



Dual Statistical Quality Control Charts with Table of Quality Determinant in Manufacturing Industries

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Abstract

Statistical Quality Control (SQC) techniques have been widely recognized as effective approaches for monitoring both manufacturing and service processes with respect to the use of either variable or attribute charts in a particular process. In this study, both variable and attribute charts were employed to evaluate the performance of a manufacturing process. The variables under study are the original gravity, CO₂, PH, dissolved oxygen, real extract, pasteurized unit, colour, alcohol and temperature. The variable chart, or rather X bar chart, was employed, to obtain the Table of Deterministic Quality Conformance Status which consequently determined the number of active variables that require close monitoring for achieving better overall conformance. The attribute chart, or rather P chart, was eventually constructed for the validation of the process based on the suspected active variables. This study reveals that the combinatorial based charts provided better process monitoring, once the active variables that serve as primary quality determinants are properly controlled. This eventually leads to the conformance of the entire process.

Keywords: Statistical Quality Control, Variable Chart, Attribute Chart, Random Variation, Assignable Variation, CO₂ and Alcohol.

1. Introduction

Experience during the last few decades in the world markets has clearly demonstrated that quality is one of the most important factors for a business success and growth. Businesses achieving higher quality on their products enjoy significant advantage in their competitions. Hence, it is important that the personnel responsible for the design, development and manufacture of products understands properly the concepts and techniques used to improve quality of products (Chandra, 2001). During the last few decades, the interest on the industrial use of quality-related system, tools and methodologies have grown significantly. As such, managers need to understand the elements of quality, as perceived by the users, to assess whether a product or service is of high quality. (See Garvin 1987 and Feigenbaum 1991) to identify eight dimensions of quality. In fact, quality is perceived as meeting the needs, requirements, expectations and even the anticipations of the customers.

In manufacturing any quality product, controlling the quality of the raw materials used is as important as controlling the quality of the relevant active ingredients and the expected finished products. Effective management of raw materials as part of quality system will help to ensure that finished products meet their quality attributes (Gummesson, 1999). It is of therefore crucial to initiate such a system at the outset of product development and build it into the product design. Having this in

place will help steer, identify and select the active ingredients from the entire raw materials used. Note that there are many products that require very many ingredients before their accomplishment. In this situation, it is necessary to determine the most active ingredients and give adequate attention to them which invariably leads to the entire conformance of the finished products. This paper aims to develop a Table of Deterministic Quality Conformance Status which helps to determine the number of active variables that require close monitoring for achieving better overall conformance.

2. Statistical Process Control

In statistical process control (SPC), the stability of a production or service process is monitored by control charts. The SPC methods extend the use of descriptive statistics and the concept of hypothesis testing to monitor the quality of products and processes. The most versatile tools adopted in SPC to monitor the stability of a process are the control charts Deng, et al. (2012), Foster (2001), Montgomery (2005) and Ott and Schilling (1990). With continuous monitoring exercise of the production process, the manufacturing companies could prevent defect items to be processed in the next stage and to take immediate corrective action once a process is found to be out of control (Hairulliza et al., 2005). Ignatio and Charles (2016), advised that, for any organization operates in a third world economy and needs to compete on a global scale, embracing SPC is a necessity. When SPC is utilized properly, it enables manufacturer to prevent problems, control their production processes, and ultimately increase profits and customer satisfaction.

However, previous researches conducted have shown problems in implementing quality control among local manufacturing organisations. Among the critical problems facing are poor process monitoring, inability to perform data analysis and the implementation of control chart only on the finished products and not in real-time manner (Hairulliza and Teoh, 2007; Hanida et al., 2009). The basic idea of control charts is to test the hypothesis that there are only common causes of variability versus the alternative that there are special causes. By continuously monitoring the process, the manufacturing industries could prevent defect items to be processed in the next stage and to take immediate corrective action once a process is found to be out of control.

A control chart is used to monitor, control, and improve the performance of manufacturing or service process over time by studying variation and its sources. Various characteristics in manufacturing or service processes that are examined through control charts can be divided into two groups of variables and attributes (Bauman, et, al 2007). A SQC definition was given by Shewhart (1980), and it states that the SQC is a preventive method where the results are compared continuously through statistical data, identifying trends for significant changes, and eliminating or controlling these changes in order to reduce them more and more. Gaurav and DeoRaj (2018) pointed out that literature survey shows that most of work on control chart applications in healthcare is carried out in Surgery, Emergency and Epidemiology departments. US, UK and Australia are the main customers where maximum amount of work was done. The US is the country where control chart in healthcare sector have been used at regular interval. This shows the gap of deploying control chart in different departments and different countries as well.

The control chart for variables is used to monitor characteristics that can be measured on continuum scales, such as height, weight, volume and so on. Example of this include the X-Bar chart (\bar{X} -chart) which is used to monitor average process performance as well as the R and S charts that are designed to monitor process variation (Montgomery, 2005 and Bauman, et al, 2007). Agboola and Ikubanni (2017) used X-bar and R-control chart to investigate the stability of the tank calibration process for some fabricated oil storage tanks.

The Control charts for attributes are used to measure quality characteristics that are rather counted than measured. Attributes are discrete in nature and entail simple yes-or-no decisions. For example, this could be the number of non-conforming light bulbs or the proportion of broken eggs in a carton. The chart for attribute has implication when either discrete data are obtained or when there is a desire to classify continuous observations, radiator leaks or assembling defects and the second category by recording the cars which fail to meet an exhaust emission standard or fatigue failures.

3. Description of Data

The data used for this study were obtained for the months of September, October and November, 2013 from International Breweries Plc, Ilesa, Osun State, Nigeria. The company produces several beverages and drinks such as Trophy Black, Betamalt, Grand malt, Redds Lemon and Redds Vodka. However, this study only considered Betamalt while the associated variables are original gravity, CO₂, PH, dissolved oxygen, real extract, pasteurized unit, colour, alcohol and temperature each with four levels respectively.

During the period of concern in this study, several batches of Betamalt were produced. In particular 42, 46 and 59 batches of Betamalt were produced in September, October and November respectively. From each batch, a random sample of size 4 was selected for the purpose of obtaining summary statistics that are required for the construction of the \bar{X} and P charts and the Deterministic Quality conformance tables.

4. Methodology

This section discusses and also illustrates the principle behind the use of X bar charts, P charts and the Table of Deterministic Quality Conformance Status.

4.1 \bar{X} -Chart

A mean control chart is often referred to as \bar{X} -chart. It is used to monitor changes in the mean process. To construct a mean chart, there is a need to first construct the centre line of the chart. To do this, multiple samples are taken and their means are computed. Usually these samples are small with about four or five observations. Each sample has its own mean \bar{x} . The centre line is then computed as the mean of all k samples, where k is the number of samples:

$$\bar{\bar{X}} = \frac{\bar{x} + \bar{x}_2 + \dots + \bar{x}_k}{k}$$

The upper and lower control limits are computed as follows:

$$\begin{aligned} \text{UCL and LCL} &= \bar{\bar{X}} \pm \frac{3}{d_2\sqrt{n}} \bar{R} \\ &= \bar{\bar{X}} \pm A_2 \bar{R} \end{aligned} \quad (1)$$

Thus,

Upper control limit (UCL) = $\bar{\bar{x}} + A_2 \bar{R}$ and

Lower control limit (LCL) = $\bar{\bar{x}} - A_2 \bar{R}$

Where $\bar{\bar{x}}$ is the mean of the sample means and \bar{R} is the mean of the ranges of the sample.

4.2 P-Chart

Percentage defective charts are also known as P-charts. The Percentage defective chart shows graphically the proportion of the production that is not acceptable. The sample proportion nonconforming is defined as the ratio of the number of nonconforming units to the sample size, n. The p-chart accommodates “pass or fail”- type inspection as determined by one or more go-no-go gauges or tests.

The upper and lower control limits are computed as follows:

$$\text{UCL and LCL} = \bar{P} \pm 3 \sqrt{\frac{\bar{P}(1-\bar{P})}{n}} \quad (2)$$

where,

$p = \frac{\text{total number of defective}}{\text{total number of items supplied}}$, \bar{p} = the mean proportion defective

n = Sample size

Thus,

Upper control limit (UCL) = $\bar{P} + 3 \sqrt{\frac{\bar{P}(1-\bar{P})}{n}}$ and

$$\text{Lower control limit (LCL)} = \bar{P} - 3\sqrt{\frac{\bar{P}(1-\bar{P})}{n}}$$

4.3 The Deterministic Quality Conformance Status (DQCS) Table

Here, the principle behind the use of DQCS table will be discussed. There are nine ingredients: original gravity, CO₂, PH, dissolved oxygen, real extract, pasteurized unit, colour, alcohol and temperature with four levels each. These ingredients are mixed together to attain a finished product of Betamalt. This study firstly screen each of these ingredients using the \bar{X} -charts based on the available dataset on the measurement taken on every ingredient. This leads to the recognition of set of ingredients that are good for the production. Then, \bar{P} -chart is used and a critical analysis is done in comparing the status of every ingredient and its contribution to the conformance of \bar{P} -chart. The goodness of any ingredient is achieved based on its status on the DQCS Table.

Table 1: Illustration of Deterministic Quality Conformance Status Table

Ingredients or Parameters	Not Conforming (Significant)	Conforming (Not Significant)		
		Good	Better	Best
Original gravity			√	
PH				√
CO ₂		√		
Dissolved oxygen		√		
Real extract	√			
Pasteurized unit				√
Colour	√			
Alcohol			√	
Temperature		√		

5. Discussion of Results

In this section, the results of analysis of the data will be presented and a discussion of the results will also be given for each month.

5.1 \bar{X} -charts for the month of September

Figure 1 shows the \bar{x} -charts for the nine ingredients for the month of September. The points for original gravity (Figure 1a) are close to the central line and none lie beyond the upper and lower control limits. Therefore original gravity conforms to the quality standard. This is also observed for CO₂ (Figure 1c), Dissolved oxygen (Figure 1d), Pasteurized unit (Figure 1f), Alcohol (Figure 1h) and Temperature (Figure 1i). The other characteristics are out of control because they have some points that lie outside the upper and lower control limits. As shown in Figures 1b, 1e and 1g.

In general, for September, the \bar{x} charts for PH, Real extract and Colour were not in control, while the \bar{x} charts for Original gravity, CO₂, Dissolved oxygen, Pasteurized unit, Alcohol and Temperature were in control. The level of conformance of the ingredients that are in control is summarized in Table 2.

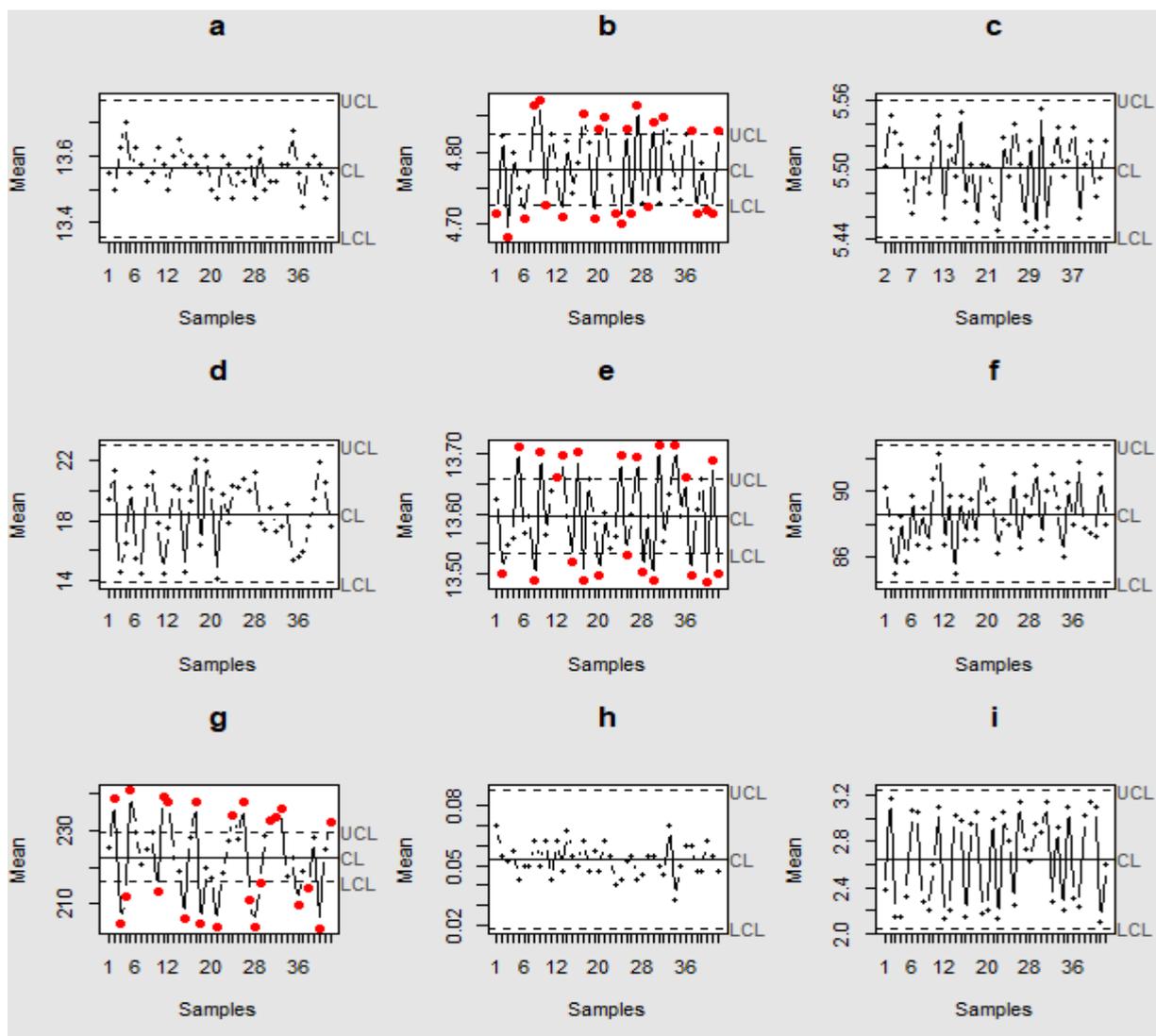


Figure 1: \bar{x} -chartson the nine ingredients for the month of September. Key: Original gravity (a), PH (b), CO2 (c), Dissolved oxygen (d), Real extract (e), Pasteurized unit (f), Colour (g), Alcohol (h) and Temperature (i).

Table 2.:The Deterministic Quality Conformance Status (DQCS) Table for the month of September

Ingredients or Parameters	Not Conforming (Significant)	Conforming (Not Significant)		
		Good	Better	Best
Original gravity			√	
PH	√			
CO2		√		
Dissolved oxygen		√		
Real extract	√			
Pasteurized unit		√		
Colour	√			
Alcohol			√	
Temperature		√		

5.2 \bar{x} -charts for the month of October

The \bar{x} -charts for Original gravity, PH, CO₂, Dissolved oxygen Real extract, Pasteurized unit, Colour, Alcohol and Temperature are respectively displayed in Figures 2a, 2b, 2c, 2d, 2e, 2f, 2g, 2h, and 2i for the month of October.

All the processes that are not in control in the month of September are observed to not be in control in the month of October. In addition to these three, dissolved oxygen is also not in control. Therefore out of the nine ingredients that were being monitored in the month of October, only five are in statistical control as all points are within the control limits. These ingredients are Original gravity, CO₂, Pasteurized unit, Alcohol and Temperature. However for CO₂, the process is in control but it needs to be closely monitored, so as to prevent an out-of-control situation due to the fact that some points in the plot are very close to the control limits.

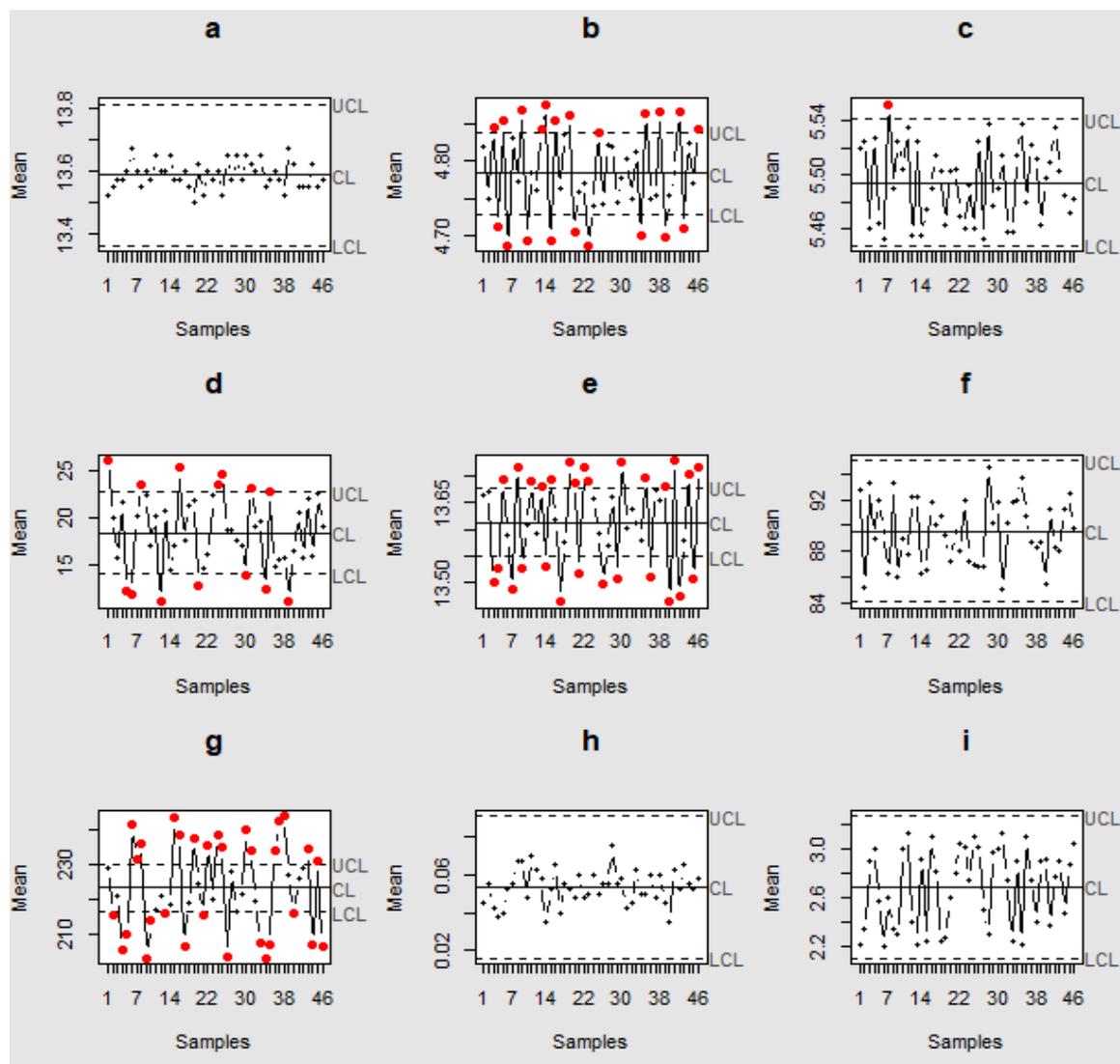


Figure 2: \bar{x} -charts on the nine ingredients for the month of October. Key: Original gravity (a), PH (b), CO₂ (c), Dissolved oxygen (d), Real extract (e), Pasteurized unit (f), Colour (g), Alcohol (h) and Temperature (i).

In general, for October, the \bar{x} charts for PH, Real extract, Dissolved oxygen and Colour were not in control, while the \bar{x} charts for Original gravity, CO₂, Pasteurized unit, Alcohol and Temperature were in control but at different levels of conformance which is summarized in the Table 3 below.

Table 3.:The Deterministic Quality Conformance Status (DQCS) Table for the month of October

Ingredients or Parameters	Not Conforming (Significant)	Conforming (Not Significant)		
		Good	Better	Best
Original gravity				√
PH	√			
CO2		√		
Dissolved oxygen	√			
Real extract	√			
Pasteurized unit		√		
Colour	√			
Alcohol			√	
Temperature		√		

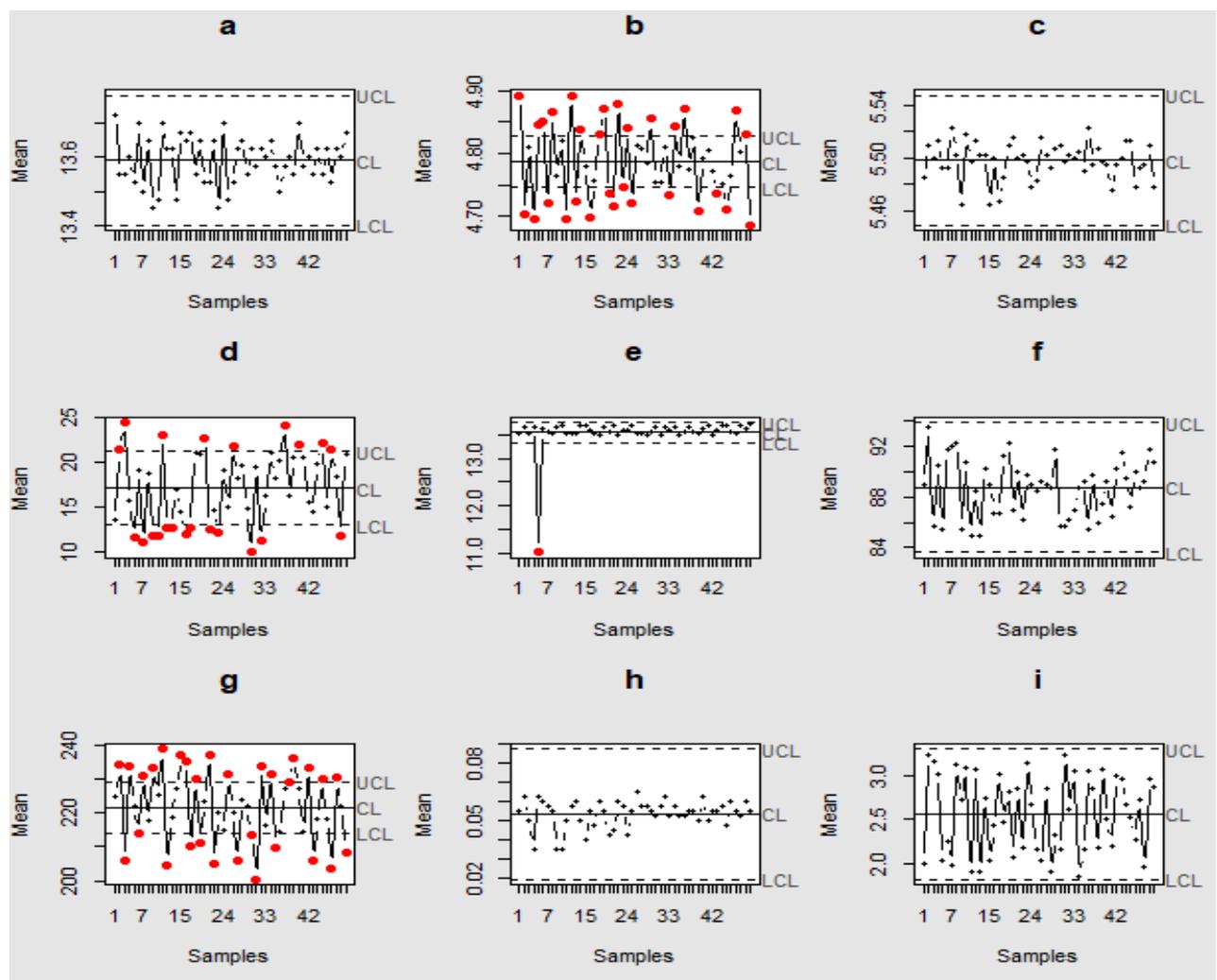


Figure 3: \bar{x} -charts on the nine ingredients for the month of November. Key: Original gravity (a), PH (b), CO2 (c), Dissolved oxygen (d), Real extract (e), Pasteurized unit (f), Colour (g), Alcohol (h) and Temperature (i).

5.3 \bar{X} -charts for the month of November

Figures 3a – 3i gives the \bar{x} -charts for the nine ingredients that are under investigation for the month of November. What was observed in the month of November is similar to that of the month of October in terms of which ingredients are in control and the ingredients that are required to be

improved upon because they were not in statistical control. As opposed to what was observed on October about CO₂, the process of CO₂ in November is in control and the points are mostly clustered around the central line. In general, for November, the \bar{x} charts for PH, Real extract, Dissolved oxygen and Colour were not in control, while the \bar{x} charts for Original gravity, CO₂, Pasteurized unit, Alcohol and Temperature were in control but at different levels of conformance which is summarized in the Table 3.

Table 4.:The Deterministic Quality Conformance Status (DQCS) Table for the month of November

Ingredients or Parameters	Not Conforming (Significant)	Conforming (Not Significant)		
		Good	Better	Best
Original gravity		√		
PH	√			
CO ₂				√
Dissolved oxygen	√			
Real extract	√			
Pasteurized unit		√		
Colour	√			
Alcohol				√
Temperature		√		

5.4 P-chart for the month of September

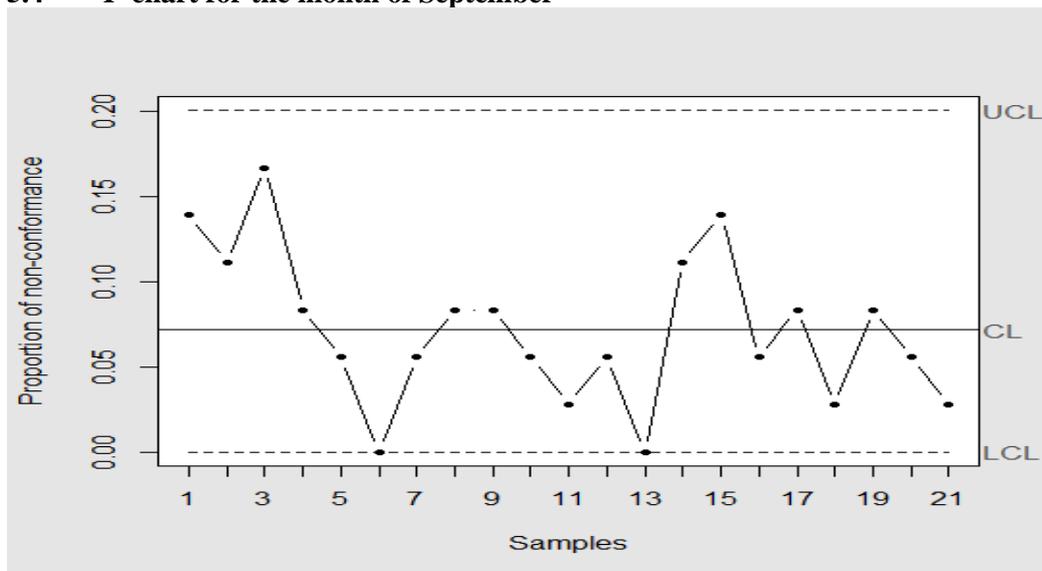


Figure 4: p-chart on proportion of non-conformance for the month of September

Figure 4 gives the p-chart for the month of September. It is observed that the process is in control due to the fact that none of the points is outside the control limits, although samples 6 and 16 are exactly on the lower control limit and should be investigated. From Figure 5 above, the process appears to be in control due to the fact that none of the points is outside the control limits. However, samples 6 and 16 are on the lower control limit and need to be investigated

5.5 P-chart for the month of October

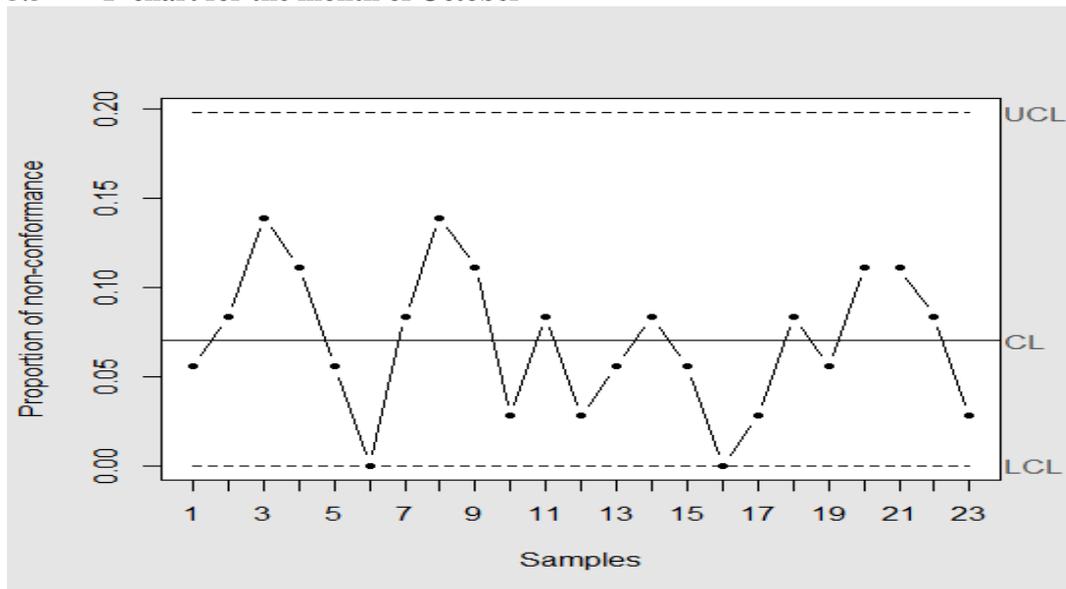


Figure 5: p-chart on proportion of non-conformance for the month of October

5.6 P-chart for the month of November

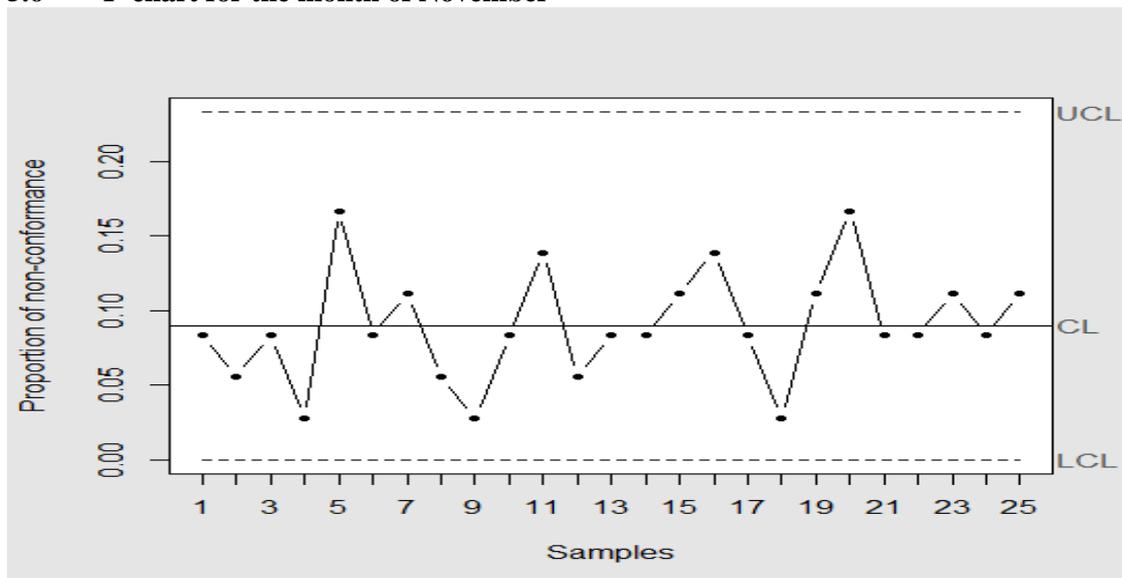


Figure 6: p-chart on proportion of non-conformance for the month of November

From Figure 6 above, it can be observed that the process appears to be in control. In addition, by critically observing the points, we could see that they are all closer to the control limits. This is an evidence of better conformance. In general, we see that all the p-charts are in control but that of November is more in control than that of September and October which are relatively the same.

6. Conclusion

Screening of the ingredients before they are mixed prior the commencement of real production process was carried out by $\bar{X} - Charts$. This is to ascertain and affirm the state of quality of the raw materials prepared for the production. From the statistical quality control charts (\bar{x} charts) for the months of September, October and November performed on the entire parameters (ingredients) considered, the results reveal that the process was statistically stable, conform and under control with no special (assignable) cause of variation for CO₂ and Alcohol. It could also be seen that all the points

are clustered around the central limit most especially for the month of November. This is obvious from the Deterministic Quality Conformance Status (DQCS) Tables for ingredients. Indeed the DQCS table rightly points out CO₂ and Alcohol as the most active parameters (ingredients) that determine the conformance of a process as a whole. The efficiency and effectiveness of DQCS table is also seen from Table 4 for the month of November, as to the fact that CO₂ and Alcohol status were both at the best level of conformance in their respective \bar{x} -charts. This invariably gave better conformance for the entire production process with the application of P-chart. This means that the process conformed to reasonable number of points clustered around the central limit and this indeed a good sign of better conformance. In conclusion, CO₂ and Alcohol should be given adequate attention while production processes are going on since it is clear that they are the most active parameters that greatly contribute to the conformance of the final production processes as a whole. By so doing this might improve the level of conformance of the production processes of the company and also address the quest to remain competitive.

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