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Effect of Carbonation on Physicochemical Characteristics of Tomato Based Beverage

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Authors' contributions

This work was carried out in collaboration among all authors. Authors AD and MKJ designed the study, analysed the data statistically, wrote the protocol, wrote the first draft of the manuscript. Author RV performed analyses of the study. Author MG managed the literature searches, and manuscript checking. All authors read and approved the final manuscript.

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ABSTRACT

Tomato based carbonated beverage was developed using optimization techniques of response surface methodology. Effect of carbonation on tomato-based beverage was also investigated. Three independent variables were taken into account: tomato juice (A; 10–30%), sugar solution (B; 12–18 ^{0}B), and carbonation concentration (C; 90–110 psi) for the optimization of tomato based carbonated beverage. Twenty experimental runs were carried out to determine the impact of independent variables, such as pH, acidity, vitamin C, and overall acceptability, on product responses. The ideal conditions were determined to be 30% tomato juice, 18 ^{0}B sugar solution, and

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100 psi carbonation concentration. Changes in physicochemical properties of tomato based carbonated beverage during storage were also investigated. pH and vitamin-C content of the tomato based carbonated beverage sample were gradually decreased from 4.50 to 4.10 and 17.91 mg/100 g to 12.40 mg/100 g, respectively whereas titratable acidity gradually increased from 0.28 % to 0.39% during storage period.

Keywords: Carbonation; tomato; beverage; optimization; storage study.

1. INTRODUCTION

The Asia-Pacific region produces the most tomatoes. Tomato production in 2021–2022 was 20300.19 tons, according to National Horticulture Board data (APEDA Agri Exchange, 2024). The worldwide tomato processing market is being driven by the increasing production and consumption of processed tomatoes. Globally, processed tomato consumption was 82.54 million tons in 2023; by 2032, consumption is expected to rise to 115.46 million tonnes (Custom Market Insights, 2024). Tomato juice does, however, have a smaller worldwide market than other goods derived from tomatoes.

Tomatoes are good source of Vitamin A and C (Butu and Rodino, 2019), phytochemicals, lycopene and carotenoids (Hadely et al., 2004), calcium, magnesium, potassium, iron and folate (Bhowmik et al., 2012). Many studies have shown the health benefits of tomatoes and tomato-based products, including their ability to prevent prostate cancer (Rowles et al., 2018; Rao and Agrawal, 1999), lower blood pressure and heart disease (Song et al., 2017; Yoshimura et al., 2010), treat diabetes (Zhu et al., 2020; Leh et al., 2021), treat skin conditions (Grether-Beck et al., 2017), and reduce neurodegenerative disease (Cheng et al., 2019).

Carbonated beverages are defined as those that have dissolved carbon dioxide gas, which gives them their characteristic fizz and acidic flavor (Chaudhary, 2018; Steen, 2005). Code of federal regulations acknowledges CO2 as safe. According to the "custom market insights" study, the market for carbonated beverages was valued at USD 496.46 billion in 2024 and is expected to rise at a compound annual growth rate (CAGR) of 5.60% to reach USD 771.3 billion by 2033 (Expert Market Research, 2024).

The worldwide popularity of carbonated beverages can be attributed to its pleasant tingling sensation, thirst-quenching impact, and acidic bite but there is more evidence to support the recommendation to reduce the intake of soft drinks due to research findings that indicate these beverages provide energy without much nutritional value, and are associated with a number of serious health issues, including obesity, overweight and diabetes etc. (French et al., 201; Vartanian et al. 2007; Brownell and Horgen, 2004).

Fruits and vegetables have antioxidant potential because of having numerous bioactive compounds (Navdeep et al., 2023). Therefore, the pulp of abundantly available fruits and vegetables should be used to make carbonated beverages in order to address the issue of just offering energy with little nutritional value. Considering the benefits of carbonation i.e flavor enhancement and refreshing sensation (Saint-Eve et al., 2009), sparkling appearance (Sternini, 2013), bubbling effect (Descoins et al., 2006), shelf life enhancement (Park et. al., 2020), the carbonated fruit based nutritious juice will be a better alternative than soft drink and energy drink.

Optimization with multiple processing parameters is crucial because of so many experimental runs (Moqbali et al., 2023; Ramya et al., 2023). Therefore, it is important to use such tool, which minimizes the experimental runs to manage possible. Processing parameter optimization can be achieved with the Response Surface Methodology (RSM) approach. RSM can also be used to analyze the model's relevance and the data's statistical accuracy (Dixit et al., 2024).

The aim of this study was to address the nutritional issue with soft drinks by using tomato juice in combination with carbonation. The effect of carbonation on physicochemical and sensory parameters of developed beverage was also investigated. Carbonated fruit (tomato) based beverage will open the new avenue for nutrious sparkling, fizzy and pop drink.

2. MATERIALS AND METHODOLOGY

2.1 Raw Materials

The study was carried out in the Department of Food Processing & Technology, College of Food Technology, Sardarkrushinagar Dantiwada

Agricultural University, Sardarkrushinagar, Banaskantha, Gujarat, India. Tomatoes and sugar (Madhur brand) were procured from local market of Dantiwada, Gujarat, India. Sodium benzoate and citric acid (Himedia) were procured from Himedia Laboratories Pvt. Ltd., Mumbai, India.

2.2 Preparation of Tomato Based Carbonated Beverage

The method of making carbonated beverage is shown in the below mentioned flow diagram (Fig. 1).

2.3 Experimental Design for Optimization of Tomato Based Carbonated Beverage

The experimental combinations were designed using RSM. A central composite rotatable design (CCRD) with three variables (five levels of each variable) was used. The independent variables considered for optimization of tomato based carbonated beverage were tomato juice (A; 10–30%), sugar solution (^{0}B; 12–18) and carbonation concentration (C; 90–110 psi). There are twenty experimental runs in the design. Every experimental run was carried out three times.

2.4 Physico-Chemical Analysis of Tomato Based Carbonated Beverage

A tomato-based carbonated beverage was subjected to a physico-chemical analysis using the Ranganna method (Ranganna, 2012). Tomato based carbonated beverage was analysed for, pH, titratable acidity and Vitamin-C content. Overall acceptability of developed beverage was determined using 9-point hedonic scale.

Tomatoes (Fully ripe)

↓

Washing

↓

Sorting and trimming (Removing green portion and stem)

↓

Cutting and chopping

↓

Heating at 80 ^{0}C for 5 mins.

↓

Extraction of tomato juice

↓

Preparation of sugar solution

↓

Mixing of sugar solution and tomato juice

↓

Addition of sodium benzoate and citric acid (50 ppm +50 ppm)

↓

Heating at 85 ^{0}C for a minute

↓

Cooling at 5 ^{0}C

↓

Carbonation at different concentrations

↓

Filling in PET bottles and storage at refrigerated temperature 7$\pm$10 ^{0}C

Fig. 1. Flow diagram for preparation of tomato based carbonated beverage

3. RESULTS AND DISCUSSION

3.1 Analysis of Data

To determine the impact of independent variables on measured responses, experiment data was analyzed. To investigate the statistical significance of the model as presented in equation 1, the second order polynomial equation was utilized. The following equation was fitted using the responses (pH, acidity, vitamin C and overall acceptability) for the various experimental conditions:

$$Y = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \beta_3 x_3 + \beta_{11} x_{12} + \beta_{22} x_{22} + \beta_{33} x_{32} + \beta_{12} x_1 x_2 + \beta_{13} x_1 x_3 + \beta_{23} x_2 x_3 + \varepsilon \quad (1)$$

Where,

Y = response variable

β_0 = constant

β_1, β_2, β_3 = linear effects of regression coefficient

β_{11}, β_{22}, β_{33} = interaction effects of regression coefficient

β_{12}, β_{13}, β_{23} = quadratic effects of regression coefficient

ε = random errors

x_1, x_2, x_3 = independent variables

The experimental data was analyzed using response surface approach of design expert software. At the 5% level of significance, quadratic models were deemed adequate for all responses based on their R^2, F, and P values.

3.2 pH of Developed Beverage

pH is crucial, when it comes to carbonated beverages. It explains how bioactive substances in carbonated drinks stay stable (Sánchez-Moreno et al., 2006). The tomato-based carbonated beverage had a pH that ranged from 3.9 to 5.89 (Table 1). The combination of 3.18 percent tomato juice, 15° brix sugar solution, and 100 psi carbonation level resulted a tomato-based carbonated beverage with a pH value of 5.89, while the combination of 36.82 % tomato juice, 15° brix sugar solution, and 100 psi carbonation level produced a tomato-based carbonated beverage with a pH value of 3.9. The statistical features of pH are displayed in Tables 2 and 6. The regression model's F-value of 7.39 indicates that the model is significant when fitted to the pH experimental data. The 1.32 "Lack of Fit F-value" indicates that the Lack of Fit is not statistically significant in comparison to the pure error. The coefficient of determination R^2 (0.8693), was also used to express the model's fit and shows that the model could account for 86.93% of the response's variability. Table 6 shows that the signal was deemed sufficient with an adequate precision of 10.18. This approach can be utilized to navigate the design space because a ratio larger than 4 is desirable. After taking into account all of the aforementioned factors, the model (Eq. 2) was chosen to depict pH change.

According to the coded levels of the variables, the quadratic model derived from regression analysis for pH was as follows:

$$\textbf{pH} = 4.79 - 0.45\,A + 0.016\,B - 0.10\,C + 0.010\,AB - 0.032\,AC + 0.010\,BC + 0.032\,A^2 + 6.14 \times 10^{-4}\,B^2 + 0.013\,C^2 \quad (2)$$

Where,

A= Tomato juice

B= Sugar solution

C= Carbonation level

3.3 Effect of Tomato Juice, Sugar Solution Concentration and Carbonation Level on pH of Developed Beverage

Response surface 3D graphs (Fig. 2) illustrate the interaction effect of process parameters (tomato juice, sugar solution, and carbonation concentration) on the pH of the developed beverage. Equation (2) shows that, at a 95% confidence level, the pH of the developed beverage had a highly significant negative linear effect of tomato juice (A). The interaction and quadratic terms were determined to be not significant. Fig 2 illustrates how the pH content of the created beverage is significantly impacted by the concentration of sugar, tomato juice, and carbonation level. As tomato juice level increased, the ph content was seen to gradually drop, as shown in fig. 2. Low ph concentration in tomato juice is the cause of this. As carbonation concentration increased, Fig. 2 showed a little reduction in pH. Scientists have also examined the impact of carbonation on carrot juice and have observed a drop in pH (Khuram, et al., 2014). The particular sugar solution had no discernible impact on pH.

Table 1. Experimental central composite design and result of responses for tomato based carbonated beverages

Run	Variables			Responses			
	Tomato juice (%)	Sugar Solution (^{0}B)	Carbonation (psi)	pH	Acidity (%)	Vitamin C (mg/100g)	Overall Acceptability
1	10	12	90	5.21	0.13	0.7	5.37
2	30	12	90	4.58	0.28	2	4.5
3	10	18	90	5.34	0.11	0.7	6.66
4	30	18	90	4.68	0.24	2.1	7
5	10	12	110	5.03	0.15	0.5	5.75
6	30	12	110	4.2	0.38	1.5	5.5
7	10	18	110	5.13	0.16	0.5	7.3
8	30	18	110	4.41	0.31	1.7	8.29
9	3.18	15	100	5.89	0.09	0.2	5.3
10	36.82	15	100	3.9	0.4	2.7	6
11	20	9.95	100	4.9	0.2	1.1	4.2
12	20	20.05	100	4.71	0.28	1.2	7.83
13	20	15	83.18	4.95	0.2	1.8	5.33
14	20	15	116.82	4.73	0.22	0.9	7.33
15	20	15	100	4.99	0.17	1.1	6.66
16	20	15	100	4.85	0.22	1.35	7.1
17	20	15	100	4.58	0.29	1.13	7.33
18	20	15	100	4.73	0.23	1.17	7.25
19	20	15	100	4.56	0.28	1.27	7
20	20	15	100	5.01	0.18	1.3	6.9

Table 2. ANOVA for pH of tomato based carbonated beverage

Source	Sum of Squares	DF	Mean Square	F- Value	Prob> F	
Model	2.978612	9	0.330957	7.391266	0.0022	significant
A-Tomato juice	2.802702	1	2.802702	62.59279	< 0.0001	
B- Sugar solution	0.003559	1	0.003559	0.079479	0.7838	
C- Carbonation level	0.145574	1	0.145574	3.251108	0.1015	
AB	0.0008	1	0.0008	0.017866	0.8963	
AC	0.00845	1	0.00845	0.188714	0.6732	
BC	0.0008	1	0.0008	0.017866	0.8963	
A^2	0.01516	1	0.01516	0.338568	0.5735	
B^2	5.43E-06	1	5.43E-06	0.000121	0.9914	
C^2	0.002431	1	0.002431	0.054295	0.8205	
Residual	0.447768	10	0.044777			
Lack of Fit	0.255234	5	0.051047	1.325663	0.3823	not significant
Pure Error	0.192533	5	0.038507			
Cor Total	3.42638	19				

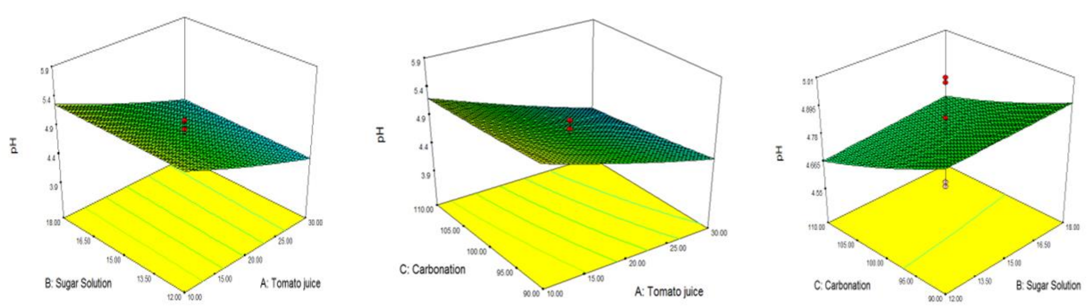

Fig. 2. 3-D surface graph showing the effect of process variables on pH of developed beverage

3.4 Titratable Acidity of Developed Beverage

Developed beverage had titratable acidity in the range of 0.09 to 0.4 (Table 1). The combination of 36.82 % tomato juice, 15° brix sugar solution, and 100 psi carbonation level produced a high acidic tomato-based carbonated beverage (0.09), whereas the combination of 3.18 % tomato juice, 15° brix sugar solution, and 100 psi carbonation level produced a low acidic tomato-based carbonated beverage (0.4). Table 3 and 6 show the statistical attributes of acidity. The acidity experimental results were fitted with a regression model, and the model's F-value of 6.08 indicates significance. The "Lack of Fit F-value" of 0.66 suggests that there is no statistical significance between the pure error and the Lack of Fit. The model's fit was further demonstrated by the coefficient of determination R^2 (0.8456), which shows that the model could account for 84.56% of the response's variability. Table 6 shows that the signal was deemed sufficient with an adequate precision of 9.112. This approach can be utilized to navigate the design space because a ratio larger than 4 is desirable. After taking into account all of the aforementioned factors, the model (Eq. 3) was chosen to depict the variance in acidity.

Regression analysis yielded the following quadratic model for titratable acidity in terms of coded levels of the variables:

Titratable Acidity = $0.23 + 0.087\,A + 1.065 \times 10^{-3}\,B + 0.020\,C - 0.012\,AB + 0.013\,AC + 0.000\,BC + 3.388 \times 10^{-3}\,A^2 + 1.620 \times 10^{-3}\,B^2 - 8.986 \times 10^{-3}\,C^2$ ………………...(3)

Where,

A= Tomato juice
B= Sugar solution
C= Carbonation level

3.5 Effect of Tomato Juice, Sugar Solution and Carbonation Concentration on Titratable Acidity of Developed Beverage

Response surface three-dimensional graphs (Fig. 3) illustrate the interaction effect of tomato juice, sugar solution, and carbonation concentration on the titratable acidity of the generated beverage. According to equation (3), tomato juice (A) had a significant positive linear effect on the titratable acidity of the generated beverage at a 95% confidence level. It was determined that the interaction and quadratic terms were not significant. Titratable acidity rose significantly as tomato juice was added, as shown in Fig. 3. Increased acidity with rising carbonation is also shown in Fig. 3. Similar findings were also reported by Ryu et al., 2018.

Table 3. ANOVA for Titratable Acidity of tomato based carbonated beverage

Source	Sum of Squares	DF	Mean Square	F- Value	Prob> F	
Model	0.11168552	9	0.01241	6.0847343	0.0046	significant
A-Tomato juice	0.10219055	1	0.102191	50.1069558	< 0.0001	
B- Sugar solution	1.5488E-05	1	1.55E-05	0.00759399	0.9323	
C- Carbonation level	0.00548271	1	0.005483	2.6883302	0.1321	
AB	0.00125	1	0.00125	0.61291082	0.4518	
AC	0.00125	1	0.00125	0.61291082	0.4518	
BC	0	1	0	0	1.0000	
A^2	0.00016541	1	0.000165	0.0811076	0.7816	
B^2	3.7829E-05	1	3.78E-05	0.01854868	0.8944	
C^2	0.0011638	1	0.001164	0.5706429	0.4674	
Residual	0.02039448	10	0.002039			
Lack of Fit	0.00811115	5	0.001622	0.66033793	0.6700	not significant
Pure Error	0.01228333	5	0.002457			
Cor Total	0.13208	19				

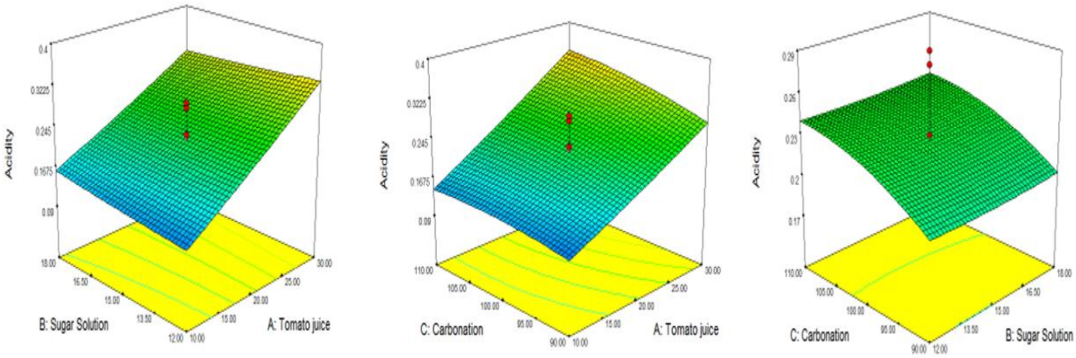

Fig. 3. 3-D surface graph showing the effect of process variables on titratable acidity of developed beverage

Table 4. ANOVA for Vitamin C of tomato based carbonated beverage

Source	**Sum of Squares**	**DF**	**Mean Square**	**F- Value**	**Prob> F**	
Model	6.806727	9	0.756303	41.06935	< 0.0001	significant
A-Tomato juice	6.069596	1	6.069596	329.5959	< 0.0001	
B- Sugar solution	0.01605	1	0.01605	0.871557	0.3725	
C- Carbonation level	0.579667	1	0.579667	31.4775	0.0002	
AB	0.01125	1	0.01125	0.610906	0.4526	
AC	0.03125	1	0.03125	1.696962	0.2219	
BC	0.00125	1	0.00125	0.067878	0.7997	
A^2	0.048644	1	0.048644	2.641498	0.1352	
B^2	0.033159	1	0.033159	1.800631	0.2093	
C^2	0.007454	1	0.007454	0.404776	0.5389	
Residual	0.184153	10	0.018415			
Lack of Fit	0.133353	5	0.026671	2.625053	0.1565	not significant
Pure Error	0.0508	5	0.01016			
Cor Total	6.99088	19				

3.6 Vitamin C content of Developed Beverage

According to Table 1, the tomato-based carbonated beverage's estimated vitamin C content ranged from 0.2 to 2.7. By mixing 3.18 percent tomato juice, 15° brix sugar solution, and 100 psi carbonation level, the tomato-based carbonated beverage yielded the lowest value of vitamin C content (0.2 mg/100g). Conversely, the tomato-based carbonated beverage with 36.82 percent tomato juice, a 15° brix sugar solution, and a 100-psi carbonation level yielded the highest value of vitamin C content (2.7 mg/100g). The statistical characteristics of Vitamin-C are displayed in Tables 4 and 6. The regression model fitted to the experimental results for vitamin-c indicates that the model F-value of 41.07 is significant. The "Lack of Fit F-value" of 2.62 implies that the Lack of Fit is not significant relative to the pure error. The R^2 value for vitamin-C model equation was 0.9736. The model could account for 97.36% of the response's variability. There exists a satisfactory agreement between the "Adj R-Squared" of 0.9499 and the "Pred R-Squared" of 0.8446. The Adequate Precision was 23.36 (Table 6). Considering all the above criteria, the model (Eq. 4) was selected for representing the variation of Vitamin C. Regression analysis yielded the following quadratic model for vitamin C in terms of coded values of the variables:

$$\text{Vitamin-C} = 1.22 + 0.67\,A + 0.034\,B - 0.21\,C + 0.038AB - 0.062\,AC + 0.013\,BC + 0.058\,A^2 - 0.048\,B^2 + 0.023\,C^2 \quad (4)$$

Where,

A= Tomato Juice

B= Sugar Solution

C= Carbonation

3.7 Effect of Tomato Juice, Sugar Solution and Carbonation Concentration on Vitamin C Content of Developed Beverage

Response surface 3D graphs, as shown in Fig. 4, illustrate the interaction effect of tomato juice, sugar solution, and carbonation concentration on the vitamin C content of the developed beverage. The developed beverage's vitamin-C had a very significant positive linear influence of tomato juice (A) and a negative significant linear effect of carbonation concentration (C) at a 95% confidence level, as can be shown from equation (4). The interaction and quadratic terms were determined to be not significant. Because citrus fruits are an excellent source of ascorbic acid, the developed beverage's vitamin C content increased when the amount of tomato juice increased (Fig. 4) (Hadley et al., 2004; Kadam, et al., 2014).

3.8 Overall Acceptability of Developed Beverage

The overall acceptability values of tomato based carbonated beverage varied from 4.2 to 8.29 (Table 1). Combining 20 percent tomato juice, 9.95° brix sugar solution, and 100 psi carbonation level produced the tomato-based carbonated beverage with the lowest overall acceptability value (4.2). On the other hand, beverage containing 30 % tomato juice, 18° brix sugar solution, and 110 psi carbonation level had the highest overall acceptability value (8.29). The statistical features of overall acceptability are displayed in Tables 5 and 6. The overall acceptability of the regression model fitted to the experimental data indicates that the model's F-value of 26.77 is significant. The 2.18 "Lack of Fit F-value" indicates that the Lack of Fit is not statistically significant in comparison to the pure error. The R^2 value for overall acceptability model equation was 0.9601. The model could account for 96.01% of the response's variability. There exists a satisfactory agreement between the "Adj R-Squared" of 0.9242 and the "Pred R-Squared" of 0.7754. The Adequate Precision was 18.36 (Table 6). Considering all the above criteria, the model (Eq. 5) was selected for representing the variation of overall acceptability. Regression analysis yielded the following quadratic model for overall acceptability in terms of coded values of the variables:

Overall Acceptability $=7.03 + 0.10\,A + 1.04\,B + 0.49\,C + 0.31\,AB + 0.16\,AC + 0.069\,BC - 0.42\,A^2 - 0.29\,B^2 - 0.17\,C^2$ (5)

Where,

A= Tomato Juice

B= Sugar Solution

C= Carbonation

3.9 Effect of Tomato Juice, Sugar Solution and Carbonation Concentration on Overall Acceptability of Developed Beverage

Response surface 3D graphs (Fig. 5) illustrate the interaction effect of tomato juice, sugar solution, and carbonation concentration on the overall acceptability of the developed beverage. Equation (5) shows that, at a 95% confidence level, the overall acceptability of the developed beverage had a highly significant positive linear effect of the carbonation concentration (C) and sugar solution (B). Tomato juice (A^2) and sugar solution (B^2) had a negative quadratic effect, and their quadratic term was extremely significant. The tomato juice and sugar solution interaction term significantly improved the developed beverage and showed a concave form fluctuation with the variable values changing. Figure 5 illustrates how the overall acceptability rises when tomato juice and sugar solution concentrations rise. Carbonation has a major impact on the created beverage's overall acceptance when it comes to flavored carbonated milk drinks (Lederer et al., 2004).

3.10 Compromised Optimum Conditions for Development of Tomato Based Carbonated Beverage

A numerical multi response optimization technique was used to optimize process parameters in order to develop a tomato based carbonated beverage. To achieve market acceptability, attempts were made to create a healthy fizzy drink with the highest possible sensory acceptability score. Goals were set for all the independent variables to optimize the ingredients. The uncoded optimum ingredients for development of tomato based carbonated beverage were, 26.75 % of tomato juice, 18 % brix of sugar solution and 100 psi of carbonation. The responses predicted by the design expert software for these optimum ingredients resulted in 4.52 of pH, 0.25 of Acidity, 7.87 of overall acceptability with desirability of 0.877.

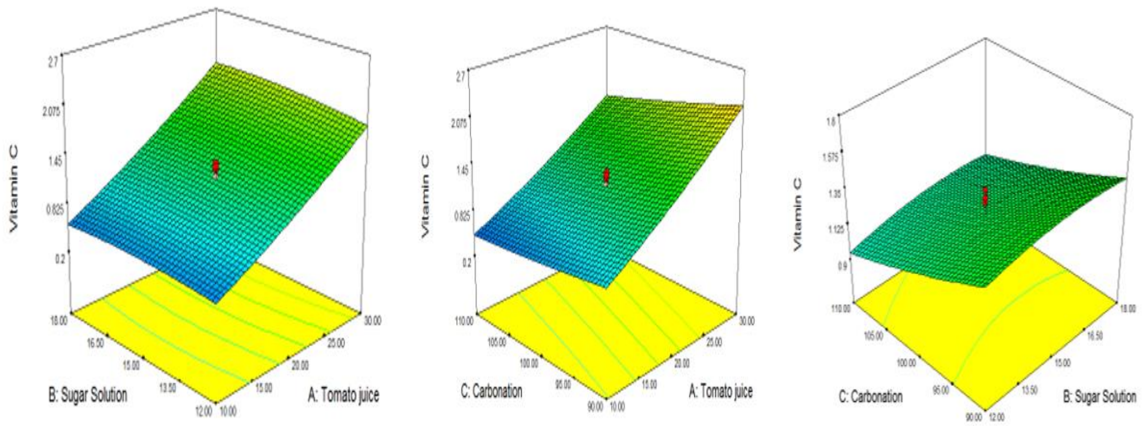

Fig. 4. 3-D surface graph showing the effect of process variables on vitamin-C of developed beverage

Table 5. ANOVA for Overall Acceptability of tomato based carbonated beverage

Source	**Sum of Squares**	**DF**	**Mean Square**	**F- Value**	**Prob> F**	
Model	22.76972	9	2.529969	26.76995	< 0.0001	significant
A-Tomato juice	0.140917	1	0.140917	1.491057	0.2501	
B- Sugar solution	14.83743	1	14.83743	156.9969	< 0.0001	
C- Carbonation level	3.261128	1	3.261128	34.50645	0.0002	
AB	0.750313	1	0.750313	7.939161	0.0182	
AC	0.201613	1	0.201613	2.13329	0.1748	
BC	0.037813	1	0.037813	0.400099	0.5412	
A^2	2.484826	1	2.484826	26.29229	0.0004	
B^2	1.180357	1	1.180357	12.48952	0.0054	
C^2	0.440444	1	0.440444	4.660403	0.0562	
Residual	0.945078	10	0.094508			
Lack of Fit	0.647678	5	0.129536	2.1778	0.2066	not significant
Pure Error	0.2974	5	0.05948			
Cor Total	23.7148	19				

Table 6. Model statistical attributes for different responses of tomato based carbonated beverage

	Responses			
Parameters	**pH**	**Titratable Acidity**	**Vitamin C**	**Overall Acceptability**
Std. Dev.	0.211605	0.04516	0.135703	0.307421
Mean	4.819	0.226	1.246	6.43
C.V %	4.39106	19.98241	10.89108	4.781045
R^2	0.869318	0.079979	0.973658	0.960148
Adj R^2	0.751703	0.84559	0.94995	0.924282
Pred R^2	0.352161	0.706621	0.844628	0.77535
Adeq Precision	10.18367	0.394467	23.36862	18.36409

3.11 Changes in Physicochemical Properties of Tomato Based Carbonated Beverage during Storage

Table 7 shows that the produced beverage's pH dropped slightly from 4.50 on the first day to 4.10 at the end of storage. Ascorbic and citric acids may have affected the product's protein and sugar components, causing a pH drop that was noticed during storage. Numerous investigators have likewise documented a similar drop in pH during the storage duration. (Khurdiya et al., 1996; Sandhan et al., 2009).

Titratable acidity of the tomato based carbonated beverage samples gradually increased from the first day (0.28 %) to the end of storage (0.39 %) (Table 7). The presence of carbon dioxide and acidity regulators in beverages, as well as the chemical interactions and enzymatic reactions between organic constituents, could all contribute to an increased acidity during storage (Yadav et al., 2013). Similar observations were also reported by various researchers in different carbonated beverages (lamaran and Amutha, 2007; Omokpariola, 2022).

Vitamin-C content of tomato based carbonated beverage samples gradually decreased from the first day (17.91 mg/100 g) to the end of storage (12.40 mg/100 mL) (Table 7). Vitamin C content of tomato juice and wheatgrass-pomegranate blended juice was found to be lost by 30.35% and 26.31%, respectively, during storage, according to studies conducted by Pavlović et al., 2019 and Kashudhan et al., 2016. The oxidation of ascorbic acid is the cause of a significant decrease in the concentration of vitamin C. Dehydroascorbic acid is the oxidative byproduct of ascorbic acid. As soon as dehydroascorbic acid is hydrolyzed, it loses its vitamin characteristics (Adeola and Aworh, 2013, Al Fata et al., 2018). When exposed to heat, vitamin C rapidly deteriorates (Leoni, 2002).

3.12 Changes in Microbial Load of tomato based carbonated beverage during storage

A microbiological assessment of tomato based carbonated beverage was also conducted. There was no bacterial load seen throughout the duration of the storage. The bacteria were eliminated by heat and the preservatives activity. Throughout the course of storage, no fungus development was noted in the developed beverage. Throughout the course of storage, no growth of indicative organisms, such as coliforms, was seen in the samples. Preservatives' inhibitory effects and heat treatment both prevented the growth of coliforms (Frazier and Westhoff, 1978).

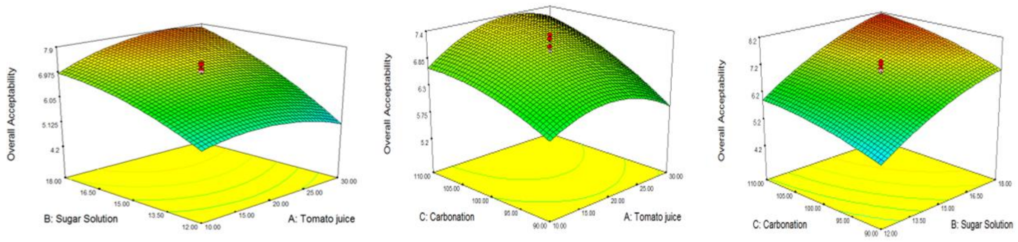

Fig. 5. 3-D surface graph showing the effect of process variables on overall acceptability of developed beverage

Table 7. Effect of storage on physico-chemical changes of tomato based carbonated beverage

	pH	Acidity (%)	Vitamin C (mg/100g)
0 day*	4.50 ± 0.01	0.28 ± 0.02	17.91 ± 0.02
10th day*	4.42 ± 0.02	0.31 ± 0.01	15.70 ± 0.02
20th day*	4.32 ± 0.04	0.34 ± 0.02	14.80± 0.04
30th day*	4.10 ± 0.05	0.39 ± 0.01	12.40 ± 0.02
CV (%)	3.99	14.21	14.99
SE(d)	0.087	0.023	1.14

**Values represent the mean ± standard deviation of 3 replicates (n = 3)*

4. CONCLUSION

The tomato based carbonated beverage with highly acceptable quality can be prepared using 26.75 % tomato juice, 18 ^{0}Brix sugar syrup solution, and 100 psi carbonation. The responses predicted by the design expert software for these optimum ingredients resulted in 4.52 of pH, 0.25 of Acidity, 7.87 of overall acceptability with desirability of 0.877.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc) and text-to-image generators have been used during writing or editing of this manuscript.

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COMPETING INTERESTS

Authors have declared that they have no known competing financial interests OR non-financial interests OR personal relationships that could have appeared to influence the work reported in this paper.

REFERENCES

Adeola, A. A., & Aworh, O. C. (2013). Effects of sodium benzoate on storage stability of previously improved beverage from tamarind (*Tamarindus indica* L.). *Food Science & Nutrition, 2*(1), 17-27.

Al Fata, N., Georgé, S., Dlalah, N., & Renard, C. M. G. C. (2017). Influence of partial pressure of oxygen on ascorbic acid degradation at canning temperature. *Innovative Food Science & Emerging Technologies, 49*, 215-221.

APEDA Agri Exchange. (2024). Retrieved from https://agriexchange.apeda.gov.in

Bhowmik, D., Kumar, K. S., Paswan, S., & Srivastava, S. (2012). Tomato—a natural medicine and its health benefits. *Journal of Pharmacognosy and Phytochemistry, 1*(1), 33-43.

Butu, M., & Rodino, S. (2019). Fruit and vegetable-based beverages—nutritional properties and health benefits. *Natural Bever, 13*, 303-338.

Chaudhary, V. (2018). Soft carbonated beverages. In D. Mudgil & S. Barak (Eds.), *Beverages: processing and technology* (pp. 90-111). Jodhpur Scientific Publishers.

Cheng, H. M., Koutsidis, G., Lodge, J. K., Ashor, A. W., Siervo, M., & Lara, J. (2019). Lycopene and tomato and risk of cardiovascular diseases: A systematic review and meta-analysis of epidemiological evidence. *Critical Reviews in Food Science and Nutrition, 59*, 141-158.

Custom Market Insights. (2024). Retrieved from https://www.custommarketinsights.com/report/carbonated-beverages-market

Descoins, C., Mathlouthi, M., Le Moual, M., & Hennequin, J. (2006). Carbonation monitoring of beverage in a laboratory scale unit with on-line measurement of dissolved CO2. *Food Chemistry, 95*(4), 541-553.

Dixit, A., Jaipal, M. K., & Tejani, N. (2024). Development of low-fat Gujarati traditional snack "ganthiya" using hydrophilic polymers and modified natural polysaccharides. *Journal of Scientific Research and Reports, 30*(7), 496–506.

Expert Market Research. (2024). Retrieved from https://www.expertmarketresearch.com/reports/tomato-processing-market

Frazier, W. C., & Westhoff, D. C. (1978). *Food microbiology*. Tata McGraw-Hill Publishing Company Limited.

French, S., Rosenberg, M., Wood, L., Maitland, C., Shilton, T., Pratt, I. S., & Buzzacott, P. (2013). Soft drink consumption patterns among western Australians. *Journal of Nutrition Education and Behavior, 45*(6), 525-532.

Grether-Beck, S., Marini, A., Jaenicke, T., Stahl, W., & Krutmann, J. (2017). Molecular evidence that oral supplementation with lycopene or lutein protects human skin against ultraviolet radiation: Results from a double-blinded, placebo-controlled, crossover study. *British Journal of Dermatology, 176*(5), 1231–1240.

Hadley, C. W., Schwartz, S. J., & Clinton, S. K. (2004). Tomato-based beverages. In T. Wilson & N. J. Temple (Eds.), *Beverages in Nutrition and Health* (pp. 107-123). Humana Press.

Kadam, A. R., Khamkar, M. B., Saitwal, Y. S., & Kapse, B. M. (2014). Development of carbonated sweet orange RTS beverage. *BIOINFOLET - A Quarterly Journal of Life Sciences, 11.1B*, 210-211.

Kashudhan, H., Dixit, A., & Kumar, K. (2016). Development of wheatgrass-pomegranate blended therapeutical juice using response surface methodology. *Journal of Food Processing and Preservation, 41*(2), e12869.

Khuram, H., Aslam, W., Shakeel, A., Shoaib, M., Sikandar, H. A., Naheed, N., & Raza, M. S. (2014). Effect of carbonation on the chemical composition and shelf life of carrot juice. *Journal of Global Innovations in Agricultural Sciences, 2*(1), 11-15.

Khurdiya, D. S., Islam, & Verma, O. P. (1996). Processing and storage of carbonated guava beverage. *Journal of Food Processing and Preservation, 20*(1), 79-86.

Lamaran, M., & Amutha, S. (2007). Effect of total soluble solids and CO2 pressure on physicochemical and sensory qualities of carbonated banana and sapota beverages. *Journal of Food Science and Technology, 44*(2), 178-182.

Lederer, C. L., Bodyfelt, F. W., & McDaniel, M. R. (1991). The effect of carbonation level on the sensory properties of flavored milk beverages. *Journal of Dairy Science, 74*(7), 2100-2108.

Leh, H. E., Mohd Sopian, M. H., Abu Bakar, M., & Lee, L. K. (2021). The role of lycopene for the amelioration of glycaemic status and peripheral antioxidant capacity among type II diabetes mellitus patients: A case-control study. *Annals of Medicine, 53*(1), 1059-1065.

Leoni, C. (2002). Improving the nutritional quality of processed fruits and vegetables: The case of tomato. In W. Jongen (Ed.), *Fruit and Vegetable Processing, Improving Quality* (pp. 55–60). Woodhead Pub Ltd.

Moqbali, F. H., Rabaani, M. A., & Ghaithi, N. A. (2020). Physico-chemical analysis of various samples of tomato ketchup. *Asian Journal of Applied Chemistry Research, 6*(4), 59-66.

Navdeep, J. P., Ramesh, V., Kumar, A., Singh, S., Jaipal, M. K., & Dixit, A. (2023). Development of protein enriched whey-bael beverage and its evaluation for antioxidant potential. *The Pharma Innovation Journal, 12*(1), 254-259.

Omokpariola, D. O. (2022). Influence on storage condition and time on properties of carbonated beverages from utilization of polyethylene terephthalate (PET) bottles: Chemometric and health risk assessment. *Environmental Analysis Health and Toxicology, 37*(3), e2022019-0.

Park, S. J., Nurika, I., Suhartini, S., Cho, W. H., Moon, K. D., & Jung, Y. H. (2020). Carbonation of not-from-concentrate apple juice positively impacts shelf-life. *LWT - Food Science and Technology, 134*, 110128.

Pavlović, N. V., Mladenović, J. D., Zdravković, N. M., Moravčević, Đ. Z., Poštić, D. Ž., & Zdravković, J. M. (2019). Effect of tomato juice storage on vitamin C and phenolic compounds and their stability over one-year period. *Bulgarian Chemical Communications, 51*(3), 400-405.

Ramya, H. N., Kandkur, S., Ashwini, A., & Roopa Bai, R. S. (2023). Utilization of tomato powder as a technological functional ingredient in bakery products: A review. *International Journal of Plant & Soil Science, 35*(18), 157-161. https://doi.org/10.9734/ijpss/2023/v35i183279

Ranganna, S. (2012). *Handbook of analysis and quality control for fruit and vegetable products*. Tata McGraw-Hill Publishing Company Limited.

Rao, A. V., & Agarwal, S. (1999). Role of lycopene as antioxidant carotenoid in the prevention of chronic diseases: A review. *Nutrition Research, 19*(2), 305-323.

Rowles, J. L., Ranard, K. M., Applegate, C. C., Jeon, S., An, R., & Erdman, J. W. (2018). Processed and raw tomato consumption and risk of prostate cancer: A systematic review and dose-response meta-analysis. *Prostate Cancer and Prostatic Diseases, 21*, 319-336.

Ryu, H. K., Kim, Y. D., Heo, S. S., & Kim, S. C. (2018). Effect of carbonated water manufactured by a soda carbonator on etched or sealed enamel. *Korean Journal of Orthodontics, 48*(1), 48-56.

Saint-Eve, A., Déléris, I., Aubin, E., Semon, E., Feron, G., Rabillier, J. M., Ibarra, D., Guichard, E., & Souchon, I. (2009). Influence of composition (CO2 and sugar) on aroma release and perception of mint-flavored carbonated beverages. *Journal of Agricultural and Food Chemistry, 57*(13), 5891-5898.

Sánchez-Moreno, C., Plaza, L., De Ancos, B., & Cano, M. P. (2006). Nutritional characterization of commercial traditional pasteurized tomato juices: Carotenoids, vitamin C, and radical-scavenging capacity. *Food Chemistry, 98*(4), 749-756.

Sandhan, V. S., Nandre, D. R., & Kushare, B. M. (2009). Storage studies of carbonated beverage from pomegranate juice. *International Journal of Agricultural Sciences, 5*(1), 217-220.

Song, B., Liu, K., Gao, Y., Zhao, L., Fang, H., Li, Y., Pei, L., & Xu, Y. (2017). Lycopene and risk of cardiovascular diseases: A meta-analysis of observational studies. *Molecular Nutrition & Food Research, 61*(9), 1601009.

Steen, D. (2005). Carbonated beverages. In P. R. Ashurst (Ed.), *Chemistry and technology of soft drinks and fruit juices* (pp. 150-180). Oxford Blackwell Publishing Ltd.

Sternini, C. (2013). In search of a role for carbonation: Is this a good or bad taste? *Gastroenterology, 145*(3), 500-503.

Vartanian, L. R., Schwartz, M. B., & Brownell, K. D. (2007). Effects of soft drink consumption on nutrition and health: A systematic review and meta-analysis. *American Journal of Public Health, 97*(4), 667-675.

Yadav, R., Tripathi, A. D., & Jha, A. (2013). Effect of storage time on aloe vera beverage. *International Journal of Food, Nutrition and Public Health, 6*(2), 173–192.

Yoshimura, M., Toyoshi, T., Sano, A., Izumi, T., Fujii, T., Konishi, C., Inai, S., Matsukura, C., Fukuda, N., Ezura, H., & Obata, A. (2010). Antihypertensive effect of a γ-aminobutyric acid rich tomato cultivar 'dg03-9' in spontaneously hypertensive rats. *Journal of Agricultural and Food Chemistry, 58*(1), 615-619.

Zhu, R., Chen, B., Bai, Y., Miao, T., Rui, L., Zhang, H., Xia, B., Li, Y., Gao, S., Wang, X. D., & Zhang, D. (2020). Lycopene in protection against obesity and diabetes: A mechanistic review. *Pharmacological Research, 159*, 104966.

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