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One approach in using multivariate statistical process control in analyzing cheese quality

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Abstract

The objective of this paper was to investigate possibility of using multivariate statistical process control in analysing cheese quality parameters. Two cheese types (white brined cheeses and soft cheese from ultra-filtered milk) were selected and analysed for several quality parameters such as dry matter, milk fat, protein contents, pH, NaCl, fat in dry matter and moisture in non-fat solids. The obtained results showed significant variations for most of the quality characteristics which were examined among the two types of cheese. The only stable parameter in both types of cheese was moisture in non-fat solids. All of the other cheese quality characteristics were characterized above or below control limits for most of the samples. Such results indicated a high instability and variations within cheese production. Although the use of statistical process control is not mandatory in the dairy industry, it might provide benefits to organizations in improving quality control of dairy products.

Key words: cheese, quality, statistical process control

Introduction

According to the official statistical data the total milk production in Serbia is around 1.5 billion litres per year (L/year). Approximately 700 million litres (nearly 50 %) are processed in 200 dairy plants of different capacities (Yearbook, 2011; Analysis, 2012). The big industrial dairy plants are mainly focused on the production of milk (pasteurized and sterilized) and fermented milks (liquid and solid yoghurts), while cheese production represent app. 20% of total milk processing (Popovic, 2009). Dairy sector in the Republic of Serbia is of high economic importance for the country (Djekic et al., 2013a).

Cheese production has a long tradition of production and consumption in the Balkan region, including Serbia. The total cheese production in Republic of Serbia is app. 20,000 tons per year with little variations over years. Soft cheeses, mainly white brined cheeses (WBC) are the most important group of cheeses in Serbia as well as neighbouring countries (the Mediterranean region). White brined cheeses are the most widely produced and consumed cheeses in Serbia and represent about 60 % of the total cheese consumption (Dozet et al., 2006). Currently, WBC in Serbia is produced by both, traditional and industrial, methods (Pudja et al., 2012). However, for the last two decades large

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number of cheese factories started to produce white cheeses from ultra-filtered milk (UF cheese) in type of Feta cheese, which is similar to traditionally produced white brined cheeses. The industrial production of soft cheeses, mainly in type of WBC, represents about 35 % of total cheese production in Serbia (Kljajić et al., 2009).

The quality and the safety of dairy products are of highest importance and represent one of the main goals of the dairy industry. For the last few decades, food producers were strongly challenged with new regulations and consumer oriented market that requires continuous improvement and development in order to get better safety and quality of products. Liberalization of the EU market pushed the industry to be more consistent with regulations and with high and constant quality of products. Hence, it is very important to perform modern statistical analysis in different food sectors including quality and safety characteristics of dairy products. Even more, there it became evident that some modern statistics originated from food processing and agricultural production (Lim and Antony, 2013).

According to Lim and Antony (2013) the application of statistical process control (SPC) is much more common in the dairy industry in comparison to other groups of food producers. Such findings were based on the nature of dairy products which could be easily contaminated why it required implementation of powerful quality control techniques.

The aim of this study was to investigate the possibility of using multivariate statistical process control for analysing quality of two type of cheese produced in Serbia.

Statistical process control

Variability is inherent in every process due to two main causes: (a) natural or common causes, and (b) special or assignable causes. A process that is operating with only common causes of variation is in the state of statistical control (Mahesh and Prabhuswamy, 2010). SPC is a quality tool used to detect the occurrence of assignable causes, and where possible, eliminate the variability in the processes. These features promoted SPC as a tool for analysing quality problems and improving the performance of both, the production process and the product in all industries (Gildeh et al., 2014).

Control charts are the most common tools in SPC. Depending on the type of data (variable or attribute), many types of control charts have been developed such as X and R charts, EWMA (exponentially weighted moving average) charts, control charts for standard deviation (σ charts) and charts related to defects and defective products (np-chart, p-chart, c-charts, u-charts), etc. (Oakland, 2008). According to the survey on quality management effects and the use of quality tools in companies producing food of animal origin in the Republic of Serbia, high rate of application of this statistical quality tool was reported in almost 40 % of the companies (Djekic et al., 2014).

The aim of using control chart in food business, and further deployment through SPC, is to increase knowledge about the process, to steer it to behave in the desired way and to reduce the variation of final product parameters, or in other ways improve performance of a process (ISO, 2006). In choosing quality characteristics to be followed, the choice is either in analysing a characteristic that is currently experiencing a high number of nonconformities (Juran, 1998), or to control a parameter that is critical to quality or food safety (Djekic et al., 2013b). This tool is rarely used in the area that deals with microbial contamination (Augustin and Minvielle, 2008). Some studies were published in introducing the application of statistical process control into HACCP systems and validation of CCPs (Hayes et al., 1997; Ittzés, 2001; Srikaeo and Hourigan, 2002).

Autocorrelation or seasonal dependency is a measure of the dependence between data points that are collected over time. If the autocorrelation is moderate or high, it can lead to incorrect test results. Auto-correlated data exhibit positive autocorrelation, which can reduce the within-subgroup variation and lead to a higher false alarm rate (StatSoft, 2013).

Multivariate statistical process control

In many industries, it is required to monitor several quality characteristics at the same time. These quality characteristics are in most cases correlated, and therefore, separate univariate control charts for monitoring individual quality characteristics may not be adequate for detecting outliers and changes in the overall quality of the product (Abu-

Shawiesh et al., 2014b). When there is more than one outlier, the detection situation becomes more difficult due to masking and swamping. Masking occurs when we fail to detect the outliers while swamping occurs when observations are incorrectly declared as outliers (Abu-Shawiesh et al., 2014a). Missing data or lack of data for some variables has a severe effect on the ability to monitor the process or detect shifts in the process mean. Also, this weakens the correlation between the variables, and can result in incorrect conclusions (Elsayed, 2000).

The quality control in the food industry is related to a set of multiple features such as sensory properties, physical, safety, chemical and nutritional value, net weight of the product, viscosity, solid-to-liquid ratio, salt content, fat content, vacuum seal pressure, etc. (Grigg and Walls, 2007; Elsayed, 2000).

Statistical process control, initially applied to a single quality characteristics (of a process or a product), proved inadequate in studying simultaneously several quality characteristics of the same product.

The first original study in multivariate quality control was introduced by Hotelling (Hotteling, 1947). Three of the most popular multivariate control statistics are Hotelling's T^2, the MEWMA (Multivariate Exponentially-Weighted Moving Average) and the MCUSUM (Multivariate Cumulative Sum) (Elsayed, 2000). T^2 charts have been extensively investigated and accepted as appropriate statistical techniques to the simultaneous control of several product characteristics (Abu-Shawiesh et al., 2014b). These control charts can take into account the simultaneous nature of the control scheme and the correlation structure between the quality characteristics (Alt, 1985). In particular, the multivariate control charts can be used as a tool to detect multivariate outliers, mean shifts, and other distributional deviations from the in-control distribution (Abu-Shawiesh et al., 2014b). In statistical quality control concepts, an outlier is defined as an observation that deviates so much from other observations as to arouse suspicion that it was generated by a different mechanism (Hawkins, 1980). Outliers have a big influence on resulting estimates and cause any out-of-control observations to remain undetected (Abu-Shawiesh et al., 2014a).

This study covers the motivation for using Hotelling's T^2 multivariate quality control in cheese production.

Materials and methods

Materials

During year 2012, two types of cheeses have been analysed for different physical characteristics and chemical composition. The two types of cheese were: (i) soft cheese from ultra-filtered milk (UF cheese) with declared minimal 45 % of fat in the dry matter (FDM) produced in two packages in 250 g and 500 g; (ii) white brined cheese with declared minimal 45 % of FDM produced in two packages in 250 g and 450 g. In total 506 samples of cheeses have been collected and analysed.

A total of 84 samples of UF cheese were analysed for the following quality characteristics: milk fat and dry matter contents, pH value and salt content (NaCl), while FDM and moisture in non-fat solids (MNFS) were calculated.

According to the Serbian regulation, cheeses should be classified and declared according to fat in dry matter content as well as moisture in non-fat solids in one of several groups as follows: extra fat, full fat, semi fat, reduced fat and/or extra hard, hard, semi hard and soft cheeses, respectively (Regulation, 2014). On the other hand, pH value and NaCl content represent significant parameters of cheese quality (Guinee and Fox, 2004).

A total of 422 samples of white brined cheese were analysed for the following quality characteristics: milk fat and dry matter contents, salt (NaCl) and proteins contents, while FDM, MNFS and carbohydrates were calculated.

Methods of physical-chemical analysis

The milk fat and the dry matter contents of cheeses were determined by referent methods (ISO, 2008; ISO, 2004). The pH value was determined using a pH meter (Consortia C931, Belgium), while proteins were determined by the Kjeldahl method (ISO, 2001). The milk fat in the dry matter and moisture in non-fat substances were calculated. All chemical analyses were performed in an ISO 17025 accredited laboratory.

Statistical processing

The statistical process in analysing of cheese quality characteristics was divided into two phases.

Table 1. Statistical control process results for "UF cheese"

Phase I 84 samples	FDM	MNFS	pH	NaCl
Mean values ± standard deviation ($\mu \pm \sigma$)	46.052±0.887	77.385±0.903	4.817±0.142	2.105±0.273
UCL	47.967	79.493	5.058	2.552
LCL	44.137	75.277	4.576	1.657
Autocorrelation test	Pass	Pass	Pass	Pass
Process capability test	Fail	Pass	Fail	Fail
Number of samples out of control limits	6	0	8	10
Phase II - 3 characteristics (subsample with 59 samples)				
Mean values ± standard deviation ($\mu \pm \sigma$)	45.869±0.635	77.283±0.978	4.780±0.042	
UCL_1	47.597	79.526	4.877	
LCL_1	44.140	75.039	4.683	
Normality test (Anderson - Darling test)	Pass	Pass	Pass	
Outlier test (Dixon's r22 Ratio Test)	Pass	Pass	Pass	
Phase II - 3 characteristics (subsample with 31 samples)				
Mean values ± standard deviation ($\mu \pm \sigma$)	45.685±0.534	77.473±0.824		2.207±0.037
UCL_1	47.125	79.700		2.287
LCL_1	44.245	75.246		2.128
Normality test (Anderson - Darling test)	Pass	Pass		Pass
Outlier test (Dixon's r22 Ratio Test)	Pass	Pass		Pass
Phase II - 4 characteristics (subsample with 27 samples)				
Mean values ± standard deviation ($\mu \pm \sigma$)	45.626±0.524	77.468±0.874	4.783±0.032	2.211±0.037
UCL_1	46.967	79.909	4.864	2.288
LCL_1	44.285	75.027	4.701	2.133
Normality test (Anderson - Darling test)	Pass	Pass	Pass	Pass
Outlier test (Dixon's r22 Ratio Test)	Pass	Pass	Pass	Pass

UCL - upper control limit, LCL - lower control limit, FDM - fat in dry matter, MNFS - moisture in non-fat substances

Phase I was performed for detection of out-of-control situations for each of the cheese quality characteristics (Trip and Wieringa, 2006). In order to analyse each of the selected characteristics separately, mean and standard deviations were calculated, as well as a process capability test was run with to determine whether one or more points were outside the control limits. All samples that exceeded the limits for at least one of the quality characteristics were excluded from further analysing/processing. As explained above, samples were analysed randomly during one year and it was not expected to meet any type of correlation. Regardless of this assumption, autocorrelation test was performed in this phase and the correlation between consecutive data was set at ≤0.2. Phase II included the analysis of samples/data which were within the control limits for selected quality characteristics. This phase consisted of the following: (a) normality test, (b) outlier test (c) calculating bivariate charts with 99 % confidence region and (d) using Hotteling T^2 model. Autocorrelation test was set at calculating correlation between consecutive data ≤0.2. Anderson-Darling test was performed for testing normality of the data for each of the physical characteristics observed. Dixon's r22 Ratio Test was performed for identified possible outliers. Data were processed using ©Microsoft Office Pack 2007 and Minitab 17.

Table 2. Statistical control process results for "white brined cheese"

Phase I - 422 samples	P	FDM	MNFS	NaCl	CH
Mean values ± standard deviation ($\mu\pm\sigma$)	12.166±0.272	45.960±0.638	78.885±0.545	1.566±0.077	2.779±0.109
UCL	12.762	47.610	80.230	1.646	3.035
LCL	11.570	44.310	77.541	1.487	2.507
Autocorrelation test	Fail (r=0.4)	Pass	Pass	Fail (r=0.5)	Pass
Process capability test	Fail	Pass	Pass	Fail	Fail
Number of samples out of control limits	10	0	0	85	10
Phase II - 5 quality characteristics (subsample with 206 samples)					
Mean values ± standard deviation ($\mu\pm\sigma$)	12.046±0.166	45.955±0.646	79.007±0.419	1.567±0.030	2.776±0.098
UC L1	12.449	47.571	80.067	1.624	2.993
LCL 1	11.643	44.339	77.947	1.519	2.518
Normality test (Anderson-Darling test)	Pass	Pass	Pass	Pass	Pass
Outlier test (Dixon's r22 Ratio Test)	Pass	Pass	Pass	Pass	Pass
Phase II - 4 quality characteristics (P, FDM, MNFS, NaCl); subsample with 243 samples					
Phase II - 4 quality characteristics (P, FDM, MNFS, CH); subsample with 387 samples					
Phase II - 4 quality characteristics (FDM, MNFS, NaCl, CH); subsample with 249 samples					

UCL - upper control limit, LCL - lower control limit, FDM - fat in dry matter, MNFS - moisture in non-fat substances, P - protein content, CH - carbohydrates

Results and discussion

UF cheese

Phase I revealed that from 84 analysed products, only MNFS was within the control limits. All of the other analysed quality characteristics (FDM, pH, NaCl) were above or below the calculated control limits (Table 1).

Phase II excluded results exceeding the control limits and created a subsample containing all results within the control limits into three different combinations: (a) for three quality characteristics (pH, FDM and MNFS), (b) for three quality characteristics (FDM, MNFS and NaCl) and (c) for all four quality characteristics (pH, FDM, MNFS, NaCl).

The most unstable quality characteristic was the NaCl content, which indicated an unstable salting process, despite the high level of automation. When iteration towards creating a subsample with pH, FDM and MNFS was performed, the subsample comprised 59 samples. However, when pH value was replaced with the NaCl content, and another subsample was created with FDM, MNFS and NaCl, only 31 samples remained. Finally, a subsample containing all four characteristics within the control limits, consisted of only 27 samples. Such results showed that dropout of out-of-control samples was almost 70 % for all four characteristics.

Second step in phase II was to statistically process the subsamples. The results showed that all subsamples passed both, normality and outlier tests. In the case of a bivariate Normal process, a control ellipse may be used. Bivariate charts were calculated for all combinations of the four characteristics. A 99 % confidence region was drawn in order to outline the potential of out-of-control samples for the two quality characteristics (data not shown). These results showed that the bivariate charts did not display any out-of-control for any combination of the four quality characteristics.

The T^2 control charts are presented in Figures 1 and 2. All of the T^2 values were below the 99 %

confidence limit for a multivariate control chart with three quality characteristics which was in line with the bivariate charts containing no out-of-control points (Figure 1). However, expanding the statistical processing on all four quality characteristics identified one sample above the confidence limit (Figure 2). A failed point indicated the existence of a non-random pattern in the data, whicmay be a result of a special-cause variation.

White brined cheese

Phase I revealed that only FDM and MNFS were within the control limits for the entire sample (Table 2). For other three quality characteristics (proteins, NaCl, carbohydrates), there were samples with results above or below the control limits. This phase also revealed that two quality characteristics (P, NaCl) failed the autocorrelation test with a moderate degree of correlation (r = 0.4 for P and r=0.5 for NaCl) between consecutive data points.

Phase II consisted of excluding results out of control limits and creating subsamples with all results within the control limits in four variants: (a) for four quality characteristics (P, FDM, MNFS, NaCl), (b) for four quality characteristics (P, FDM, MNFS, CH) (c) for four quality characteristics (FDM, MNFS, NaCl, CH) and (d) for all five quality characteristics (P, FDM, MNFS, NaCl, CH).

Figure 3 depicts the T^2 control charts for selected four quality characteristics where it can be observed that two (Figure 3a) and one (Figure 3b) of the T^2 values lie above the 99 % confidence limit. The most unstable quality characteristic was the NaCl content affecting the process stability. Performing iteration towards creating stable subsamples for four quality characteristics revealed that when NaCl was among the four quality characteristics, almost 200 samples were excluded. Cheese salting is a very complex process that is affected by numerous factors such as the salting method, cheese geometry, salting time, temperature etc. (Guinee and Fox, 2004). Consequently, when NaCl was not included, only 35 samples were excluded. Finally, a subsample with all five characteristics within the control limits consisted of only 206 samples. Such activity showed that dropout of out-of-control samples was over 50 % for all five characteristics.

Second step in the phase II was to statistically process the subsamples. Considering the obtained results, all subsamples passed both, normality and outlier tests. Bivariate charts were calculated for all combinations of the five characteristics. The ellipsoid presented in Figure 4 represents the 99 % probability area of the bivariate Normal process for the two quality characteristics. The out-of-control points presented on bivariate charts showed that although all of the analysed characteristics were within control limits, these charts may be a useful tool to highlight the out-of-control samples. Figure 4 presents two bivariate charts with out-of-control limits. Figure 4a presents the two quality characteristics P and MNFS, and samples #34 and #94 were out-of-control. Figure 4b presents quality characteristics MNFS and CH where sample #198 is out-of-control. Other bivariate charts had no out-of-control samples.

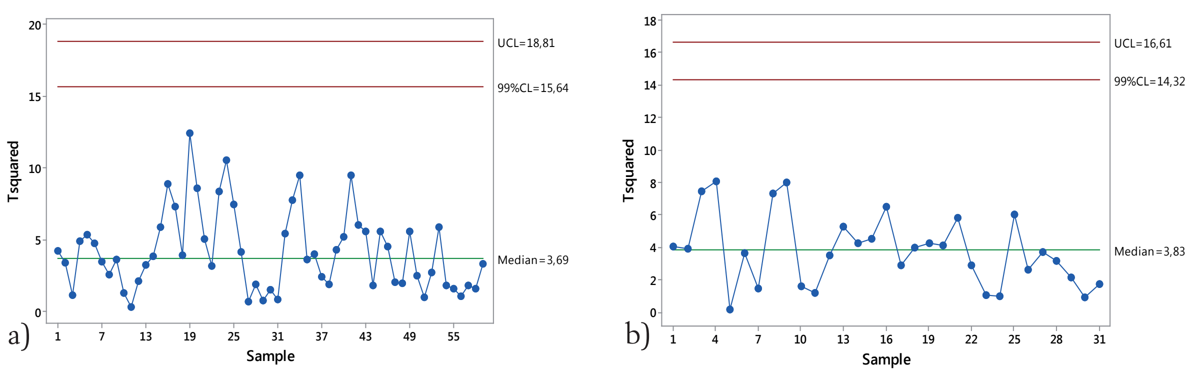


Figure 1. T^2 control chart for "UF cheese" three quality characteristics: a) pH, fat in dry matter, moisture in non-fat substances; b) fat in dry matter, moisture in non-fat substances, NaCl

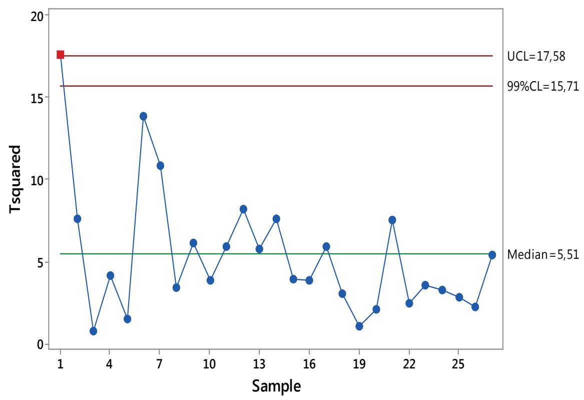


Figure 2. T^2 control chart for "UF cheese" for four quality characteristics (pH, fat in dry matter, moisture in non-fat substances, NaCl)

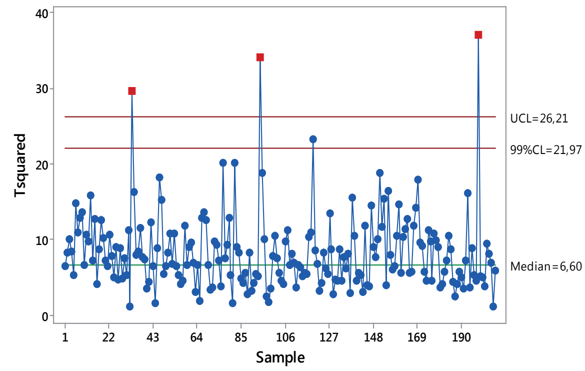
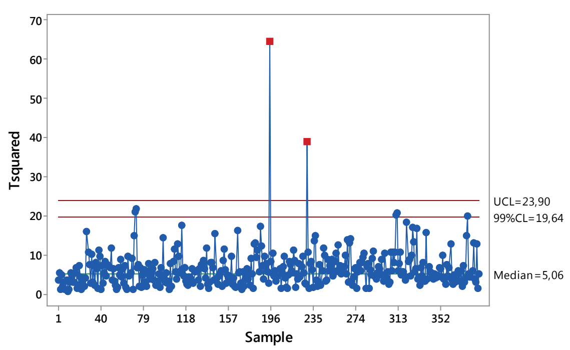
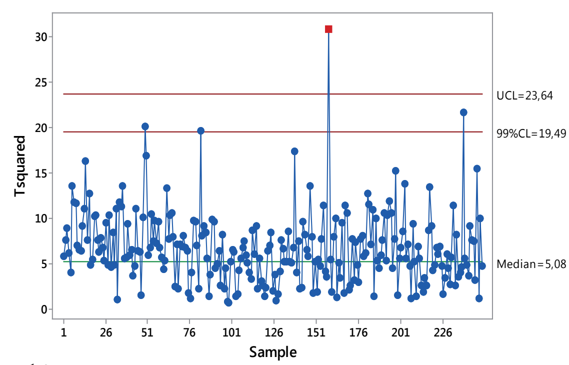


Figure 5. T^2 control chart for “white brined cheese” for five quality characteristics

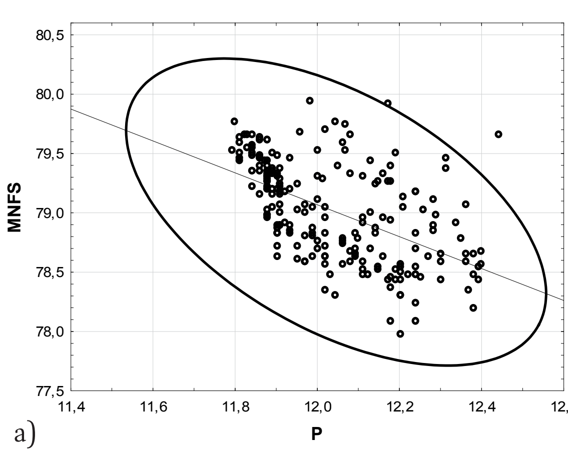


a)

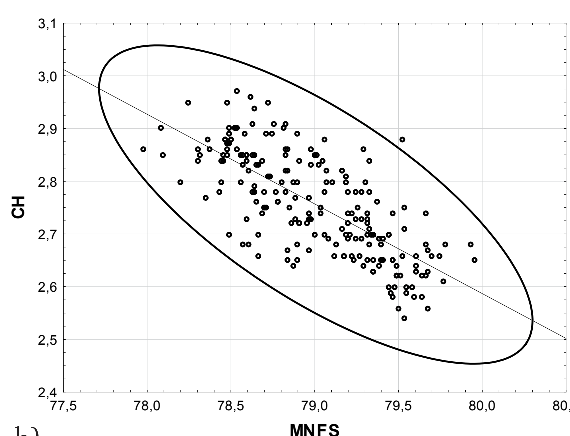


b)

Figure 3. T^2 control chart for "white brined cheese" four quality characteristics: a) proteins, fat in dry matter, moisture in non-fat substances, carbohydrates; b) fat in dry matter, moisture in non-fat substances, NaCl, carbohydrates



a)



b)

Figure 4. Bivariate charts for "white brined cheese" for two quality characteristics: a) moisture in non-fat substances and proteins; b) moisture in non-fat substances and carbohydrates

The T^2 control chart is shown in Figure 5. Most of the T^2 values were below the 99% confidence limit for a multivariate control chart with five quality characteristics which was in line with bivariate charts. Above the UCL were samples #34, #94 and #198, as indicated in Figure 5. However, one sample was above the 99 % confidence limit and below the UCL (sample #119) which might be interpreted as an out-of-control point too. Failed points indicated the existence of a non-random pattern in the data which may be a result of special-cause variation.

Conclusion

The presented results for the two types of cheeses showed that quality varied significantly for most of the quality characteristics. The only stable parameter in both samples was MNFS. Other cheese quality characteristics were characterized above or below the control limits for most of the analysed samples. Such results indicated a high instability and variations within the cheese production. Also, for white brined cheese, proteins and NaCl showed a certain type of autocorrelation which resulted in questions considering the causes of this phenomenon and whether it was a result of the quality of raw milk, the technological processes parameters in the dairies or did these changes occur during shelf life of the product.

After several iterations and creating a subsamples with quality characteristics within the control limits, results showed that even when results were within limits, additional statistical processing indicated out-of-control points in bivariate and/or multivariate control charts.

Although SPC is not a mandatory requirement in the food industry, it can provide benefits to organizations in the dairy sector regardless of their particular product portfolio and size of the dairy plant. Multivariate monitoring based on Hotelling's T^2 statistic might be effective if the data are not highly correlated and the number of variables p is not too large ($p<10$).

Among other advantages in relation to an univariate study, these charts prevent the production of a large number of documents/charts and lead to more accurate analysis by considering the correlation among variables.

Limitations of the research stem from the use of a convenience sample in relation to sample size and quality characteristics analysed. Since the products were collected randomly, the current results should not be generalized. Future research should focus on the use of multivariate control charts in production plants, investigating out-of-control products and define potential technological impact on assignable causes of variation.

Jedan pristup u primjeni multivarijantne statističke kontrole procesa u analizi kvalitete sireva

Sažetak

Cilj ovog rada bio je ispitati mogućnost primjene multivarijantne statističke kontrole procesa u analizi parametara kvalitete sireva. Odabrane su dvije vrste sira (bijeli sir u salamuri i meki sir od ultrafiltriranog mlijeka) kojima je analizirano nekoliko parametara kvalitete kao što su udio suhe tvari, mliječne masti, proteina, pH vrijednost, udio soli, masti u suhoj tvari i vode u bezmasnoj tvari sira. Prikazani rezultati za dvije vrste sira pokazali su da kvaliteta značajno varira za većinu ispitivanih karakteristika. Za obje vrste sira samo udio vode u bezmasnoj tvari sira bio je stabilan. Ostali parametri kvalitete su za većinu uzoraka bili ispod ili iznad kontrolnih granica. Ovi rezultati ukazuju da postoje visoka nestabilnost i značajna variranja u proizvodnji sireva. Iako upotreba statističke kontrole procesa nije obavezna u mljekarskoj industriji, svakako je da može pružiti korist u poboljšanju kontrole kvalitete proizvoda od mlijeka.

Ključne riječi: sirevi, kvaliteta, statistička kontrola procesa

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