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Determination of the Quality of a Milk Blend Product Based on Fuzzy Logic

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ABSTRACT
In this work it is described a method to determine the quality of a milk blend product based on fuzzy logic. The method classify the quality of the product as bad, regular, acceptable, good and excellent based on eight input variables. Moreover, these variables are qualitative and quantitative with different value ranges, which generate a quite large number of possible combinations complicating the decision making process for determining the quality of the milk. The large number of combinations induces that the quality diagnostic generates not homogeneous diagnostics since the appreciation of each quality inspector induces to have different quality classification. This implies that one sample can have different quality levels depending on the analyst, which mean a vulnerability for the company. For these reasons the company requires a methodology to analyze the input data with the same mathematical criteria in order to have homogeneous and precise results of the quality of the milk product. Here, it is shown that by applying fuzzy logic the quality determination can be performed in a systematic way by taking into account the quantitative and qualitative variables. Additionally, it allow us to incorporate into the analysis the practical expertise of the analyst and the experimental restrictions which are relevant for quality determination.
Keywords–Quality Assessment, Fuzzy Logic, Food Industry.

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I. INTRODUCTION

In Mexico more than 90% of all dairy milk products are sold directly in supermarkets and grocery stores. Therefore for the producer companies it is quite important to have reliable systems to predict the quality of the products when these are on the shelves, since depending of this estimation they can take the decision of recall the product before customers buy a product in decomposition or either with bad color, aroma or flavor. Here, the quality of the dairy milk products can be defined as the set of properties and characteristics which can satisfy the needs explicitly and implicitly expressed by the customer.

The quality of a dairy milk product depends on different parameters, therefore it is not a straightforward process. In general when it is necessary to take a decision it implies that there are more than one alternatives and therefore it implies that it is necessary to analyze the advantages and disadvantages of select one of them. Here, the alternative selected is the one that we consider will provide us the largest probability of success or the one that fits our needs or goals [1]. Here, all decision must be based on a standard (criteria) and the decision maker must use it as guide to choice a solution. The criteria normally are restricted by rules which can be corporative, institutional or practical. The multi-criteria analysis is a supporting tool for the decision making process. It allows us to have an integral vision of the problem since it consider different criteria. Normally this tool is used to take decisions related with election, sorting and classification of alternatives [2]. Moreover, the multi-criteria tools can be classified as a) Discrete: when the solution is selected from a finite set of alternatives; and b) Multi-objective: when the solution can be taken from an infinite number of possible alternatives [3]. The process to determine the quality of a product can be classified as multi-objective since the quality can have an infinity number of alternatives. Hence, in literature it can be found several methodologies to determine the quality of a product, which are based on very different mathematical fundaments. The choice of a particular methodology depends directly on the needs and restrictions of the application. Fuzzy logic is an intelligent technique for multi-objective decision making process. In general fuzzy logic is useful in applications where it is necessary to make a decision based on information that it is not completely defined or that have some degree of uncertainty. Moreover, fuzzy logic allow us to model and mathematically express qualitative variables such as those related to the human perception of the things [4]. Furthermore, systems with qualitative and quantitative variables can be easily modeled with this technique.

Fuzzy logic has been applied for applications related to the quality of dairy milk products. For instance a model to determine the acceptability of goat milk yogurt was presented by [5], in that work authors classified the acceptability as unacceptable, slightly acceptable, regularly acceptable, acceptable, and highly acceptable. The classification was carried out based on the odor, flavor and viscosity of the yogurt. Here authors appointed that most of the customers ranked the level of acceptability based on the sensorial test (odor and flavor). Another interesting application was the presented by [6] in which a system based on fuzzy logic for determining the bulk tank milk quality and herd's milking practice was presented. The bulk tank milk quality was classified as excellent, good, milk cooling problem, cleaning problem, environmental mastitis, or mixed with mastitis and cleaning problems based on six microbiology test results (inputs). Another example of fuzzy logic applied to dairy milk products is the presented by [1], in which a system to determine the hygienic quality and the compositional quality of raw milk. In that work authors determined the quality level taking into account 7 different inputs.

In this work a system for determining the quality of a milk blend product based on fuzzy logic is presented. This method was applied in a company that produces dairy milk products. In particular the methodology was applied to define the quality of one of the products fabricated by the company, which is a milk blend product. Hence the quality of the product is based on eight input variables, from which 3 of them are sensorial (qualitative) variables. The system allowed us to determine in a systematic way the quality of the product. Moreover, the technique provide us homogeneous diagnostics and help to minimize errors induced by the appreciation of the quality inspectors.

II. DESCRIPTION OF THE INPUT VARIABLES

In the company the quality of the drinking milk blend product is performed by taking into account eight variables. These variables are both quantitative and qualitative.

II.A. Quantitative variables

In order to determine the quality of the product the company used the following quantitative variables:

pH- This parameter is related with the state of the milk product, if this is under 6.45 therefore it is considered that the product is under decomposition state. Moreover if the values is above 6.90 indicates that the either the blend formulation of the product is incorrect or the thermic process was not performed correctly.

Grease Separation Level (NSG)- This process quantifies the grease separation of the milk blend product over its life on the shelf. It is quantified by measuring the area of the superior part of the container which is covered by grease. Afterwards depending on the proportion of area covered by grease a value between 0 and 3 is assigned to this variable, here 0 corresponds to a 0% covered area while 3 to a 100% area.

Sediment Level- this is determined by measuring the area of the bottom of the container which is covered by solids. Depending on the proportion of the area a value within 0 and 3 is assigned to this variable.

Alcohol Stability Test- this is realized by mixing equal volumes of the formulated product and ethanol at 75%. Here depending on the precipitation the variable is quantified as positive if stabilization is observed, sandy if it is murky, and negative if precipitation do not occur.

Ebullition Test- here a sample of the milk product is heated until it reaches the ebullition point, in order to determine if lumps are formed. If lumps are formed the test is positive and a number 1 is assigned to the variable, otherwise the test is negative and a number 0 is assigned to the variable.

II.B. Qualitative variables

The qualitative variables are related with sensorial issues, which are quite important for the commercialization of the product since customer directly links these with the quality of the product and image of the brand. Hence for the company it is relevant to take into account these variables for quality determination of the product.

Color- The color of the milk ideally must be white. However in practice it can have a wide range of white shades. In our project the color was quantified with values between 0 and 10 depending on the shade of white of the product. Here, a shades of white color palette was used as a reference to carry out this test.

Odor- This is a sensorial test which consist in agitate the milk product container and smell it in order to determine if the odor is characteristic of the milk. Depending on the smell this variable is quantified with values between 0 and 10, where 10 is assigned when the product has the characteristic aroma of the milk and 0 when it is musty or acid.

Flavor- this is evaluated by taking a sample of the milk product and keeping it during a period of 10–15 seconds in the mouth. Afterwards the flavor is classified as either characteristic or not characteristic. Finally, depending on the flavor the quality inspector assign a value to this variable in the scale from 0 to 10, where 10 is for the case when the product has the characteristic flavor of milk.

In Table 1 a list of the input variables considered in our quality analysis is provided, as well as their corresponding universe of discourse.

Table1- Input variables considered in the quality analysis and their corresponding universe of discourse

INPUT VARIABLE	**UNIVERSE OF DISCOURSE**
pH	0 – 10
Grease Separation Level (NSG)	0 – 3
Sediment Level (NS)	0 – 3
Color (CL)	0 - 10
Odor (OL)	0 - 10
Flavor (SaL)	0 - 10
Ebullition Test (PE)	0 – 1
Alcohol Stability Test (EAA)	0 -1

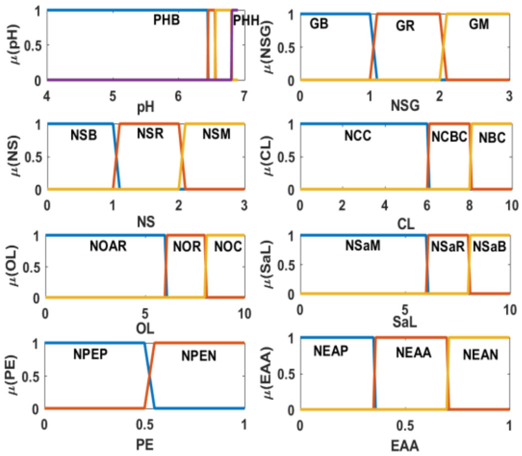

Figure1. Membership functions associated to each one of the input variables.

III. FUZZY LOGIC AND THE QUALITY OF THE MILK BLEND PRODUCT

III.A. Input variables

In order to apply fuzzy logic there were defined linguistic variables for each one of the input variables. In Table 2 the list of linguistics variables defined for our application and their corresponding interval values within the universe of discourse are presented. Based on these linguistic variables a set of membership functions for each one of the input variables was defined. For our procedure trapezoidal membership functions were considered and their profiles are shown in Fig. 1.

III.B. Output variable

The output variable is the quality of the milk blend product (CPL). Here, a universe of discourse universe between 0 and 10 was assigned to this variable. Moreover, the quality was classified as bad, regular, acceptable, good and excellent and we defined each one of these levels as the linguistic variables of the CPL (Table 3). Furthermore the membership functions for each one of the linguistic variables of the CPL are shown in Fig. 2.

III.C. Base of Rules

In our experiment eight input variables were considered. Afterwards to each one of these variables a different number of linguistic variables were associated. In this way, the pH has 4 linguistic variables, the PE has 2 variables and the other 6 input variables (NSG, NS, CL, OL, SaL, EAA) have 3 linguistic labels each one. Therefore, the possible number of linguistic variable combinations is $N = 4\times3\times3\times3\times3\times3\times2\times3 = 5832$.

Table2- Linguistic variables for each one of the input variables.

INPUT VARIABLE	**LINGUISTIC VARIABLES**			
pH	**Low (PHB)**	**Acceptable (PHA)**	**Desirable (PHD)**	**High (PHH)**
	4-6.44	6.45-6.55	6.56-6.80	6.81-6.90
Grease Separation Level	**Good (GB)**	**Regular (GR)**	**Bad (GM)**	
	0 –1	1 – 2	2 – 3	
Sediment Level	**Good (NSB)**	**Regular (NSR)**	**Bad (NSM)**	
	0 -1	1 – 2	2 – 3	
Color	**Cream (NCC)**	**Cream - WhiteCream (NCBC)**	**White Cream (NBC)**	
	0 – 6	6 – 8	8-10	
Odor	**Acid–Musty (NOAR)**	**Regular (NOR)**	**Characteristic (NOC)**	

	0 – 6	6 – 8	8-10
Flavor	**Bad (NSaM)**	**Regular (NSaR)**	**Characteristic (NSaB)**
	0 – 6	6 – 8	8-10
Ebullition Test	**Positive (NPEP)**	**Negative (NPEN)**	
	0	1	
Alcohol Stability Test	**Positive (NEAP)**	**Sandy (NEAA)**	**Negative (NEAN)**
	0 - 0.35	0.35- 0.7	0.7 – 1

Table3- Linguistic variables associated to the CPL.

LINGUISTIC VARIABLES OF QUALITY OF THE PRODUCT (CPL)				
Bad (CPLM)	**Regular (CPLR)**	**Acceptable (CPLA)**	**Good (CPLB)**	**Excellent (CPLE)**
0 - 2	2 – 4	4 – 6	6 – 8	8 – 10

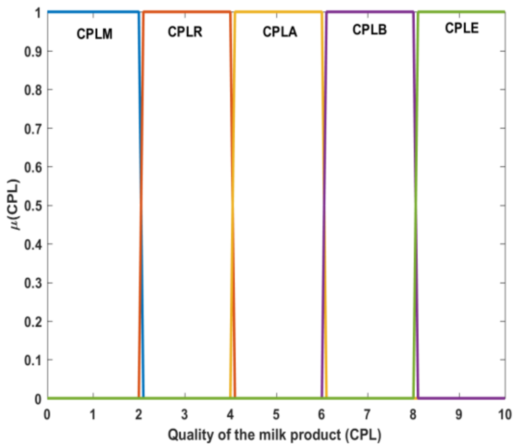

Figure2- Membership functions associated to the quality of the milk blend product.

A specific linguistic variable of the CPL must be associated to each one of the combinations of the linguistic variables of the inputs. Hence, based on the restrictions set provided by the company the 5832 combinations were reduced into a base of 31 rules. The base of rules used in this work is provided in the Annex 1. Furthermore, once all control rules are evaluated a maximization process was performed, which can be expressed as $R = \max\{R1, R2, R3, ..., R31\}$, an example of the function obtained with this procedure is shown in Fig. 3.

III.D. Defuzzification and Quality of the Milk Blend Product

In order to get a final and single numerical result from the function obtained from the evaluation of the control rules (*R*) it is necessary to apply a defuzzification procedure. In our case the centroid method was used, which consists in firstly determine the area under the curve of the function *R* and secondly in determining the point over the CPL axis that evenly split the area under the curve. In Fig.3 it is shown an example of the centroid of the function *R*. Finally, in order to determine the quality of the milk blend product the membership functions of the output variable are evaluated introducing the centroid value obtained and their results maximized to get the final quality determination.

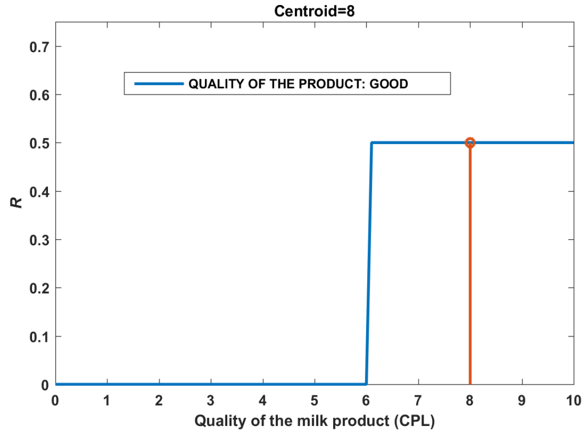

Figure3- Example of the result (*R*) obtained after evaluating the rule base and its centroid.

IV. CONCLUSION

In this work it was shown that the quality of a milk blend product can be determined by using fuzzy logic. This provides a systematic methodology which generates homogeneous results and can take into account quantitative and qualitative analysis. Moreover, it is a simple and low cost solution which can be implemented by producers of dairy milk products.

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ANNEX 1

Control rules base used in the fuzzification process:

R1= If (PHD and GB and NSB and NBC and NOC and NSaB and NPEN and NEAN) Then CPLE
R2= If (PHA and [GB or GR or GM] and [NSB or NSM or NSR] and [NBC or NCC or NCBC] and [NOC or NOR] and [NSaB or NSaR] and NPEN and NEAN) Then CPLA
R3= If (PHD and [GB or GR or GM] and [NSB or NSM or NSR] and [NCC or NCBC] and [NOC or NOR] and [NSaB or NSaR] and NPEN and NEAN) Then CPLB
R4=If (PHD and [GB or GR or GM] and [NSB or NSM or NSR]) and [NCC or NCBC]) and [NOC or NOR] and [NSaB or NSaR]) and NPEN and NEAP) Then CPLR
R5= If (PHD and [GB or GR or GM] and [NSB or NSM or NSR] and [NCC or NCBC] and [NOC or NOR] and [NSaB or NSaR] and NPEN and NEAA) Then CPLA
R6= If (PHD and [GB or GR or GM] [NSB or NSM or NSR] [NCC or NCBC] and [NOC or NOR] and [NSaB or NSaR] and NPEP and NEAA) Then CPLR
R7= If (PHD and [GB or GR or GM] and [NSB or NSM or NSR] and [NCC or NCBC] and [NOC or NOR] and [NSaB or NSaR] and NPEP and NEAN) Then CPLR
R8= If (PHA and [GB or GR or GM]) and [NSB or NSM or NSR] and [NCC or NCBC] and [NOC or NOR] and [NSaB or NSaR] and NPEP and NEAN) Then CPLR
R9= If ([PHA or PHD or PHH] [GR or GB or GM] and [NSR or NSB or NSM] and [NCC or NCBC or NBC] and NOAR and [NSaB or NSaR or NSaM] and [NPEN or NPEP] and [NEAN or NEAP or NEAA]) Then CPLM
R16= If (PHH and [GR or GB or GM] and [NSR or NSB or NSM] and [NCC or NCBC or NBC] and [NOC or NOR] and [NSaB or NSaR] and NPEP and NEAA) Then CPLR
R17= If ([PHD or PHA or PHH] and [GR or GB or GM] and [NSR or NSB or NSM] and [NCC or NCBC or NBC] and [NOC or NOR] and NPEN and [NEAN or NEAA or NEAP]) Then CPLR
R18= If ([PHD or PHA or PHH] and [GR or GB or GM] and [NSR or NSB or NSM] and [NCC or NCBC or NBC] and [NOC or NOR] and NSaM and NPEP and [NEAN or NEAA]) Then CPLR
R19= If ([PHD or PHA or PHH] and [GR or GB or GM] and [NSR or NSB or NSM] and [NCC or NCBC or NBC] and [NOC or NOR] and NSaM and NPEP and NEAP) Then CPLM
R20= If (PHD and [GR or GB or GM] and [NSR or NSB or NSM] and NBC and [NOC or NOR] and NSaB and NPEN and NEAN) Then CPLB
R21= If (PHD and [GR or GB or GM] and [NSR or NSB or NSM] and NBC and [NOC or NOR] and NSaB and NPEN and NEAP) Then CPLA
R22= If (PHD and [GR or GB or GM] and [NSR or NSB or NSM] and NBC and [NOC or NOR] and NSaB and NPEP and NEAN) Then CPLA
R23= If (PHA and [GR or GB or GM] and [NSR or NSB or NSM] and [NCC or NCBC or NBC] and [NOC or NOR] and [NSaB or NSaR] and NPEN and NEAP) Then CPLA
R24= If (PHA and [GR or GB or GM] and [NSR or NSB or NSM] and [NCC or NCBC or NBC] and [NOC or NOR] and [NSaB or NSaR] and NPEP and NEAN) Then CPLR
R25= If ([PHD or PHH] and [GR or GB or GM] and [NSR or NSB or NSM] and [NCC or NCBC or NBC] and [NSaB or NSaR] and NPEN and NEAN) Then CPLB
R26= If ([PHD or PHH] and [GR or GB or GM] and [NSR or NSB or NSM] and [NCC or NCBC or NBC] and NOC and [NSaB or NSaR] and NPEN and NEAA) Then CPLA
R27= If ([PHD or PHH] and [GR or GB or GM] and [NSR or NSB or NSM] and [NCC or NCBC or NBC] and NOC and [NSaB or NSaR] and NPEN and NEAP) Then CPLR
R28= If ([PHD or PHH] and [GR or GB or GM] and [NSR or NSB or NSM] and [NCC or NCBC

or NBC] and NOC and [NSaB or NSaR] and NPEP and NEAN) Then CPLR

R29= If ([PHD or PHH] and [GR or GB or GM] and [NSR or NSB or NSM] and [NCC or NCBC or NBC] and NOR and [NSaB or NSaR] and NPEN and NEAN) Then CPLA

R30= If ([PHD or PHH] and [GR or GB or GM] and [NSR or NSB or NSM] and [NCC or NCBC or NBC] and NOR and [NSaB or NSaR] and NPEN and [NEAA or NEAP]) Then CPLR

R31= If ([PHD or PHH]) and [GR or GB or GM]) and [NSR or NSB or NSM]) and [NCC or NCBC or NBC]) and [NSaB or SaR]) and NPEP and NEAN) Then CPLR

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