DEFINITION AND IMPLEMENTATION OF STRATEGIES FOR THE CONTINUOUS IMPROVEMENT IN THE PRODUCTION PROCESS OF MARGARINE

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ABSTRACT

The objective of this work is to define and implement strategies for the continuous improvement in the production process of margarine at FIMA – Produtos Alimentares, S.A., and focuses on three distinct areas – perceived quality assessed by Consumer/Customer Relevant Quality Standards (CRQS), aqueous phase pH value prediction, and reuse of its leftovers.

The CRQS documents were translated and updated and a document template and update guide was created to facilitate future updates. A workshop was organized to educate workers on the CRQS methodology.

The aqueous phase pH value was studied in order to model its behaviour and several modelling strategies, taking the ingredient fractions as parameters, were used. All models were statistically analysed and six were considered promising with R^2 above 0.95. A pH value prediction tool for the use of the R&D team was developed in Excel.

To facilitate the reuse of aqueous phase leftovers by operators another tool was developed in Excel to determine the possibility of conversion of an aqueous phase from a previous batch to that of a new recipe. The tool takes into account tolerances and economic factors and informs the operator of the quantities of each ingredient to add in order to perform the conversion.

The objectives were successfully accomplished and several documents, strategies, and tools are already in use.

1. INTRODUCTION

The FIMA – Produtos Alimentares, S.A., located in Santa Iria da Azóia, Portugal, produces mainly margarines and cooking oils [1]. The over sixty year old factory and its equipment show signs of wear. However, in recent years, there has been an undergoing effort to modernize equipment and improve work conditions with computerization of processes and professional training of employees. In order to further improve the production process at FIMA three key areas were chosen to intervene on.

The Consumer/Customer Relevant Quality Standards (CRQS) is a mandatory process developed by Unilever for use in its factories. The local CRQS documents must be up-to-date. Additionally, the workers need to understand the standards and accurately score the items in order to improve the perceived quality of the products to the consumer/client.

The pH value of each product is controlled by internal rules in order to maintain food safety and flavour, with citric acid being the acidity regulator presently used at FIMA. Therefore it is critical to model the acidity of the products, using their ingredient weight fractions as parameters, in order to predict the pH value or the quantity of citric acid required to obtain the desired pH value. Doing so avoids unnecessary time and raw materials costs, when developing new products.

On occasion there are leftovers from the aqueous phase of a previous batch that can be reused for other recipes reducing the operational costs. These calculations are usually done by operators, by hand, with little precision. It is desirable to have a tool that automatically calculates the ingredient amounts to add, taking into account process constraints and engineering tolerances and the raw materials cost. Additionally this tool should also be able to calculate the water amount to add in order to adjust the recipes when pure ingredients are used instead of mother solutions.

2. CRQS

2.1. Background

The scoring of items based on the CRQS process measure the minimum acceptable perceived quality against standards defined for each package type [2]. At FIMA the evaluation of consumer units is performed at the production line by the workers. The CRQS provide standards by which the relevant properties of an item are scored and are presented in a specific format, named standardized issue, where the possible defects in a product are illustrated (Figure 2.1). All standards use the same format and designations for easy identification.

The CRQS serves two purposes. They act as a standard in the design of new products and are used to measure compliance of products in factories, warehouses, and markets where they are sold [2].

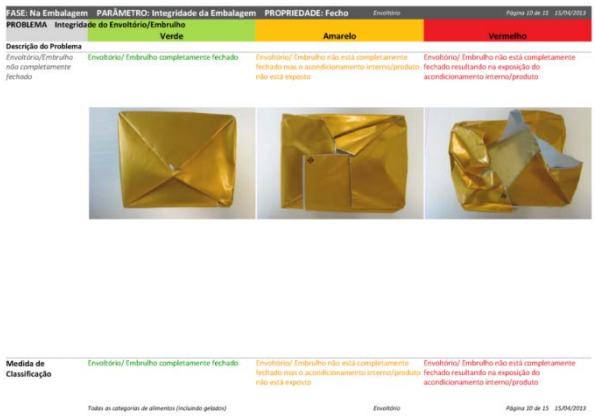

Figure 2.1 – Example of a standardized issue on a CRQS document ([2] adapted).

The scoring of consumer units is performed at three levels – "on-pack", "in-pack", and "in-use". At FIMA only the "on-pack" scoring is performed, which evaluates mostly visual properties of the exterior of the pack.

A "pack format" standard is a combination of issues that are relevant for that pack format, whereas an issue is a potential defect. The scoring of issues is made based on a colour scale, classifying them as green, amber, or red according to Table 2.1.

Table 2.1 – CRQS issue scoring table.

Green	Condition fully meets the CRQS.
Amber	Condition does not meet the CRQS and is only just acceptable for the consumer or customer.
Red	Condition will cause the consumer or customer dissatisfaction preventing purchase or repurchase.

2.2. Updating the CRQS at FIMA

Upon review of the CRQS implementation at FIMA, it was found that the outdated version 2-2011 was still in use [3]. The most recent documents were analysed and translated, and the parameters to be scored were updated in accordance with the current objectives. The CRQS in use is now version 3-2012, latest at the time.

The documents provided by Unilever are in English and PDF format. Since all workers are Portuguese native speakers, and not all of them understand English, the documents were translated and a Word template was designed to facilitate future updates.

A photographic database of fifty FIMA products, containing standard product photos from all sides was created. These allow a worker to quickly compare the item being scored to its standard. Additionally the database contains photos of issues (defects) according to their colour scale classification. The photos were taken in accordance to Unilever's internal guidelines [4]. As much as possible the photos depict real defects found in the production line. In the cases where this was not practical the defects were simulated as accurately as possible.

A procedure instruction was set in order to improve the updating process of the CRQS, ensuring the documents are updated regularly and the addition of new parameters is made directly in FIMA internal network. This instruction lists in detail the filenames and locations of the updated documents, their cycle, and where and how the workers can find the parameters in the network and who to contact for an update or in case of doubts.

2.3. CRQS Workshop

Since the last CRQS training that the workers had received occurred two years ago, a workshop was prepared to educate the workers on the changes to the quality assessment process. The one hour workshop started with an oral presentation, with PowerPoint visual aid. Afterwards the workers were divided into groups for hands-on training in the new parameter scoring, using the production line CRQS scoring sheets (Figure 2.2), and any doubts were explained.

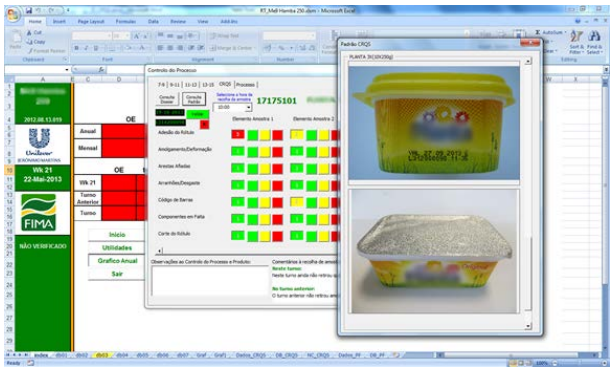

Figure 2.2 – Item scoring sheet on the production line computers with standard product images for analysis.

The workshop was conducted twice, in separate days, for groups of approximately ten workers each. The workers showed interest, actively participated, and asked questions during and at the end of the presentation. Additionally a group of new workers was taken to a large retailer where they were able to comprehend the importance of the correct application of the CRQS process. They evaluated the visual appearance of the products displayed in the shelves (Figure 2.3) so they could better identify what had caused those defects and became aware of the

importance of production line sampling. All participants were very critic, even of the smallest defects, which was considered extremely positive in their future activity as production line workers.


Figure 2.3 – Types of issues found in large retailers.

3. MODELLING THE pH VALUE OF PRODUCTS

3.1. Objectives

To assist the development and production teams at FIMA in the introduction of new products it was necessary to create a model capable of predicting their acidity from their recipe. In order to do so several modelling strategies were tried and tested. Firstly a theoretical study of the production recipes was performed. Afterwards a series of laboratory tests were conducted.

The laboratory tests were made using standard laboratory material and the Metrohm 780 pH Meter [5] which has ± 0.003 measuring accuracy and was calibrated before each test.

The pH value measurement is performed in the aqueous phase; therefore the ingredients used as inputs for the pH value modelling are only those present in that phase. Furthermore, in order to simplify the model, only those considered "main ingredients" were considered – water, whey, brine, citric acid, and potassium sorbate. The remaining ingredients were deemed negligible.

3.2. Analytical Study

Initially an analytical study of the interactions between the different ingredients, based on the production recipes, was performed. The purpose of the study was to characterize the acid-base behaviour and to create an empirical model for the pH value. Different methodologies were tried and the one which considered a mean H^+ consumption was the most promising.

In order to determine the mean H^+ consumption, the number of moles of H^+ ions ($n(H^+)$) provided by each of the five main ingredients were added, and from the observed pH value it is possible to calculate the fraction of consumed H^+ in each recipe (Equation (3.1)). This is considered a good methodology since an exact analytical solution, based on the chemical interactions and conversions of raw materials, is very hard to obtain.

$$\begin{aligned} & n(H^+)_{final} \\ & = n(H^+)_{water} + n(H^+)_{whey} + n(H^+)_{brine} \\ & + n(H^+)_{citric\ acid} + n(H^+)_{potassium\ sorbate} \\ & - n(H^+)_{consumed} \end{aligned} \tag{3.1}$$

The fraction of consumed moles from those that entered the system was then calculated for each recipe. The fractions were averaged and a value of 87.08% for the mean consumption was determined. Equation (3.1) was combined with the mean consumption and the pH values of the ingredients (Table 3.1) to obtain the pH value prediction model on Equation (3.2), where $\%(v/v)$ is the volume fraction of each ingredient in the recipe.

Table 3.1 – pH values of the main aqueous phase ingredients.

	pH
Water	7.20
Whey	6.40
Brine	6.60
Citric Acid	1.15
Potassium Sorbate	9.30

$$\begin{aligned} & pH \\ & = -\log_{10}\big(8.152 \times 10^{-9} \times \%(v/v)_{water} \\ & + 5.143 \times 10^{-8} \times \%(v/v)_{whey} \\ & + 3.245 \times 10^{-8} \times \%(v/v)_{brine} \\ & + 9.146 \times 10^{-3} \times \%(v/v)_{citric\ acid} \\ & + 6.475 \times 10^{-11} \times \%(v/v)_{potassium\ sorbate}\big) \end{aligned} \tag{3.2}$$

The pH value of the production recipes was determined and its residuals $\varepsilon_i = y_i - \hat{y}_I$ were statistically analysed (Table 3.2) to determine the adequacy of the average H^+ consumption model. The maximum observed residual was 0.63 and minimum -0.32. A histogram with the normal distribution overlaid was constructed (Figure 3.1), where the residuals were divided into seven classes with the axis labels being the centre of the class.

Table 3.2 – Residuals analysis for the empirical model using the mean H^+ consumption.

R^2	0.587
μ	5.89×10^{-2}
σ^2	6.34×10^{-2}
Skewness	9.70×10^{-1}
Kurtosis	5.70×10^{-1}

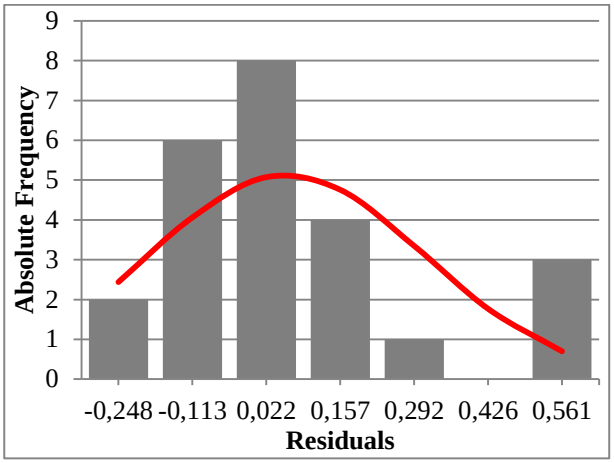

Figure 3.1 – Histogram of the residuals for the empirical model using the mean H^+ consumption with the normal distribution overlaid.

The R^2 coefficient of determination is low and the model exhibits large residuals on three recipes. The residuals behave poorly with a non-zero mean and tendency to estimate the pH value by excess (positive skewness). This analysis suggests the model has missing or incorrect parameters, therefore this model is not considered adequate for pH value prediction at FIMA.

3.3. Laboratory Tests

Since it was not possible to obtain an adequate analytical pH value prediction model, several laboratory tests were performed to better understand and model the ingredient interactions.

There was a suspicion that the citric acid and potassium sorbate had a visible reaction since workers notice an obstruction of the pasteurizer plates when large quantities of acid are used. A laboratory test confirmed the reaction with fine foam being produced when the two ingredients were mixed. The addition order of the citric acid and potassium sorbate was also tested to determine if it had any influence in the final pH value. The measured pH value difference was of 0.004 suggesting the addition order has no influence. Finally a 100 point test was performed to determine if the whey proteins had a significant influence in the pH value, but this test was inconclusive.

3.4. Factorial Analysis

When several factors influence an experiment, a factorial analysis is important [6]. This allows for the identification of which factors (i.e. the ingredients) and combinations of factors are important when modelling the response (i.e. the pH value). The analysis uses all possible combinations of factors at low (-1) and high (+1) levels to study the response.

For this study the levels used are in accordance with FIMA minimum and maximum ingredient weight fractions found in recipes and are shown on Table 3.3.

Table 3.3 – Main ingredient levels used in the factorial analysis.

	Brine *(w/w)*	Whey *(w/w)*	Citric Acid *(w/w)*	K Sorbate *(w/w)*
	A	**B**	**C**	**D**
Low (-)	0.020	0.010	0.001	0.003
High (+)	0.600	0.100	0.020	0.020

Table 3.4 shows the results of the sixteen trials (four factors at two levels) and their average pH value.

Table 3.4 – pH values measured for the sixteen aqueous phases used in the factorial analysis.

A	B	C	D	pH
-1	-1	-1	-1	5.864
1	-1	-1	-1	5.182
-1	1	-1	-1	5.950
1	1	-1	-1	5.576
-1	-1	1	-1	2.905
1	-1	1	-1	2.311
-1	1	1	-1	3.433
1	1	1	-1	2.948
-1	-1	-1	1	6.119
1	-1	-1	1	5.592
-1	1	-1	1	6.307
1	1	-1	1	5.767
-1	-1	1	1	4.180
1	-1	1	1	3.698
-1	1	1	1	4.359
1	1	1	1	4.012
	Average			**4.638**

The contrasts and effects, which are the expected variation in the response when a factor is switched from low to high level, were calculated for each combination and are shown on Table 3.5. The effects were then presented in a normal probability plot (Figure 3.2), where the factors and combinations of factors that most deviate from the normal (straight line) are those with greater influence in the response. The main effects are the ingredients by themselves and the combination of citric acid and whey, and citric acid and potassium sorbate (also in green on Table 3.5). Therefore those were the ones used in the construction of the model described in Equation (3.3), where x_1, x_2, x_3, and x_4 represent the -1 or +1 level of the factors A, B, C and D respectively.

Table 3.5 – Values of the contrasts and effects for the complete factorial analysis with four factors.

	Contrast	Effect
A	-4.031	-0.504
B	2.501	0.313
AB	0.539	0.067
C	-18.511	-2.314
AC	0.215	0.027
BC	0.815	0.102
ABC	-0.051	-0.006
D	5.865	0.733
AD	0.239	0.030
BD	-0.789	-0.099
ABD	-0.295	-0.037
CD	3.439	0.430
ACD	0.261	0.033
BCD	-0.555	-0.069
ABCD	0.347	0.043

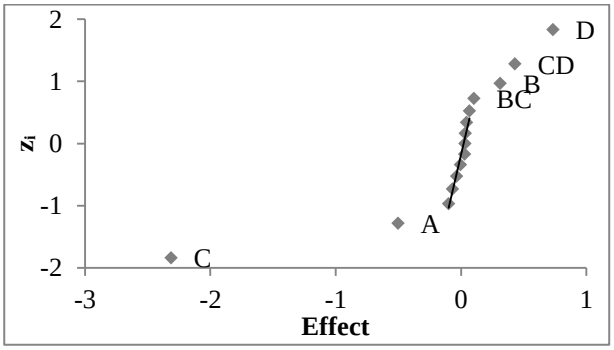

Figure 3.2 – Normalized probability plot of the effects of the factorial analysis.

$$pH = 4.368 - 0.252x_1 + 0.156x_2 - 1.157x_3 + 0.051x_2x_3 + 0.367x_4 + 0.215x_3x_4 \quad (3.3)$$

The residuals of the model exhibit a mean of 6.9×10^{-16} and a variance of 0.011, with a minimum residual of -0.162 and maximum of 0.095. The coefficient of multiple determination R^2 is 0.996 suggesting a good fit of the model. The normal probability plot shown on Figure 3.3 confirms the residuals are well behaved following a straight line.

Although the proposed model is adequate for the factorial analysis it does not allow for the prediction of the pH value of new products since the factors can only be set to -1 or +1, and nothing in between. The model also does not allow for nonlinear variations in the response of each factor, which are presumed to exist. It was therefore necessary to perform additional laboratory tests to construct a more complete model which allows for pH value prediction within the whole range of ingredient weight fractions used at FIMA.

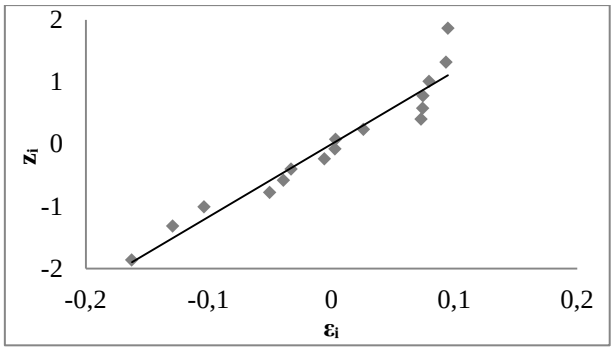

Figure 3.3 – Normal probability plot obtained from the standardized normal scores pH value modelled by the factorial analysis.

3.5. pH Value Modelling

The construction of the pH value prediction models was primarily done using multiple linear regression on different datasets:

- **Production:** 24 production recipes;
- **Laboratory:** 24 laboratory recipes (combination of ingredient minimum and maximum weight fractions used at FIMA, and also mean value for the citric acid);
- **Mixed:** Production and Laboratory datasets combined.
- **FIMA:** Mixed dataset with points outside the pH range of 3.6 – 5.1 removed.

Both the pH value and $[H^+]$ were modelled linearly and nonlinearly. In either case the parameters used were the weight fractions of the pure main ingredients of the aqueous phase.

The determination of the $\boldsymbol{\beta}$ partial regression coefficients was done using multiple linear regression [6], and when that was not possible Excel Evolutionary Solver was used. All models residuals were calculated to have the highest possible coefficient of determination R^2, and their residuals were analysed (mean, variance, skewness, kurtosis).

Initially the multiple linear regression methodology was applied to the four main ingredients to linearly model the pH value using Equation (3.4), where x_1, x_2, x_3, and x_4 represent the whey, brine, citric acid, and potassium sorbate pure weight fractions, respectively.

$$pH = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \beta_3 x_3 + \beta_4 x_4 + \varepsilon \quad (3.4)$$

The residuals analysis for the models obtained using this method (A-type) is shown in Table 3.7.

Table 3.6 – Residuals analysis for the pH value linear models of the production recipes (24), laboratory recipes (24), and both combined.

	A-type Models (pH|Linear)		
	Production	Laboratory	Mixed
R^2	0.927	0.900	0.827
μ_ε	-3.201E-14	8.327E-16	6.106E-15
σ^2_ε	1.427E-02	1.680E-01	1.442E-01
Skewness	4.012E-01	-3.102E-01	1.109E+00
Kurtosis	4.305E-01	-2.859E-01	1.485E+00

All the linear models exhibit an acceptable R^2 coefficient of determination and near-zero residual mean. The skewness and kurtosis suggest the Production and Laboratory model residuals are the ones more normally distributed, whereas the Mixed model residuals are the ones that most deviate from the normal distribution. The Laboratory model is favoured over the Production one since it has tendency to estimate the pH value by defect (negative skewness), allowing for a correction by adding citric acid.

The nonlinear terms (square of the ingredients already present, and all the two ingredients combinations) were then added to the model to improve its adjustment, as described in Equation (3.5). The residuals analysis for these models (B-type) is shown on Table 3.8.

$$pH = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \beta_3 x_3 + \beta_4 x_4 + \beta_5 {x_1}^2 + \beta_6 {x_2}^2 + \beta_7 {x_3}^2 + \beta_8 {x_4}^2 + \beta_9 x_1 x_2 + \beta_{10} x_1 x_3 + \beta_{11} x_1 x_4 + \beta_{12} x_2 x_3 + \beta_{13} x_2 x_4 + \beta_{14} x_3 x_4 + \varepsilon \quad (3.5)$$

Table 3.7 – Residuals analysis for the pH value nonlinear models of the production recipes (24), laboratory recipes (24), and both combined.

	B-type Models (pH|Nonlinear)		
	Production	Laboratory	Mixed
R^2	0.975	0.976	0.951
μ_ε	6.427E-12	-1.850E-16	5.649E-14
σ^2_ε	1.055E-02	8.436E-02	1.471E-02
Skewness	-4.598E-02	1.187E-01	-3.936E-01
Kurtosis	5.303E-01	-5.465E-01	-6.659E-01

The introduction of the nonlinear coefficients has improved the prediction of the pH value. All the coefficients of determination improved when compared to the A-type models, the residual means remains near-zero, and variance has improved considerably. The skewness values are also lower, and kurtosis remains in the same order of magnitude. From the B-type models, the Production one seems to be the most adequate, having negative skewness as preferred.

Since the pH value is a logarithmic function of the concentration of H^+, the next step was to model the $[H^+]$ directly, and apply the $-\log_{10}()$ transformation to the model. This methodology was applied to both linear and nonlinear models as described in Equations (3.6) and (3.7).

$$pH = -\log_{10}(\beta_0 + \beta_1 x_1 + \beta_2 x_2 + \beta_3 x_3 + \beta_4 x_4 + \varepsilon) \quad (3.6)$$

$$pH = -\log_{10}(\beta_0 + \beta_1 x_1 + \beta_2 x_2 + \beta_3 x_3 + \beta_4 x_4 + \beta_5 {x_1}^2 + \beta_6 {x_2}^2 + \beta_7 {x_3}^2 + \beta_8 {x_4}^2 + \beta_9 x_1 x_2 + \beta_{10} x_1 x_3 + \beta_{11} x_1 x_4 + \beta_{12} x_2 x_3 + \beta_{13} x_2 x_4 + \beta_{14} x_3 x_4 + \varepsilon) \quad (3.7)$$

The residuals analysis for both the $[H^+]$ linear (C-type) and nonlinear (D-type) models is show on Table 3.9 and Table 3.10, respectively. This analysis was done for the pH value residuals after the logarithmic transformation, in order to be able to compare them with the A- and B-type models.

Table 3.8 – Residuals analysis for the $[H^+]$ linear models of the production recipes (24), laboratory recipes (24), and both combined.

	C-type Models ($[H^+]$|Linear)		
	Production	Laboratory	Mixed
R^2	0.856	0.726	0.712
μ_ε	-4.315E-08	-2.304E-05	-6.864E-07
σ^2_ε	2.839E-02	4.619E-01	2.395E-01
Skewness	-2.945E-01	-3.486E-01	-5.471E-01
Kurtosis	-7.706E-01	-5.205E-03	1.702E+00

Table 3.9 – Residuals analysis for the $[H^+]$ nonlinear models of the production recipes (24), laboratory recipes (24), and both combined.

	D-type Models ($[H^+]$|Nonlinear)		
	Production	Laboratory	Mixed
R^2	0.980	0.942	0.915
μ_ε	-3.030E-04	-3.805E-02	-3.477E-03
σ^2_ε	8.273E-03	2.051E-01	9.166E-02
Skewness	-5.441E-01	-1.077E+00	-1.991E+00
Kurtosis	6.104E-01	2.718E+00	5.737E+00

The linear $[H^+]$ models (C-type) are worse than the pH models (A-type), therefore its use is not recommended. The nonlinear $[H^+]$ models (D-type) show promising results with high coefficients of determination, near-zero mean and low variance of residuals. However, with the exception of the Production model, the residuals are not normally distributed, having values of skewness and kurtosis very far from zero. They are still viable models since the skewness is negative.

Finally both the pH value and [H⁺] were modelled nonlinearly using the FIMA set, which comprised the 24 production recipes and 9 laboratory recipes. The residuals analysis is shown on Table 3.11.

Table 3.10 – Residuals analysis for the pH value and [H⁺] nonlinear models of the FIMA 3.6 - 5.1 pH range recipes (24 production; 9 laboratory).

	FIMA Models	
	pH Nonlinear	[H⁺] Nonlinear
R^2	0.951	0.947
μ_ε	5.649E-14	-3.330E-04
σ^2_ε	1.471E-02	1.585E-02
Skewness	-3.936E-01	-4.406E-01
Kurtosis	-6.659E-01	7.025E-02

These models are very robust, featuring high coefficients of determination, near-zero mean and low variance of residuals, and low skewness and kurtosis. The skewness has the added benefit of being negative on both models, revealing a tendency to predict the pH value by defect as preferred. The removal of recipes with pH value outside the range used at FIMA greatly improved the models.

Overall the constructed models are adequate and well behaved, with normally distributed residuals. The nonlinear models are better candidates when compared to the linear ones (higher coefficient of determination) which suggests the quadratic terms are relevant and should be included. The Mixed dataset models should be avoided since they contain points with pH value well outside the FIMA range, which increase the model domain but worsen the fit.

3.6. pH Value Prediction Tool

A pH value prediction tool was developed in Excel with Visual Basic for Applications (VBA) to be used by the engineering department at FIMA when introducing new products or modifying existing ones. The tool includes all the models from Section 3.4 and allows the user to either calculate the pH value from a recipe, or the citric acid quantity required to attain the desired pH value. The ingredient weight fractions can either be given in mother solution or pure (non-diluted) quantities.

The user interface of the tool is shown on Figure 3.4.

Figure 3.4 – User interface of the pH value calculator.

The users need to select, using a drop-down control, if they wish to provide the ingredient (whey, brine, citric acid, potassium sorbate) weight fractions in mother solution or pure quantities, with the water being automatically calculated for compliance purposes. The desired model is also selected from a drop-down control and its description and statistical analysis are displayed, along with detailed tooltips explaining the parameters. Finally the user can specify the desired confidence level for the prediction.

The tool calculates the predicted pH value using the adequate equation from Table 3.6, the $\boldsymbol{\beta}$ parameters from the selected model, and the provided ingredient weight fractions $\boldsymbol{x}$.

Lastly the prediction interval is calculated using Equation (3.8) [6], where $t_{\alpha/2,n-p}$ represents the Student's t-value at a confidence level of $1-\alpha$ with $n-p$ degrees of freedom, n being the sample size used to construct the model and p its number of parameters.

$$\begin{aligned} &\widehat{pH} - t_{\frac{\alpha}{2},n-p}\sqrt{\hat{\sigma}^2(1+\boldsymbol{x}^T(\boldsymbol{X}^T\boldsymbol{X})^{-1}\boldsymbol{x})} \\ &\leq pH \\ &\leq \widehat{pH} + t_{\frac{\alpha}{2},n-p}\sqrt{\hat{\sigma}^2(1+\boldsymbol{x}^T(\boldsymbol{X}^T\boldsymbol{X})^{-1}\boldsymbol{x})} \end{aligned} \tag{3.8}$$

The citric acid required to attain a desired pH value is calculated using a similar process, where the only noticeable difference for the user is that the citric acid weight fraction is an output and the pH value an input.

4. RECIPE CALCULATION TOOLS

4.1. Aqueous Phase Reuse

When there is an aqueous phase leftover due to technical issues its reuse for the next batch is almost always desirable. This needs to take into account the compatibility between the previous batch (origin) and next batch (target) recipes, and the tolerances set by the engineering department. It is also crucial that this reuse is made taking into account economic aspects, namely raw materials cost, in order to minimize the operational costs as much as possible.

The engineering department must provide interfaces to allow the workers to accurately perform these conversions unaware of the complex calculations involved. In this way all the workers need to do is provide the required inputs to the software and it will instruct them step-by-step on what to do to minimize costs and improve productivity. Furthermore, simple decisions can be made by the software, avoiding the need to call engineering or management personnel.

Therefore an Excel with VBA tool was developed to more accurately and efficiently perform the aqueous phase transformation calculations with all the requirements set by engineering. The tool provides all the instructions required by the operators in the control room and is intuitive, requiring minimal amount of training to use.

From the origin recipe, target recipe, leftover quantity, target quantity, and tank capacity the tool determines if the leftover should be reused or not. It determines if the recipes are compatible by analysing their compositions, given that excess vitamins and colouring are allowed, and excess flavouring requires administrative approval. If the minimum quantity to produce exceeds the desired one it also determines if the reuse is cost effective. It then calculates the ingredient quantities to add to the leftover and the number of tanks required to perform the operation. The flowchart on Figure 4.1 illustrates the calculation process and its possible decisions.

Initially the software tests the compatibility between the recipes **RO** and **RT**, making sure all ingredients present in **RO** are also in **RT** (except vitamins, colourings, and flavours, which only generate a warning). If no incompatibility is found the minimum quantity to be produced of the target recipe **A** is calculated using Equation (4.1), where **L** is the leftover quantity.

$$A = max\left(\frac{\%(w/w)_i^{origin}}{\%(w/w)_i^{target}}, 0 < i < n_{ing}\right) \times L \quad (4.1)$$

If the **A** is smaller or equal than the desired target quantity **T** the number of tanks required to equally divide the leftover **nTA** and the remaining quantity of the target recipe to prepare **R** are calculated. Finally the quantities of each ingredient to add to the leftover per reuse tank are calculated using Equation (4.2).

$$m_i^+ = \frac{\%(w/w)_i^{target} \times (T - R) - \%(w/w)_i^{origin} \times L}{nTA} (4.2)$$
$$, 0 < i < n_{ing}$$

If however A is larger than the desired target quantity it is necessary to check if the cost of producing in excess is more or less than the cost of waste disposal of the leftover. The excess quantity to prepare **E** and its respective value **VE** are calculated using the raw materials cost. Similarly the value of the leftover **VS** is also calculated. If it is favourable to produce in excess the software determines the number of tanks required and the quantities of each ingredient to add to the leftover per tank.

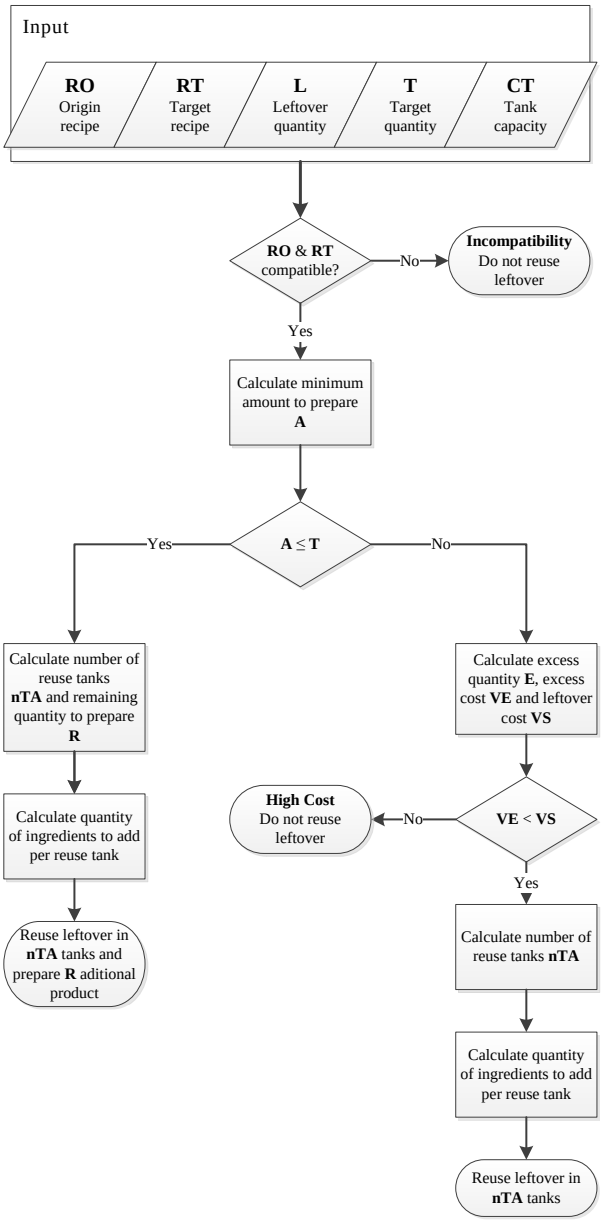

Figure 4.1 – Flowchart of the aqueous phase reuse calculator.

The user interface of the tool is shown in Figure 4.2. The control room operators select the origin and target recipes via drop-down controls, fill in the initial leftover quantity and target quantity in kilograms, and select the tank capacity. The target quantity refers to the fat phase and not the aqueous one since this is the standard used at FIMA.

The tool displays the action to be taken: Reuse the Leftover; Incompatible Phases – Waste disposal of the leftover; High Cost – Waste disposal of the leftover. It also displays a table with practical information of what needs to be done, including how many reuse and clean tanks are necessary, if there will be any excess, and the remaining amount of the target recipe to be prepared. Finally a table with the quantities of leftover and each ingredient to add per reuse tank is shown. The table features drop-down selectors to allow operators to toggle between mother solution and pure ingredients. When the phases are incompatible the offending ingredients are highlighted with a red background and if an ingredient was tolerated it is shown in red text. If the tolerated ingredient is flavouring a message to contact management personnel is displayed. This message also contains the calculated weight fraction of the flavouring in the final recipe to allow for a more informed decision.

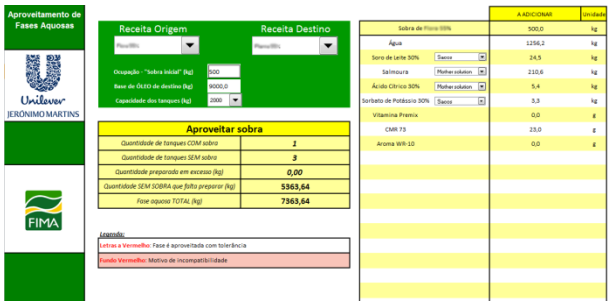

Figure 4.2 – User interface of the aqueous phase reuse calculator.

4.2. Water Quantity Adjustment

It was noted that only rarely the workers correct the water quantity of recipes when they use ingredients in pure form instead of mother solution. Since the aqueous phase reuse tool has this feature embedded a new tool (Figure 4.3) was developed using the same methodology for the purpose of correcting an arbitrary recipe.

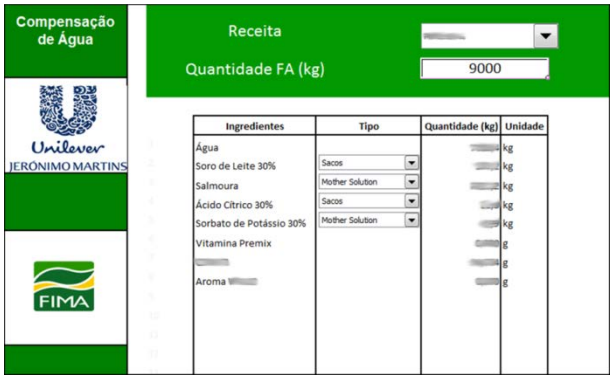

Figure 4.3 – User interface of the water quantity adjustment calculator.

The user selects the recipe from the drop-down control and types in the quantity of aqueous phase being prepared. The software displays the ingredients table along with sectors to toggle between mother solution and pure ingredients. Toggling the option for any ingredient immediately adjusts the water quantity to ensure the recipe remains the same.

5. CONCLUSION

The CRQS documents were updated and translated and a Word template and procedure instruction were created to facilitate future updates. The photographic database of product standards and defects was rebuilt solving one of the main complaints of the production line operators – the inability to identify their products in the CRQS forms. The workshop helped workers to become familiar with the new CRQS parameters and the practical exercise ensured they understood the process. It is recommended that similar workshops are organized regularly and attended by all workers, especially when CRQS parameters are updated. In order to address the complaint of lack of time to correctly apply the CRQS process in the production line the possibility of assigning a single employee to quality control should be considered. It is also important to monitor the frequency and truthfulness or the CRQS reports and compare it to customer/consumer complaints in order to continuously improve the perceived quality or the products, and access the impact of the workshops. Finally the CRQS form should be simplified in order to avoid hasty and inaccurate fillings.

The acidity of the recipes was studied both analytically and through a series of laboratory tests. The pH value was modelled using several different strategies attaining high coefficients of determination. The modelling took into account FIMA needs, namely the pH range currently used and the preference for models that predict the pH value by defect so that a correction is still possible if needed. The necessity to include quadratic terms and interactions between ingredients was well established and the models which include them exhibit better fits than those which do not. The statistical analysis shows that the residuals are generally well behaved suggesting all important factors were included in the models. The nonlinear FIMA models are the ones recommended for use since they exhibit high coefficients of determination, very well behaved residuals, and a tendency to predict the pH value by defect. However, no model can be considered the “best” since the datasets are fairly small and the pH value behaviour outside the neighbourhood of measured points is unknown. The “best” model will depend on the proximity of the recipe being analysed to the ones of the dataset. It is desirable to further improve the models using larger datasets. The pH value (and citric acid weight percentage) prediction tool should be used with

caution, bearing in mind the datasets are small, and some matrices used in the calculations are ill conditioned suffering from numerical stability issues.

The aqueous phase reuse calculator is a quick and accurate way of determining the compatibility and cost-effectiveness of a phase transformation, and the ingredient quantities to add to production leftovers. It also allows for the selection of pure or mother solution ingredients adjusting the water quantity as necessary. However, to accurately perform the calculations and split the leftover among tanks it is necessary to know the exact tank liquid level. Presently the level is estimated by sight, therefore the installation of tank level sensors is recommended. The long-term economic benefits of more accurate aqueous phase transformations should cover the initial investment. Finally the calculator only takes into account the cost of the raw materials, ideally the energy costs (e.g. stirring, pasteurization), the waste water treatment costs, among others, should also be considered.

6. REFERENCES

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