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Fuzzy inference system to calculate SO_2 requirement in red wine

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ABSTRACT
Red wine is a more popular wine among all other wines. As per research moderate consumption of red wine is healthy for health. Winemaking is a complex and non-linear process. SO2 is a more important chemical compound used in the winemaking process at different stages. It is the very first additive in grape juice, SO2 prevents grape juice from spoilage, and it acts as an antimicrobial and antioxidant during the fermentation process. Free SO2 is measured and maintained throughout the process. The amount of SO2 required at crush time is ambiguous or a person's perspective. In the present paper, we designed fuzzy inference system to estimate the required SO2 at crush time which helps winemaker to maintain SO2 in wine and designed Simulink to calculate the required amount of SO2 in gram/Liter.
Keywords:*fuzzy logic, fuzzification, membership function, SO2, fermentation, red wine*

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INTRODUCTION

Worldwide various varieties of grapes are cultivated but only a few grape varieties are chosen for wine. More than 10,000 wine grape varieties in the world, however, few wine grapes have extensive popularity [1] Grape's skin is crushed and kept in contact with the grape juice during the fermentation process giving shades of red colour like light red, dark red, deep violet, nearly black colour. The most popular red wines are Cabernet Sauvignon, Merlot, Syrah, Pinot Noir, and many others. The addition of SO2 in red wine is the most common practice and it is a frequently used chemical compound throughout the winemaking process. SO2 is added as an additive at crush time to prevent grape juice from spoilage, it acts as an antimicrobial and antioxidant during the fermentation process and it is non-toxic in food or beverages. Grape contains sulphur chemical compounds naturally in the grape's skin, so wine is not entirely sulphite-free. Before going to the winemaking process natural SO2 saves grapes from spoilage so that grapes are the more popular fruit for wine. At regular times SO2 is added and maintains desired quantity in wine at different stages like fermentation, raking, bottling, etc. SO2 affects the quality of the wine. In the winemaking process, the most common names of Sulphur Dioxide are " SO2", "Metabisulfite", and just plain "Sulphite." The concentration of SO2 in wine is measured in Parts per Million, or ppm with mg/L. Sulphite has different forms when it is added to wine as free and bound. Free is: [(molecular) SO2 + (bisulphite) HSO3 - + (sulphite) SO3 -] bisulphite and sulphite are ions [5]. Bound forms combine with phenols, acetaldehyde, and sugar. In red wine 0.6-0.8 mg/L (ppm) molecular SO2 has been considered sufficient to protect the wine. Fuzzy logic focuses on control systems perfectly, as it resembles human decision-making with an ability to generate approximate solutions. It resolves the uncertainty of the control system, fuzzy logic provides a basic structure to model vagueness, the human way of thinking, reasoning, and the perception process. Researchers can deal with ambiguity obtained in the present system at a deep level and develop a more consistent control system for the computation of input-output relations of the system [17]. In red wine, low sugar is unfavourable but high sugar leads to excessive alcohol in the wine which is stuck fermentation. The purpose of this study is to develop a fuzzy rule-based model to get required free SO2 at crushing time or pre-fermentation process and an expert system designed to calculate required amount of SO2 in gram for juice volume, pH, Free SO2, original SO2, Brix.in Carbenate Sauvignon red wine. In fuzzy rule-based model, the standard pH/ SO2 charts values are compared with Mamdani's fuzzy rule-based model values.

RELATED WORK

This section focuses on a few prominent works that are related to our work.pH plays important role in soil because it affects the availability of vital nutrients. Fuzzy Logic on Arduino for the monitoring and control of acidity or alkalinity in reservoir's irrigation water system designed by Sibiya et.al [14] which control and monitor pH or alkaline level from water irrigation automatically. They designed a fuzzy inference system with trapezium and triangular membership functions with single input-multiple output (SIMO). As expected, the logic control system controlled the tank's pH in the most favourable pH range.

Grape's quality depends upon the nutrient which gets from the soil, and it varies from vineyard to vineyard. Grapevine nutrient requirement decided based on soil test laboratory report. The nutrient analysing method varies from laboratory to laboratory. The nutrient requirement of grapevine is assessed by the farmer which is based on the soil test report from the laboratory. Vilas B. More et.al. [8] proposed work on Fuzzy Information System (FIS) with triangular membership function to calculate the requirement of nitrogen in the grape garden, and to maintain the soil quality which reduces the cost of production of grapes which resolve ambiguity in nitrogen treatment to the soil.

Before harvesting grapes, the ripeness of grapes berries is more important. Sugar, skin colour, pH, acid should be in the desired amount at harvesting time. A. Tagarakis et al. [15] designed a fuzzy inference system to model grape quality in vineyards in which Grapes Total Quality (GTQ) of wine grapes is measured before harvesting grapes. The inference system rules are generated for 4 inputs. total soluble solids (TSS, Brix), titratable acidity (TA, g/L), total anthocyanin content (Anth, mg/L), and berry fresh weight (BW, g); and one output i.e. GTQ (grapes total quality).

DESIGNING A FUZZY RULE-BASED MODEL FOR THE REQUIREMENT OF SO2

A fuzzy expert system is divided into four blocks as follows fuzzification, knowledge base, decision-making logic, and defuzzification.

Data collection

For proposed research work, to collect data visited Deccan Plateau winery which is situated in Pune city. This winery has different types of red wine and white wine, for research work red wine is preferred like Trivalli, Shiraz, Zinfandel, Cabernet-Shiraz, Cabernet Sauvignon.

Data selection and data distribution

Cabernet Sauvignon red wine grapes are cultivated worldwide, its dark colour, full-body, medium acidity, and tannins, rich in flavours and alcohol around 13.5% [1] such characteristics give priority in red wine. Cabernet Sauvignon grape type is also cultivated in their vineyard or sometimes imported from Nashik city. Target values for Cabernet Sauvignon at harvest time are as follows pH 3.3-3.4, 24-26.5° Brix, 0.6 - 0.7 TA.

MATERIAL AND METHODS

Definition of linguistic variables

For the proposed study, the volume of grape juice in gallons, the sugar level in Brix, and the pH of grape juice were selected as input variables. The output variable was required free SO_2 in grape juice.

Determination of fuzzy set and fuzzy operator

Fuzzy sets, variable values are represented into [0, 1] intervals with the use of membership function. μX: A {0, 1} where the value of A is real numbers from 0 to 1 involving 0 and 1. For constructing an inference rule "and," "or," and "not" operators are used. Combinations of these operators are known as t-Norms. The fuzzy "and" operator is given as:

$$\mu A \cap B\ (x) = \min\ [\mu A(x), \mu B(x)] \quad \text{.....(1)}$$

From this rule, we get the minimum number of the membership values and compute the "and" operation. The fuzzy "or" operator is defined as:

$$\mu A \cup B\ (x) = \max\ [\mu A(x), \mu B(x)] \quad \text{.....(2)}$$

From this rule, we get the maximum number of the membership values and compute the "or" operation. The "or" operation is computed by extracting the maximum value of the membership values of the fuzzy sets [9]. For proposed work fuzzy sets were determined for input variable Juice_Volume (low, medium, high), Brix (low, medium, high), pH(low, medium, high), and output variable as (very small, small, medium, large, verylarge). t-Norms operator used for the proposed study.

Fuzzification

A triangular membership function was used for the fuzzification process. As shown in equation 3 fuzzy parameters [a, b, c] was determined with domain expert study as shown in table 1.

$$\mu A(x) = \begin{cases} 0 & if\ x \le a \\ \frac{x-a}{b-a} & if\ a \le x \le b \\ \frac{c-x}{c-b} & if\ b \le x \le c \\ 0 & if\ c \le x \end{cases} \quad (3)$$

$$\mu medium\_pH(x) = \begin{cases} 0 & if\ x \le 3.0 \\ \frac{x-3.5}{0.5} & if\ 3.0 \le x \le 3.5 \\ \frac{4.0-x}{0.5} & if\ 3.5 \le x \le 4.0 \\ 0 & if\ x > 4.0 \end{cases} \quad (4)$$

Table 1: Fuzzy Triangular Parameter

Fuzzy Variables	Linguistic Variables	Fuzzy Triangular Parameters
Juice_Volume	Low	[-5,5,15]
	Medium	[5,15,25]
	High	[15,25,35]
pH	Low	[2.6 3 3.5]
	Medium	[3 3.5 4]
	High	[3.5 4 4.4]
Brix	Low	[16 20 25]
	Medium	[20 25 30]
	High	[25 30 35]

Fuzzy Inference System(.fis file)

MATLAB software is used to carry out the control system results. Fuzzy inference systems allow users to make and map input data and output data using fuzzy logic. By mapping input and output data concerning domain system knowledge and generating some rules to make a decision. A fuzzy inference system has membership functions, logical operators, and if-then rules. Two types of fuzzy inference systems are available in fuzzy systems one is Sugeno and another is Mamdani. For proposed research work Mamdani inference systems were applied. The output of each rule of the Mamdani inference system is a fuzzy set. Its rules are easy to understand, they are most applicable to expert system applications where the rules are generated from human expert knowledge [10]. Mamdani inference system with 3 inputs and 1 output is shown in figure 1.

Designing Rule Base

Fuzzy rules are conditional statement that helps to make decisions. Fuzzy rules in the form of IF-THEN statements. If y is B THEN x is A, where x and y are linguistic variables, and A and B are linguistic values determined by fuzzy sets [11].

Rule1: If x is A1 and y is B1, then z is C1.

Rule2: If x is A2 and y is B2, then z is C2. With the help of domain experts, the rule base was designed for the proposed study. Some of the rules are given below. In rule generation, if high sugar in grape juice, dilution of sugar is carried out so that in rule generation, high sugar does not work. High sugar in grape juice results in unbalanced wine, yeast cannot handle high alcohol levels. Less amount of sugar in grape juice gives low alcohol and higher acidity. If sugars are consumed by yeast in large amounts, then Brix reading decreases, and wine fermented to dryness or stuck fermentation [12].

Defuzzification

In the last process, the defuzzification method is applied, which aggregates and generates crisp values. There are many defuzzification methods like Mean of Maximum, Bisector of Area, and Centre of Area are commonly used defuzzification methods. Crisp values are obtained in our proposed work using the centroid method which converts fuzzy values to crisp values. As shown below using centroid method rules are evaluated.

Rule Evaluation

For the rule evaluations, we refer fuzzy sets described in table 1. In the rule
evaluation, we assume that, at harvesting time, grape juice = 8 gallons, residual sugar = 22 Brix, and pH=3.4. So we calculate the SO2 amount which is required at crush time or pre-fermentation process. After applying the inference system rule base, 6 rules are evaluated as shown in table 3.

Using centroid defuzzification method small membership function called. Using equation (1) we get the minimum number of the membership values and compute the “and” operation as follow

μsmall_so2 = min [μlow_juice (0.7), μmedium_brix (0.4), μlow_pH (0.2)] = 0.2 ....(5)

μsmall_so2 = min [μlow_juice (0.7), μlow_brix (0.6), μmedium_pH (0.4)] = 0.4 ....(6)

μsmall_so2 = min [μmedium_juice (0.5), μlow_brix (0.6), μlow_pH (0.2)] = 0.2 ....(7)

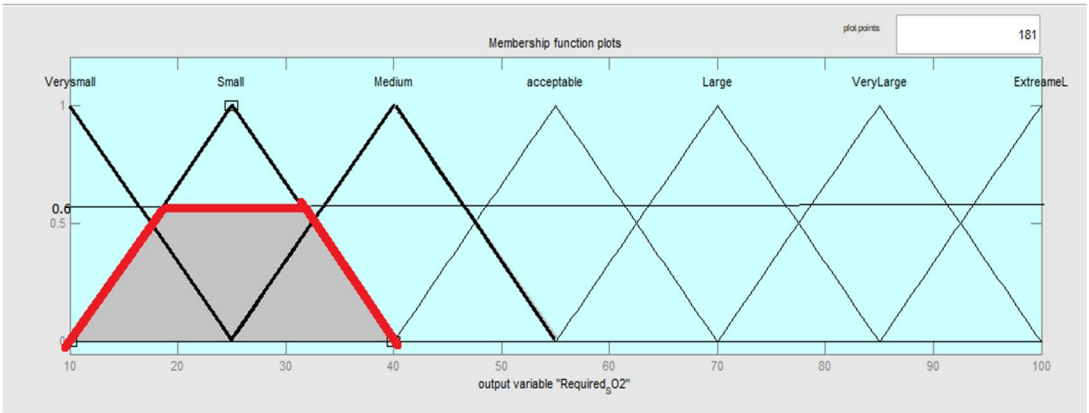

Fig 1 rule strength for small membership function

Table 2: Fuzzy Rule base

Sr. No		Juice volume		Brix		pH		Free SO2
1		High		Medium		High		Extreme Large
2		High		Medium		Medium		Very Large
3		High		Medium		Low		Medium
4		High		Low		High		Large
5		High		Low		Medium		Large
6		High		Low		Low		Medium
7	If	Medium	and	Medium	and	High	then	Acceptable
8		Medium		Medium		Medium		Medium
9		Medium		Low		High		Acceptable
10		Medium		Low		Medium		Medium
11		Medium		Low		Low		Small
12		Low		Low		Low		Very small
13		Low		Low		Medium		Small
14		Low		Medium		Low		Very small

Table 3 Rule strength

Sr. No		Juice volume		Brix		pH		Required SO_2
1		High		Medium		High		Extreme Large
2		High		Medium		Medium		Very Large
3		High		Medium		Low		Medium
4	If	High	and	Low	and	High	then	Large
5		High		Low		Medium		Large
6		High		Low		Low		Medium

The membership degrees generated and determined the rule strength for each given rule. Applying maximum degree we get equation (6) rule which determined for given input values. According to the centroid method the final SO2 can be computed as follows:

$$X^* = \frac{\sum_{i=1}^{N} Ai * \bar{X}i}{\sum_{i=1}^{N} Ai} \quad \text{.....(8)}$$

To calculate X* we put values in the formula

Required SO2 $= \frac{\sum_{i=1}^{N} Ai * \bar{X}i}{\sum_{i=1}^{N} Ai}$

Required SO2 $=\frac{(36.79+210+83.18)}{13}=25.38$

Hence it is proved that juice volume =8, sugar =22 and pH =3.4 using centroid method 25.38 free SO2 required which determines small membership function with rule low juice volume, low brix, and medium pH as shown in the figure 2.

PROPOSED ALGORITHM FOR REQUIRED SO_2 IN RED WINE GRAPE JUICE

Input:The crisp values for Juice volume in gallons, sugar in Brix, and pH, free SO_2.

Output: The crisp value for free Required_so2.

Begin

Step1: Input the crisp values of fuzzy variables (Juice volume, Brix, and pH, free SO_2)

Step 2: Generate the fuzzy numbers for Juice_volume, Brix, and pH.

Step 3: Generate the fuzzy number for free Required_SO2 for the output.

Step 4: The triangular membership function is calculated for each linguistic variable.

Juice volume(Low, Medium, High),
Brix(Low, Medium, High),
pH(Low, Medium, High).

Step 5: Perform the Fuzzy inference mechanism by Mamdani's method.

1.Use rule base (rule1, rule2 …., rule n).
2.Use of fuzzy AND operator for rule degree match for input linguistic variables.
3.Calculate the aggregation of used rules for fuzzy output variable Required_SO2.

Step 6: Use the Centroid defuzzification method for generating crips values.

$$X^* = \frac{\sum_{i=1}^{N} Ai * \bar{X}i}{\sum_{i=1}^{N} Ai}$$

Here, Ai represents the firing area of ith rules and n total number of rules fired and X represents the center of the area.

Step 7: Display the Required_SO2 value in a human understandable form.

Step 8: Stop.

SIMULINK MODEL TO CALCULATING GRAMS OF SO2 FOR THE DESIRED PPM

Development Environment

An expert system for the winemaking process was developed with software development methodology (SDLC) to calculate the required SO_2 amount in grams/L. Scikit-fuzzy, python language has been selected for the development of the web system. The required SO_2 amount to protect a wine is based on the wine's pH values. Naturally, grape skin has natural SO_2, hence 2 cases are evaluated by using the expert system model.

Code Samples

Code for setting universe of discourse for input variables

```
pH = CTRL. Antecedent (np.arange(0, 6, 1), 'pH')
Brix = CTRL. Antecedent(np.arange(0, 36, 1), 'Brix'))
```

Rule base

```
rule1 = ctrl.Rule( Juice_Volume['High']   &  Brix['Medium']  & pH['High'],    SO2['ExtreamLarge'])
rule6 = ctrl.Rule( Juice_Volume['High']   & Brix['Low']         & pH['Low'],     SO2['Medium'])
rule14= ctrl.Rule( Juice_Volume['Low']   & Brix['Medium']   & pH['Low'],     SO2['VerySmall'])
```

Code for setting triangular membership function for fuzzy linguistic variables

```
pH ['Medium'] = fuzz. trimf (pH. universe, [3.0, 3.5, 4.0])
Juice_Volume ['High'] = fuzz. trimf (Juice_Volume.universe, [15,25,35])
```

Fig 2 Console application to calculate required amount of molecular SO_2

RESULTAND DISCUSSION

Generally, fermentation tanks have a capacity of 100 litter which is approximately 25 gallons (1 gallon ~ 3.785 litters). The quality of wine is depending on its fermentation process, types of grapes, and chemical compounds which are involved. One of the most important chemical compounds is SO2 which is maintained throughout the winemaking process. SO2 is the first used at crush time as an additive. Its amount level will be decided concerning the desired quantity of pH, acid level, sugar level, and volume of juice. pH and TA (tartaric acid) are inversely proportional to each other. For the proposed research work Cabernet Sauvignon red wine grapes parameters values are considered to evaluate the system. Data is collected from the Deccan plateau winery at harvesting time Cabernet Sauvignon red wine grape juice value lies as follows pH 3.3-3.4, 23-26.5° Brix, 0.6- 0.7 TA.So that a reliable value is evaluated for sugar between 22 to 26 Brix and pH values from 3.25 to 3.85 of fuzzy output compared with domain dataset. We analyse the performance of the proposed work for the required SO2 amount in red wine juice at crush time using the fuzzy inference system to show that the SO2 values are trustworthy as shown in table 4 fuzzy output evaluation with domain data set values.

As shown in fig 4 below in rule viewer we evaluated output for pH 3.4. When we keep juice volume low and Brix low and pH low SO2 output is very small when we increase each parameter consistently SO2 value also increases. When we reach a high condition of input parameters it gives high values of SO2 amount needed in grapes juice. Brix values go up to the medium range because high Brix values are harmful to yeast which makes wine dry and stuck fermentation process. The maximum range of Brix up to 26 Brix is valid.

As shown in table 4 requirement of free SO2 fuzzy inference system file output data compared with standard values concerning the standard pH/ SO2 chart in winemaking process because natural SO2 is presented in grapes juice and its values varies with respect to vintages, grapes type, soil type, nutrients provide to the vineyard, harvesting time.

Fig 3 User Interface to calculate required amount of molecular SO2

Table 4: fuzzy output evaluation with domain data set values

Sr NO	Juice volume in Gallon	sugar in Brix	pH values	pH/SO_2 chart values Or Domain dataset value	. fis fuzzy output for free so2mg/L required for 0.8 ppm mg/L SO_2
1	X	X	3.0	13	X
2	X	X	3.05	15	X
3	X	X	3.10	16	X
4	X	X	3.15	19	X
5	5	22	3.20	21	22.1
6	5	22	3.25	23	23
7	6.30	22	3.30	26	26.5
8	7	22	3.35	29	28.2
9	8	23	3.40	32	30.9
10	13	23	3.45	37	35.8
11	15	23	3.50	40	40.0
12	15	23	3.55	46	42.3
13	16	23	3.60	50	50.8
14	17	23	3.65	57	56.0
15	19	23	3.70	63	61.9
16	24	23	3.75	72	71.00
17	25	24	3.80	79	77.7
18	25	26	3.85	91	89.1
19	X	X	3.90	99	X

CONCLUSION

In this paper, we presented required amount of SO_2 using a fuzzy-logic procedure. Our approach is to address ambiguities associated with measuring SO_2 amount concerning grape juice volume, pH, Brix. It is important because SO_2 defines the taste and quality of the wine. SO_2 play vital role in wine, each step of the winemaking process needs SO_2 adjustment which impacts the quality of the wine. By referring to table 4 and Fig 5 we examine that for red wine grape juice needs a sugar range between 22 to 26 Brix and pH value between 3.20 to 3.85 concerning consistently increasing juice volume and SO_2 values. Future studies will be carried out to cover increasing and decreasing sugar levels with chaptalization and dilution methods. pH increases and decreases with Acidify and deacidification to achieve higher accuracy.

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CONFLICTOFINTEREST

The authors have no conflict of interest.

REFERENCES

1. Master Class, What are different types of Wine Grapes https://www.masterclass. com/articles/what-are-the-different-types-of-wine-grapes-a-guide-to-the-various-types-of-red-and-white-wine-grapes-in-the-world, accessed on 28 November 2021
2. Elsa Rengifo-Salgado., & Gabriel Vargas-Arana. (2013). *Physalisangulata* L. (Bolsa Mullaca): A Review of its Traditional Uses, Chemistry and Pharmacology BolLatinoam Caribe. *Plant Med Aromat.,*12(5),431–445.
3. Grogan, K.A.(2015) The value of added sulfur dioxide in French organic wine. https://doi.org/10.1186/s40100-015-0038-1.
4. IOWA State University,, Crush in Crushing it, with SO2 https://www.extension. iastate. edu/wine/crush-crushing-it-so2/, accessed on 1 December 2021.
5. TERLATO Wines, Sulfur Dioxide and Its role in Wine Making https://www.terlatowines. com/knowledge/sulfur-dioxide-and-its-role-winemaking accessed on 5 December 2021.
6. Santa Rosa Junior College, Introduction to Enology, Calculating Molecular SO2 http://srjcstaff.santarosa.edu/~jhenderson/SO2.pdf accessed on 10 December 2021.
7. More Wine, Guide to SO2 Management and SO2 Calculator https://morewinemaking.

com/articles/SO2_management. Accessed on 12 December 2021.
8. Pandey, D.C., Kushwaha, G.S. & Kumar, S. Mamdani (2020). Mamdani fuzzy rule-based models for psychological research. https://doi.org/10.1007/s42452-020-2726-z
9. Vilas B. More, D. N. Kashid, B. T. Jadhav and B. More,"Development of Fuzzy Inference System for Nitrogen Requirement in Grape Vineyard, Inernational". Journal of Engineering Research and Applications ISSN: 2248-9622, Vol. 6, Issue 2, (Part - 3) February 2016, pp.18-25
10. Rizvi, S., Mitchell, J., Razaque, "A fuzzy inference system (FIS) to evaluate the security readiness of cloud service providers". J Cloud Comp 9, 42 (2020). https://doi.org/10.1186/s13677-020-00192-9.
11. Mathworks, Mamdani and Sugeno Fuzzy Inference Systems, https://in.mathworks. com/help/fuzzy /types-of-fuzzyinferencesystems.html?searchHighlight=mamdani&s_tid=srchtitle_mamdani_2, accessed on 15 December 2021
12. M. Kalpana (Tamil Nadu Agricultural University, India) and A. V. Senthil Kumar (Hindustan College of Arts and Science, India) Fuzzy Expert System in Agriculture Domain DOI: 10.4018/978-1-5225-9175-7.ch001.
13. Wine Maker, Understanding Brix Readings, https://winemakermag.com/article/cellar-dwellers-4 accessed on 16 December 2021
14. I.K. Mujawar, B.T. Jadhav, "Web-based Fuzzy Expert System for Diabetes Diagnosis" International Journal Of Computer Sciences And Engineering. DOI: 10.26438/ijcse/v7i2.9951000
15. Sibiya, Malusi & Sumbwanyambe, Mbuyu. (2020), "PH sensor using Fuzzy Logic on Arduino for the monitoring and control of acidity or alkalinity in reservoir's irrigation water", 1-6. 10.1109/icABCD49160.2020.9183824.
16. Tagarakis, A., Koundouras, S., Papageorgiou, (2014) "A fuzzy inference system to model grape quality in vineyards", Precision Agric 15, 555–578 (2014). https://doi.org/10.1007/s11119-014-9354-9

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