International Research Journal of Biochemistry and Bioinformatics (ISSN-2250-9941) Vol. 8(1) pp. 001-012, February, 2018
DOI: http:/dx.doi.org/10.14303/irjbb.2017.078
Available online http://www.interesjournals.org/IRJBB

Full Length Research Paper

Shelf quality studies: modelling of the flow quality and lactic acid bacteria-bifidobacteria quantity, as parameters for monitoring shelf quality of stirred yogurt using shelf time, ph, bostwick consistency and temperature

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ABSTRACT

Prediction of shelf quality of yogurts is very essential for effective shelf quality monitoring process, development and optimisation of current products. This paper suggests various models which may be used to define the shelf status of stirred yogurts at definite shelf time and product temperature. The variables which were used in the modelling process include pH, lactic acid bacteria and bifidobacteria quantity, Bostwick consistency, shelf time and temperature. A polynomial model which consisted of the shelf time and pH of the product was obtained for the prediction of the quantity of lactic acid bacteria-bifidobacteria($R^2 adj = 0.87$). The flow quality of the yogurts was expressed by introducing the Fundamental Flow index, FFI. which encompasses parameters such as temperature, Bostwick consistency and total solids. The distribution of FFI. values were observed to depend on temperature and total solids of the yogurt. The pH and Bostwick consistency were also observed to be depended on temperature and as such temperature correction models were established which depend on the temperature correction factor, α. The predicted values show no significance difference with the actual at 95% confidence interval (p>0.05) and the validation methods indicate that the models have greater prediction power for estimating accurate values.

Keywords: Shelf quality, Shelf time, Bostwick consistency, Temperature, Lactic acid bacteria-Bifidobacteria quantity.

INTRODUCTION

The physical, chemical and biological properties of food and food products are always in dynamic transformation as time changes. This has formed the basis for the prediction of shelf life and shelf quality of most foods by establishing the time at which the changes in these properties is no longer acceptable/fit for human consumption nor suitable for other processes. Degradation of food is initiated from its production date. The rate and degree of food degradation depends on both the composition and the environmental conditions during storage and distribution.

Sharma (2013), illustrates that the quality of yogurts may be measured using Bostwick consistency, viscosity, measuring syneresis, gel strength, microbial aspects and sensory attributes (flavour, taste, texture, and colour). Yogurt starter cultures comprise of a combination of mesophilic microbes (*L .lactis, L. cremoris, L. diacetylactis, Leuconostoc spp.*) and thermophilic microbes (*S. themophilus, L. bulgaricus*),(Sfakianakis and Tzia, 2014; Shima et al., 2012). The yogurts also contain probiotics which are usually *L. casei, Bifidobacterium bifidum*and*L. acidophilus* (Sharma, 2013).

Probiotics are added as food adjunct cultures and reach concentrations that range between 10^7-10^9 cfu/g. It was further shown that probiotics may or may not participate in the fermentation process during storage (Sfakianakis and Tzia, 2014). It has been suggested that the probiotics should be present in food to a minimum level of 10^6 cfu/g (Robinson, 1987; Sharma, 2013; Ashraf and Shah, 2011 and Panesar and Shinde, 2011). Symbiosis of the starter cultures is important in achieving a pH < 4.5, a desirable texture (due to aggregation of protein micelles) and the required flavours through proteolysis.

The shelf life analysis gives end-point examination of food quality (Fu and Labuza, 2000). However, it is always necessary to check if the attributes of the products are in the acceptable levels within the predicted shelf time. Continuous analysis and monitoring of the shelf life status of yogurts is very central to product evaluation and optimization, but it can be time consuming and cost ineffective considering the methods of analysis, the number of products and the required time for analysis. Effective and less expensive methods may be employed with the help of mathematical models to give quality inferences of the parameters which require more time and cost. For example, this paper uses the yogurt shelf-time and pH to predict the quantity of the lactic acid bacteria-bifidobacteria. This means that we might find the quantity of these microorganism in yogurt using parameters such as pH and shelf time. Shelf-time and pH are ideal parameters because their measurement procedure is quicker and more cost effective than the conventional methods in practice.

McCarthy and McCarthy (2009), and Cadavid (2014),illustrate the use of Bostwick consistency for measurement of complex flow behaviour of most non-Newtonian fluids like tomato paste, gruels and yogurts. However, the value given by the Bostwick consistometer is observed to be affected by many parameters, including temperature and soluble solids (Ebrahim *et al.,* 2015 and McCarthy and McCarthy 2009). Thus, we also come up with a correlation model which is based on the Bostwick consistency, temperature and the total solids to determine the flow quality of the yogurts and it was referred to as the Fundamental Flow index, FFi.

METHODS AND MATERIALS

Sample collection and preparation

Stirred yogurt samples were randomly collected from several markets in Harare, Zimbabwe(at different days and sampling times) and stored within a temperature range of 2-5$^{\circ}C$ prior to analysis. The yogurt types collected were distinguished as either fruit based- or smooth-yogurts. The samples were also categorized according to the amount of total solids they contained, i.e. low total solids (<19g) and high total solids (≥19g). Thus, at the end the yogurts were coded as fruit based yogurts with high total solids (FhT), smooth yogurts with high total solids (ShT) and smooth yogurts with low total solids (SlT).

Testing for pH and Temperature

The pH was measured using a digital pH meter (SARTORIUS PH METER-PB 11, FISHER SCIENTIFIC, USA). The pH meter was calibrated before and during the tests using 2-point calibration at pH 4 and pH 7. The pH electrode was rinsed thoroughly with distilled water and then immersed in the product. The reading on the pH meter was allowed to stabilize before being recorded. After testing the electrode was rinsed with distilled water and placed in KClsaturated solution. Temperature of the product was also measured and recorded before every test using a digital thermometer.

Lactic acid bacteria-bifidobacteria quantity (LABBq or N) testing

The yogurt microbial test used involved the determination of the microbial quantity of the lactic acid bacteria-bifidobacteria (LABBq) using DeMan Rogosa Sharpe (MRS) agar (OXOID, BASINGSTOKE, HAMPSHIRE, ENGLAND).The viable lactic acid bacteria and bifidobacteria count was conducted according to da Silva *et al* (2013). Pour plate method was used and 1mL of the diluted inoculum was transferred to a petri dish and approximately 12-15mL of MRS agarwas added to it. The agar was set to solidify and the petri dishes were tightly covered using aluminium foil and polyethylene to promote CO_2 build up during the incubation period. The petri dishes were incubated at 30$^{\circ}C$ for 5 days. Colonies were counted after the incubation period using a colony counter.

Testing for the Bostwick consistency

The methodology and instrument calibration for the measurement of Bostwick consistency was in accordance to Gatenby (2009) and www.labomat.eu. The reservoir was filled with the product, approximately 100 mL. The product was allowed to flow for 30 seconds and the reading was taken thereafter. After each test the consistometer was cleaned using water and dried thoroughly with paper towel before reuse in another test. The temperature of the sample was also measured before each test.

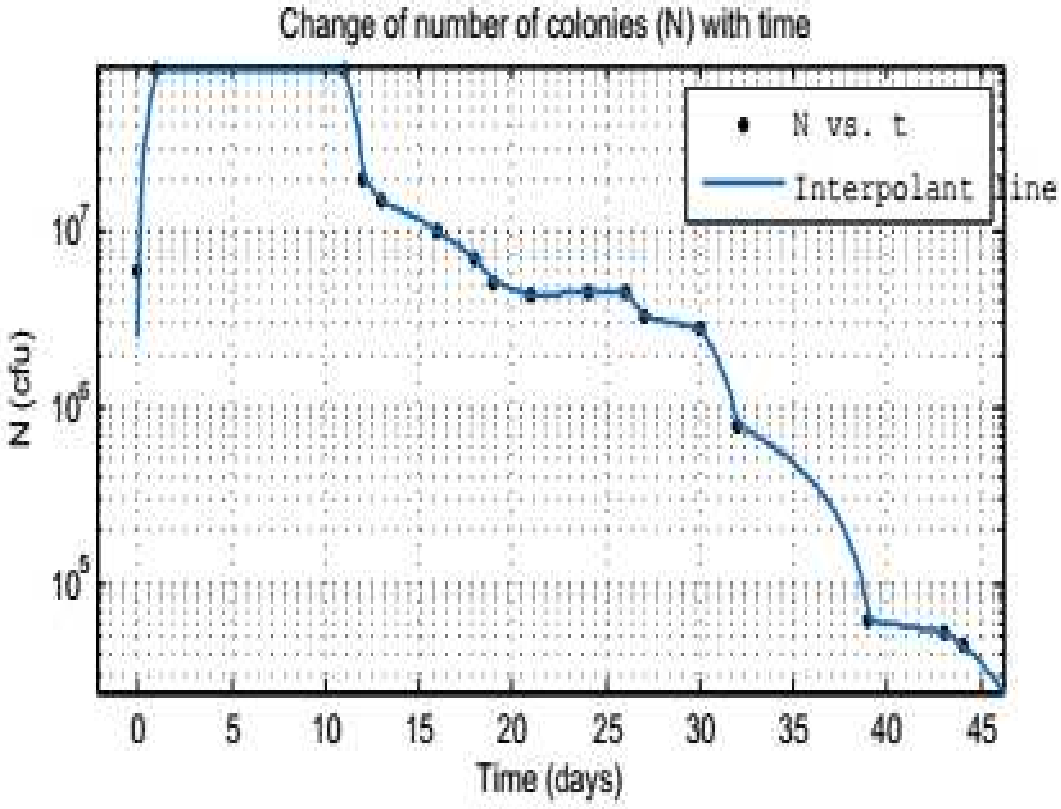

Figure 1. Plot ofN (cfu/g) with time (days).

Testing for total solids

Total solids were measured for each sample using a moisture analyser (MOISTURE ANALYSER MX-50, A&D COMPANY LIMITED, JAPAN). The sample was weighed using the balance pan of the analyser. Approximately 1.0±0.05g of the sample was used for analysis. The total solids were determined at 160℃ for 11.5 minutes.

Data analysis

The data recorded was then analysed using statistical software packages; Matlab (Mathworks version R2013a), SPSS (IBM, version 22) and XLStat 2017. Modelling of the shelf quality variables and validation of the models was conducted.

RESULTS AND DISCUSSION

Lactic Acid Bacteria-Bifidobacteria Quantity, LABBq/N

A plot oflactic acid bacteria-bifidobacteria quantity (represented by N or LABBq) against shelf time t on a logarithmic scale is shown Figure 1. At day 0 the number of colonies where around 10^6 cfu/g. They increased to a peak of 10^8 cfu/g before embarking on a continuous decline from approximately day 11. It was further observed that as shelf-time increases beyond day 15 up to day 30 the value of N, though decreasing, was within the range of 10^6-10^7cfu/g. The values of N observed for t above 30 days were below 10^6 cfu/g.

Sharma (2013) and O'Neil *et al* (1979) indicate that the number of probiotics generally decreases with increasing shelf-time and the number of colonies reside below 10^6 cfu/g at day 21. According to this observation it took an extra 9 days for the number of colonies to decline below 10^6cfu/g. This could have been caused by lack of strict selectiveness of the media to other lactic acid bacteria which were not used as probiotics or starter cultures. The inclusion of the yogurt starter cultures in the enumeration is important since Sohrabvandi *et al* (2012), emphasize that the yogurt starter cultures such as *Lactobacillus delbrueckii spp. bulgaricus* should be incorporated in the enumeration of the probiotics as they are beneficial to human health and they improve yogurt quality as evidenced by an increase in shelf-time.

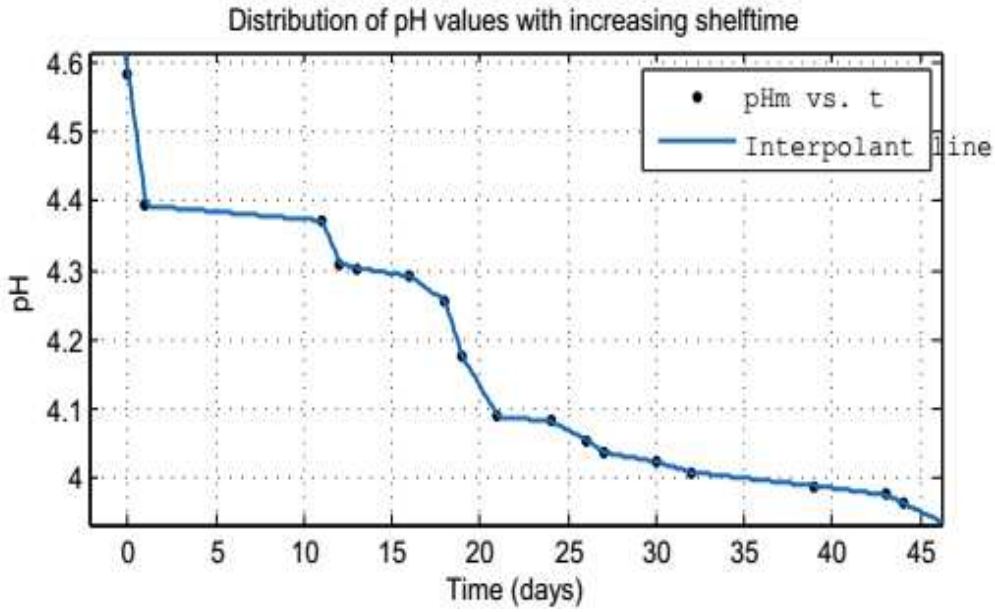

Figure 2. Distribution of pH with time (days).

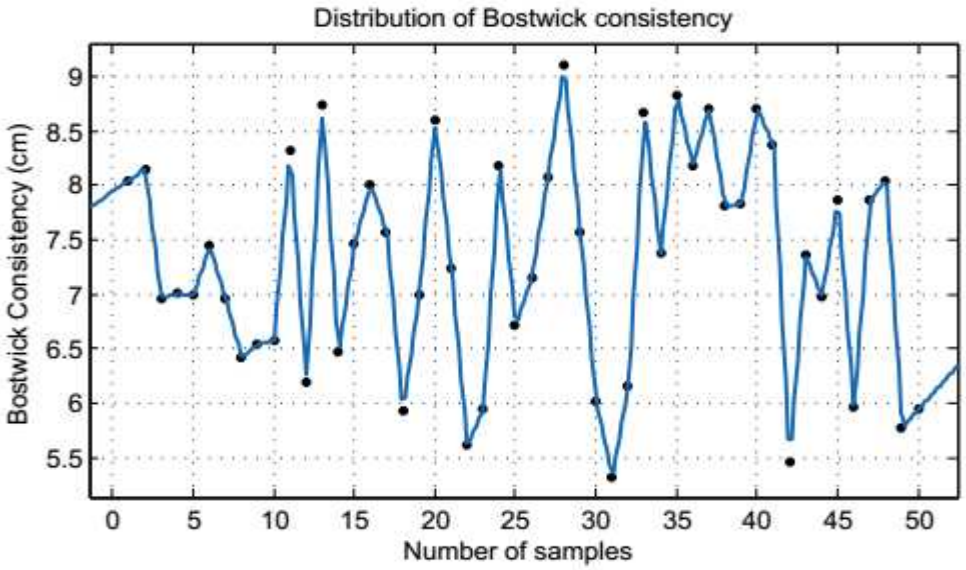

Figure 3. Distribution of Bostwick consistency (corrected values).

PH

the samples generally exhibit higher pH values just after production. pH values then continue to decline as shelf-time increases (see Figure 2) though the distribution was not perfectly linear. The graph shows that within 15 days of storage the pH values were around 4.30 and the pH value decreased to approximately 4.10 in 20 days. After day 35 the pH values decrease below 4.0 (i.e. mature yogurts).

Bostwick consistency

The graph (Figure 3) shows the distribution of Bostwick consistency values sorted as shelf time increases at temperature of $5 \pm 05°C$. Though the distribution is

Table 1. Determination of the temperature coefficient

Yogurt code	Equation	Correlation factor, R^2
FhT_1	$pH = -0.0104\theta + 4.38$	88.25%
FhT_3	$pH = -0.0062\theta + 4.26$	81.88%
FhT_2	$pH = -0.0047\theta + 4.24$	94.66%
FhT_4	$pH = -0.0076\theta + 4.35$	97.44%
ShT_2	$pH = -0.0132\theta + 4.30$	95.85%
ShT_1	$pH = -0.0073\theta + 4.61$	99.35%
ShT_3	$pH = -0.0093\theta + 4.35$	99.17%
FhT_5	$pH = -0.0057\theta + 4.10$	95.34%
FhT_6	$pH = -0.0076\theta + 4.34$	99.38%
SlT_1	$pH = -0.0064\theta + 4.54$	97.22%
SlT_2	$pH = -0.0055\theta + 4.46$	31.57%
FhT_7	$pH = -0.0049\theta + 4.25$	94.03%
ShT_4	$pH = -0.0070\theta + 4.47$	49.28%

observed to be non-linear (zig-zag) it can be noticed that lower Bostwick consistency values were observed as shelf-time increases. In general, the viscosity of yogurts increase with shelf time. Jooyander *et al*(2015), shows that the mean value of viscosity increases from 17.49 $Pa.s$ (first day of storage) to 19.98 $Pa.s$ after 21 days of storage. Though Bourne (1982), suggests that the results given by Bostwick consistometer cannot be directly related to fundamental rheological parameters because factors other than viscosity (e.g. surface tension and wetting power/stickiness) may be involved. The results are consistent with literature which suggests that Bostwick consistency is inversely proportional to viscosity. For example, McCarthy and Seymour (1994) showed that higher apparent viscosity values were observed at lower Bostwick consistency values. Thus, we expected to observe minimum Bostwick consistency values as the shelf-time increased, shown in Figure 3. However, the discontinuities observed in the distribution trend in Figure 3 could be due to measurement errors or other production inconsistencies of yogurt.

Modelling of the parameters used for shelf quality evaluation of yogurts

Temperature Correction Model for pH

The model for correcting the measured pHpH_{obs}, to absolute pHpH_{abs},was established. It made use of measured temperature, θ_{obs} and critical temperature, θ_{crit}. This was made possible by establishing the temperature coefficient, α. The α values were the gradient of pH-temperature equations derived from data acquired from various yogurts, Table 1.

Thus:

$$\alpha = \frac{\Delta pH}{\Delta \theta} = \frac{pH1 - pH2}{\theta_1 - \theta_2}; \qquad pH.^{\circ}C^{-1} \tag{1}$$

where; θ is the product temperature.

Using α, and other parameters a linear model for correcting pH at critical temperature, θ_{crit} was established.

Thus:

$$pH_{abs} = pH_{obs} - \alpha(\theta_{obs} - \theta_{crit}) \tag{2}$$

The overall value of α for all the yogurts, at different shelf-time was calculated by taking the average temperature coefficient for different types of yogurt samples measured.

Thus:

$$\alpha_{av} = \frac{\sum_{i=1}^{n} \alpha_i}{N} = \frac{(\alpha_1 + \alpha_2 + \alpha_3 + \cdots + \alpha_n)}{N} = -0.0073692 \;\; pH.^{\circ}C^{-1} \tag{3}$$

where; N is the total number of yogurt samples.

Thus, the general model (equation 2) becomes:

$$pH_{abs} = pH_{obs} + 0.0073692(\theta_{obs} - \theta_{crit})$$

Figure 4 shows the plot of observed pH values against the corrected pH values. As shown in Figure 4, when the temperature values were close to the critical temperature (5℃) the predicted values were somewhat much nearer to the observed pH. However, as the temperature rose the predicted pH values were seen to be drifting away from the observed pH values by a factor of 0.0073692 per 1 ℃ increase.

The validation data (n=24) was fitted in the pH-temperature model. The results show the adjusted coefficient of determination R^2_{Adj} of 1.0. The correlation

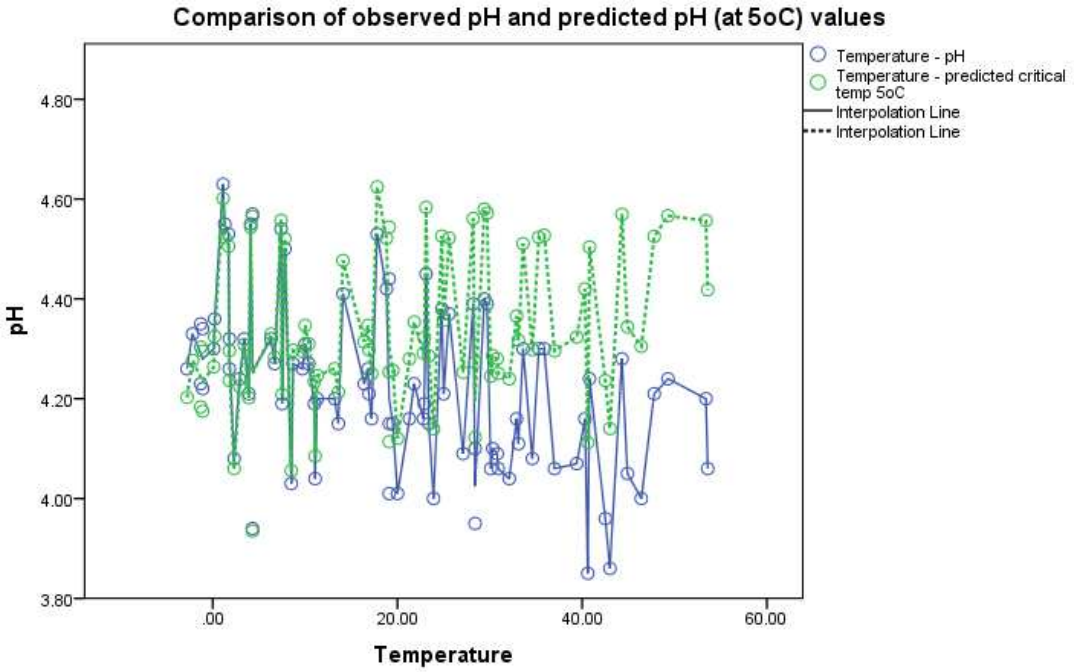

Figure 4. Comparison of the predicted and observed pH values

between the observed and the predicted values was tested using Pearson correlation r. The r value was observed to be 0.999. Thus, both the results from the coefficient of determination R^2_{Adj} and Pearson correlation r suggest that the pH-temperature model is capable of correcting pH values observed at a defined temperature value to absolute pH value considering desired critical temperature.

The t-test was carried using a null hypothesis which assumes that the mean of observed and predicted values were significantly the same ($H_0: \mu_{obs} = \mu_{pred}$) against the alternative hypothesis which suggest that the mean of observed and predicted values were not the same ($H_0: \mu_{obs} \neq \mu_{pred}$). The paired t-test at 95% confidence interval (CI) indicates that there was no significant difference between the observed and the predicted pH values. The null hypothesis was retained which presumes the equality of sample means, since $p\ (0.095) > 0.05$. Thus, since the mean of the predicted and observed data were significantly the same at 95% CI this indicates some good predictive properties of the pH-temperature correction model.

Temperature correction model for Bostwick consistency

The model was developed to correct the observed consistency, φ_{obs} to the absolute consistency, φ_{abs} using the measured temperature, θ_{obs} and the desired temperature, θ_{crit}. The same approach illustrated above was employed for the pH-temperature correction model and we obtain:

$$\varphi_{abs} = \varphi_{obs} - \alpha(\theta_{obs} - \theta_{crit}) \quad (4)$$

The temperature coefficient, $\alpha\ (cm.°C^{-1})$ was taken as the average of the temperature gradients of the samples used during modelling (n=65). Hence, at the critical temperatureθ_{crit}, of $5°C$ the model becomes:

$$\varphi_{abs} = \varphi_{obs} - 0.205383333(\theta_{obs} - 5)$$

The observed and the predicted consistency values were plotted as indicated below, Figure 5. The graph indicates a shift in the predicted consistency values due to the rectification effect of the consistency-temperature correction model. It was observed that the consistency values diverged from the critical temperature ($5°C$) by a factor of $0.20538333\ cm$ per $1°C$.

The validation of the Bostwick consistency-temperature correction model at critical temperature of $5°C$ was observed using validation data (n=25) with temperature values ranging from 4.6°C to 5.9°C. The predicted and the observed data shows a Pearson correlation r of 0.998. When the validation data was fitted to the Bostwick consistency-temperature model the coefficient of determination R^2_{Adj} was found to be 1.0 at 95% CI.Using paired t-test the data was analysed to test

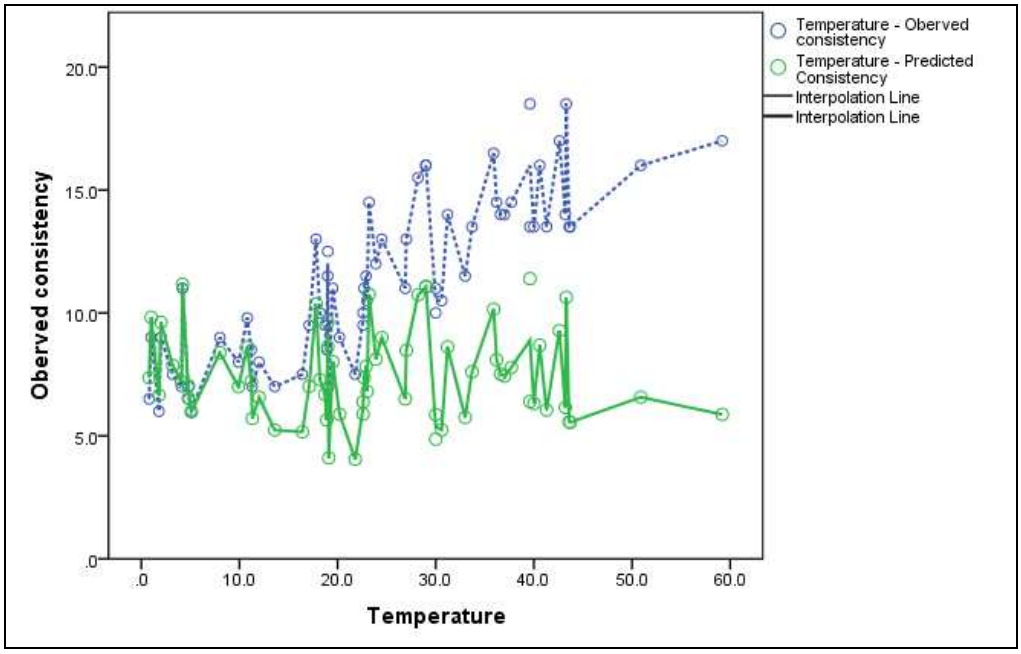

Figure 5. Comparison of the corrected and observed Bostwick consistency values

Table 2. Comparison of the models' coefficient of determination (Adjusted), Mean Square Errors (MSE), gradient (g) and intercept (c_i).

Model		R^2adj	MSE	g	c_i
Eqn (5)	$Log\ (N) = \alpha Log[N_0 \times \exp(\mu_{max} t)]$	0.75	0.2362	2.1	-4.7
Eqn (6)	$LogN = \frac{\alpha + (\gamma - \alpha)}{(\left(1 + \left(\frac{t}{\sigma}\right)\right)^{\beta})^{\omega}}$	0.87	0.1239	1.1	-0.6
Eqn (7)	$LogN = \frac{\alpha + (\gamma - \alpha)}{(\left(1 + \left(\frac{pH}{\sigma}\right)\right)^{\beta})^{\omega}}$	0.81	0.1864	0.2	5.4
Eqn (8)	$LogN = \beta_0 + \beta_1.t + \beta_2.pH$	0.67	0.3148	1.2	-1.3
Eqn (9)	$LogN = \beta_0 + \beta_1.t + \beta_2.pH + \beta_3.t^2 + \beta_4.pH^2$	0.87	0.1199	0.9	0.5
Eqn (10)	$LogN = \beta_0 + \beta_1.t + \beta_2.pH + \beta_3.(t.pH)$	0.86	0.1302	1.0	0.1
Eqn (11)	$Log\ N = \beta_0 + \beta_1.t + \beta_2.pH + \beta_3.(t.pH) + \beta_4.pH^2$	0.87	0.1283	1.0	0.4
Eqn (12)	$LogN = \beta_0 + \beta_1.t + \beta_2.pH + \beta_3.t^2 + \beta_4.(t.pH) + \beta_5.$	0.86	0.1291	1.0	-0.1

*$\alpha, \beta, \gamma, \sigma$ and ω are proportionality constants

if there is no significant difference between the observed and predicted consistency values (null hypothesis, $H_0: \mu_{pred} = \mu_{obs}$). The t-test indicated that no statistical difference existed between the observed and the predicted consistency values, i.e. p(0.057)>0.050. Thus, we failed to reject the null hypothesis.

Models to Predict Lactic Acid Bacteria-Bifidobacteria Quantity (LABBq Or N)

Various models were established to predict the Lactic acid bacteria-bifidobacteria quantity (LABBq or N), at shelf time t. Table 2 shows various types of models from polynomial to power law functions. Equation 5 is an exponential model commonly used to predict the number of microorganisms at time t, using growth rate μ_{max}, (Gospavic *et al*., 2011). The polynomial models show high correlation with pH and shelf-time t.

Selection and Validation of the Best Predictive Model

The selection of the best model to determine the yogurt LABBq was done by comparing various factors such as coefficient of determination R^2adj, Mean square error,

Table 3. Comparison of some values from the validation method in order to choose the best predictive model

Model	Deming	Passing & Bablok			Bland & Altman		
	R2	P value	Mean	STD	P value	Bias	Standard error
Eqn (9)	0.938	0.996	6.577	1.005	0.110	0.119	0.350
Eqn (10)	0.933	0.847	6.569	0.942	0.136	0.112	0.354
Eqn (11)	0.934	0.996	6.559	0.982	0.179	0.101	0.357
Eqn (12)	0.933	0.847	6.757	0.935	0.000	0.299	0.352

*STD-Standard deviation

MSE, gradient g and intercept c_i. The mean values of pH and Log N were used (n=24) for model validation. Various validation methods were used for instance, Bland-Altman method, Passing and Bablok regression and Deming regression.

Consideration of the R^2adj, MSE, Gradient and Intercept

Literature supports the use of the adjusted coefficient of determination, R^2adj since the increase in the value is independent of the number of predictors used in the equation (Montgomery and Runger, 2003 and Gujarati and Porter, 2009). Thus, from Table 2 most models have R^2adj values ranging from 0.81 to 0.87. It was also observed that the models with higher values of R^2adj have lower values of MSE. However, equation 5 and 7 shows lower R^2adj values and higher MSE values as compared to the other models which means that they have lower prediction power.

If the graph of the measured vs predicted Log N values is plotted (equation 13) for a perfect model, a slope gradient g, of 1.0 and intercept c_i of 0.0 should be observed (Moriasi *et al*., 2007).

$$Log\ N\ (measured) = g.LogN\ (predicted) + c_i \quad (13)$$

Thus, using this concept any deviation from the predetermined values (1.0 and 0.0) can be a result of over prediction or under prediction of the model. For this paper, we decided to accept models with a combination of g and c_i which are much closer to 1.0 and 0.0 respectively. As shown in Table 2, equations 5, 6 and 8 show that the models underestimate the value of the LABBq, and that equation 7 overestimate the microbial quantity as compared to other models.

For these reasons and considering the MSE and R^2adj, equations 5, 6, 7, and 8 were dropped for further validation processes in preference for equations 9, 10, 11 and 12.

The Bland-Altman, Passing and Bablok Regression, and Simple Deming Regression Validation Methods

The Bland-Altman validation method recognises the use of the t-statistic, standard error, bias and Pearson correlation coefficient. Passing and Bablok regression analysis is a statistical procedure that allows precise estimation of analytical methods, their degree of correlation and the possible systematic bias that might exist between them (Bilić-Zulle, 2011). It can be used to compare 2 measurements and it overcomes the assumptions of the classical linear regression method of validation. The method is robust, non-parametric, and non-sensitive to distribution of errors and data outliers (Bilić-Zulle, 2011). The Deming regression method allows the comparison of two analytical methods or models. The Deming regression method assumes that measurement errors are present in both Log N (measured) and Log N (observed).

We use some of the values obtained from the validation methods in Table 3 to determine the best predictive model. Generally, all the equations have potential to be good predictive models. However, some models, e.g. equation 12 indicate that the mean (average) of the predicted data were not similar to observed data (p< critical value, 0.05) using the Bland and Altman validation method, Table 3.

Equation 12 had higher bias values and a lower Deming coefficient of determination and a such equation 12 was not considered to be the best predictive model for LABBq determination in yogurts. Equation 10 had a lower Deming coefficient of determination and a higher standard error as compared to equation 9 and 11, and this devalues its potential as the best predictive model. Equation 9, could have been adopted as the best model but the Passing and Bablok regression method indicated that it had higher values of standard deviation and higher bias values as compared to equation 11 and 10. However, we considered equation 11 to be the best model since it had preferable values across all validation methods. For instance, it had lower STD and bias values. Model 11 also exhibited a higher p value which was indicative of the higher predictive strength of the model. Nevertheless, the model also showed a higher standard error as compared to the other models. The coefficients of the best fit model (equation 11) are shown in Table 4 below:

The Concept of the Fundamental Flow Index, FFi.

The measured values of Bostwick consistency were given as distance (φ, cm) travelled at fixed time

Table 4. Coefficients values of the best fit model

Constant	β_0	β_1	β_2	β_3	β_4
Value	−42.16	−0.4256	27.15	0.08122	−3.586

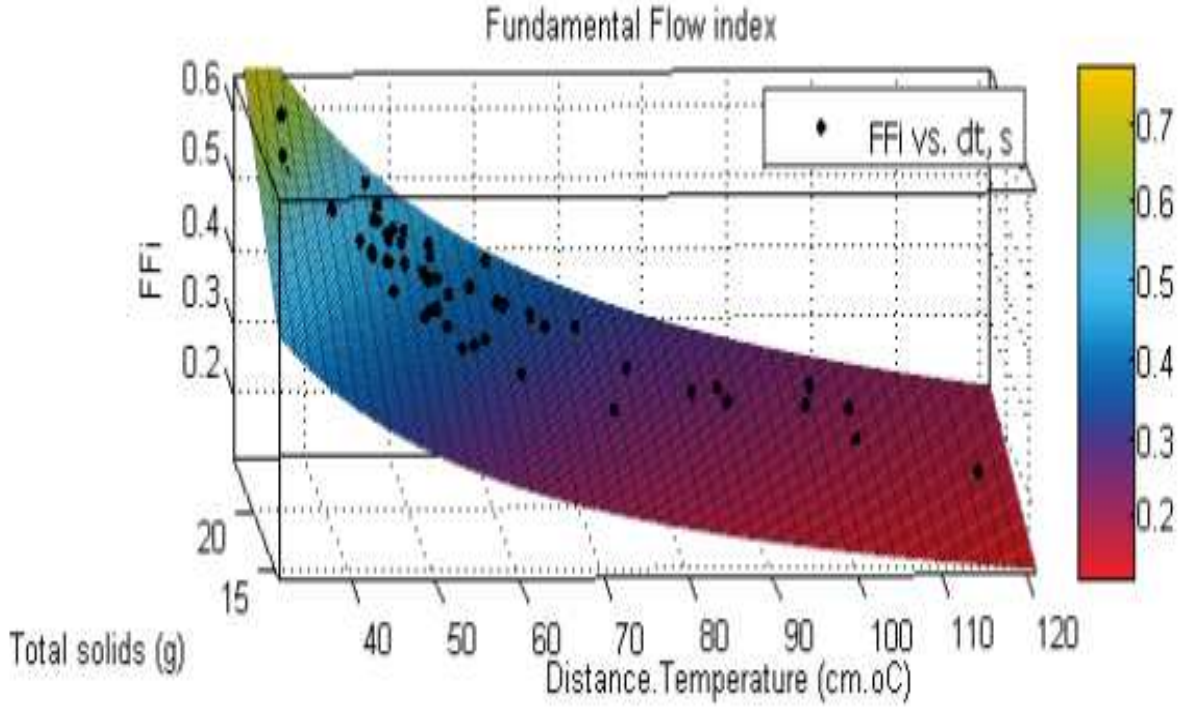

Figure 6. Fundamental Flow index plot.

($t = 30s$) and specific temperature($\theta, ℃$). However, as indicated by Mouquet (1998), the flow behaviour of yogurt can be affected by the total solids s, and temperature θ. The value of the Bostwick consistency may be suggested to depend on these factors, assuming that the friction coefficient of the consistometer is significantly constant. The aim was to express total solids s, of the yogurts in relation to the distance φ, moved in the consistometer (i.e. mass flow rate defined in terms of distance) considering the impact of temperature. Thus, in essence the mass flow rate of the yogurt was expressed as a function of temperature;

$$FFi.(\theta) = \frac{s}{\varphi.\theta} \quad (g.cm^{-1}.℃^{-1}) \qquad 14$$

In general, the relationship of $FFi.$, total solids and the product of distance and temperature ($\varphi.\theta$) was observed to follow a power law function, as shown in Figure 6, with higher $FFi.$values observed at higher total solids values and lower Bostwick consistency-temperature combinations.

Effect of Temperature Change on $FFi.$ Values

The effect of temperature on the distribution of $FFi.$ values was observed using data obtained from various yogurt samples (n=201). Thus, equation 14 may be used as a quality signature to infer the flow quality of yogurt considering the total solids s, distance moved by the sample φ, and the specific temperature θ, of the sample. The model suggests that if the samples are measured at temperatures of a significant range, a plot of the $FFi.$values against temperature should produce a power law model, as shown in Figure 7.

The graph in Figure 7, indicates that products have higher $FFi.$ values at low temperatures and lower $FFi.$ values at higher temperatures.$FFi.$ values depend on the type of yogurt and the defined temperature scales. The

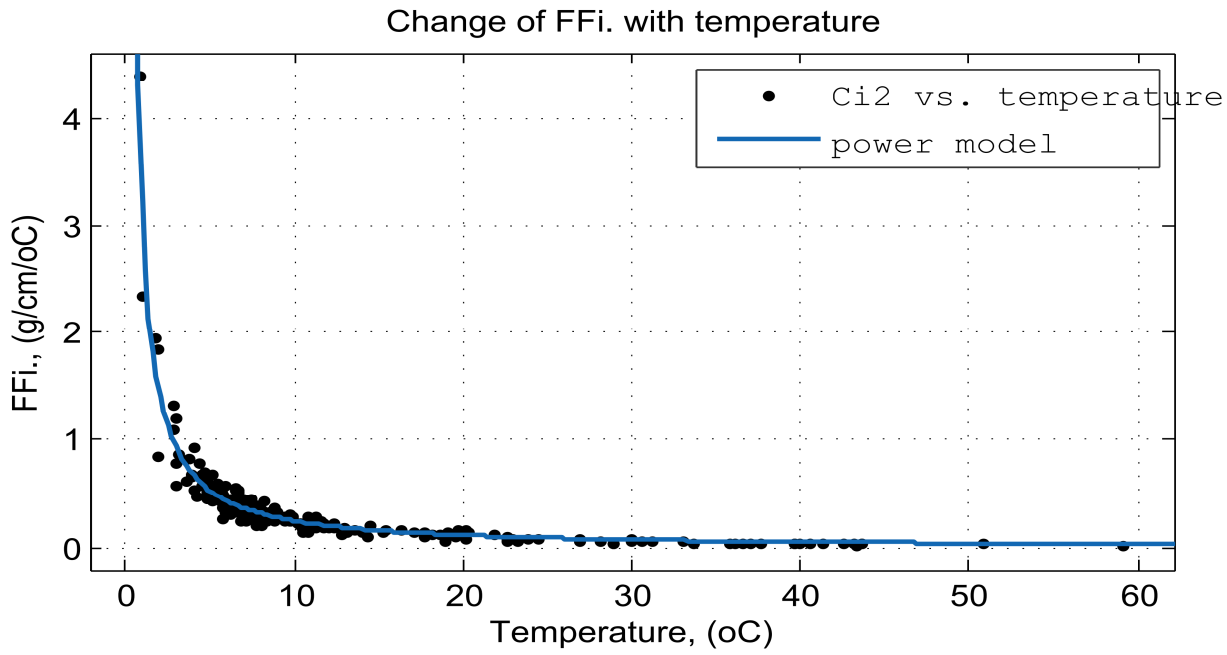

Figure 7. Change of the $FFi.$ values with temperature

Table 5. Distribution of $FFi.$ in defined temperature scales.

Yogurt Type: ShT and FhT	
Temperature scale (°C)	$FFi.(g.cm^{-1}.°C^{-1})$
$0 < \theta < 3$	$FFi. \geq 1$
$3 < \theta < 20$	$0.1 < FFi. < 1$
$20 < \theta < 50$	$0.01 < FFi. < 0.1$
Yogurt Type: SlT	
Temperature scale (°C)	$FFi.(g.cm^{-1}.°C^{-1})$
$0 < \theta < 15$	$0.1 < FFi. < 1$
$15 < \theta < 60$	$0.01 < FFi. < 0.1$

$FFi.$ values range from $0.01\ g.cm^{-1}°C^{-1}$ and increase in excess of $1.0\ g.cm^{-1}.°C^{-1}$. Yogurts with higher values of total solids s, (e.g. ShT and FhT) generally have higher $FFi.$ values at any temperature interval as compared to those with lower total solids (SlT), Table 5.

The distribution of $FFi.$ values at specific temperature scales was thus defined as the flow quality of yogurt at that temperature interval, Table 5. The $FFi.$ approach may be used to determine the perceived quality of the yogurt within the specified temperature scale, but there is need to correlate the $FFi.$ values with other quality variables such as syneresis and sensory data.

The $FFi.$ model was observed to relate to the general shear thinning power law model. This means that the graph of $FFi.$ against temperature has identical behaviour to that of viscosity against shear rate (Behnia *et al.*, 2013). Thus, the Fundamental Flow index-temperature model may be observed as follows:

$$FFi. = K(\theta)^n \quad (15)$$

And, general power law model

$$\sigma = K(\dot{\gamma})^n \quad (16)$$

where; K is the consistency index; σ is the shear stress; $\dot{\gamma}$ is the shear rate (analogous to θ); and n represents the flow behaviour index.

The Fundamental Flow index-temperature model (equation 15) was log-linearized to determine the values of n and K.

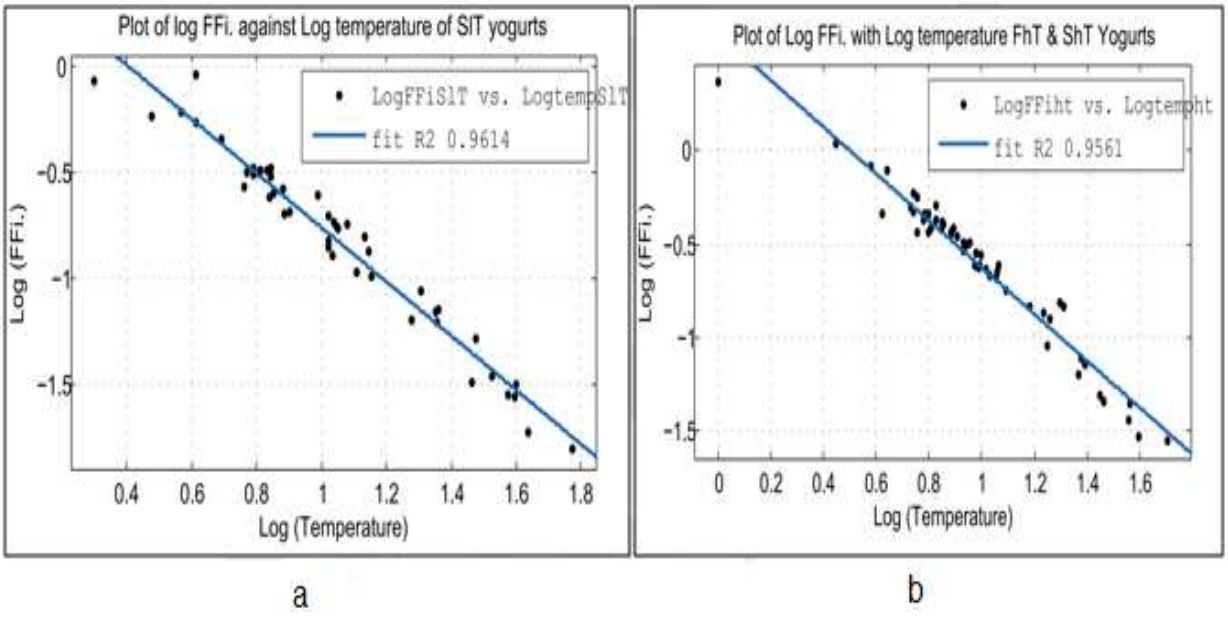

Figure 8. Plots of log $FFi.$ and log temperature

Table 6. Shows the calculated values of n and K at defined temperature scales.

Yogurt types	Temp Scale	n	K	R^2
FhT & ShT	$0 < \theta < 3$	−0.8079	2.681	0.7339
	$3 < \theta < 20$	−1.1535	3.611	0.9231
	$20 < \theta < 50$	−1.6959	18.264	0.8682
SlT	$0 < \theta < 15$	−1.1196	2.445	0.8860
	$15 < \theta < 60$	−1.5003	6.849	0.9096

Thus:

$$log(FFi.) = nlog(\theta) + \log(K) \quad (17)$$

where; n is the gradient and $log(K)$ is the intercept

The plots of $\log(FFi.)$ against $\log(\theta)$ for SlT and, FhT and ShT are shown if Figure 8 (a and b respectively). The graphs shows a linear relationship between the $\log(FFi.)$ and $\log(\theta)$.

The values of n, $\log(K)$ and K, against temperature scales, are given in Table 6. The table shows that the flow behaviour index n, decreases as temperature increases and the consistency coefficient/index K, increases with increasing temperature. Thus, the K and n values may be used to interpolate the temperature dependent flow quality of yogurts. K values are directly related to $FFi.$ values and flow rate, but are in inverse relation to flow quality of yogurt at the observed temperature (Behnia *et al*., 2013). Conversely, n values are inversely related to $FFi.$ values and flow rate and directly related to flow quality of the analysed product at a defined temperature.

CONCLUSION

Shelf quality modelling is a fundamental process in the evaluation of shelf life of food products. Due to the coherent flow in the dynamics of the quality attributes that are used to determine the shelf quality of yogurts we may use parameters such as pH, shelf time and Bostwick consistency to predict other variables, like lactic acid bacteria-bifidobacteria quantity and flow quality. pH, shelf time and Bostwick consistency are relatively easy to measure, and consume less time and financial resources. Conversely, variables such as lactic acid bacteria-bifidobacteria quantity and flow quality are more difficult to measure, and they consume more time and financial resources. Thus, the lactic acid bacteria-bifidobacteria was estimated using pH and shelf time. The flow quality of yogurt was expressed through the introduction of the

concept of the Fundamental Flow index, FFi. which was defined by the total solids, temperature and Bostwick Consistency. Though the FFi. values were observed to correlate well with the product temperature, further research should be conducted to find the relationship with sensory and syneresis data.

ACKNOWLEDGEMENTS

We would like to appreciate Kefalos Cheese (Pvt) Limited for availing their laboratories and other resources that aided in this research. We are also grateful to Mr. A Chindezwa who proofread the paper to ensure that we wrote what we meant.

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