by the damaged collecting facilities, the irregular

[4]If there is a qualitative sign with a growing value preference, e.g. the presence of ingredients that increase the nutritional values of foodstuff, then the role of the limits LCL and UCL would be reversed.

performance of the production or the inaccuracies in the testing equipment.

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