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USE OF FACTORIAL DESIGN METHODOLOGY IN FRUIT JUICE QUALITY RETENTION STUDIES

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ABSTRACT

Deterioration of fruit juice, an inherent problem that tends to impede the development of the fruit juice industry, is influenced by many variables in processing, handling, storage and distribution. Ascorbic acid is the least stable of all fruit juice nutrients, it is readily oxidized. Thus, its concentration is an index to the retention of the original nutritive value. The use of factorial design methodology in monitoring the degradation of ascorbic acid in fruit juices during ambient storage and distribution is presented in this work. The effects of storage temperature (x_1), brix value (x_2), pH (x_3), quantity of antioxidant (x_4) and duration of storage (x_5) on the ascorbic acid levels in orange, mango and pineapple juices, under non-refrigerated storage and distribution were investigated; optimal shelf-life and quality value models were developed. Data were drawn from a 2^5 full factorial experiments conducted in three replicates with the order of the replicate experiments randomized. Multivariate regression analysis was used for relating the variables. The optimal shelf-lives of the orange, and pineapple juices was 16 days and the respective values of ascorbic acid for this duration were 22.93mg\100ml, 25.89mg\100ml, and 11.69mg\100ml. The regression analysis model confirmed the mango juice model to be inadequate.

INTRODUCTION

Fruit juice is assuming a more important role in Nigeria's diversified food industry. However, in the course of processing, distribution and storage of fresh market fruit juice, there is an inevitable decline in quality. The loss occurs because of the sensitivity of ascorbic acid content of juices to some storage and environmental conditions (Heimann, 1980). Ascorbic acid level is usually the criterion for judging fruit juice quality. It is one of the vitamins that should be routinely assayed in a range of fruit juices (Philip, 2005)

It is the responsibility of the juice manufacturers to ensure that quality losses in juice are minimal. The manufacturer must seek to monitor the factors which influence the ascorbic acid level under production, distribution and storage conditions. To predict the extent of deterioration of nutrient value, a knowledge of the loss of important nutritive quality index as a function of the deteriorative factors are needed (Owen, 1976; Philip, 2005). Through modeling of the various deteriorative factors, the juice manufacturer can specify the value of his product, which is essential, if nutrient claims are to be made on the label or advertising associated

with the products.

Five main factors have been identified as critical to the retention of ascorbic acid in fruit juices during non-refrigerated storage and distribution. These are: the storage temperature, the total soluble solid (brix value), the pH, the level of dissolved oxygen and the duration of storage (Frederick *et al.,* 1994). Balancing these factors will bring about satisfactory control of ascorbic acid degradation in fruit juices during non-refrigerated storage and distribution. To completely describe the multiple-variable phenomena of ascorbic acid degradation with respect to the deteriorative factors, a scientific procedure of conducting multiple-factor test is required.

The proportion of multiple-factors i.e. tests accounting for the effects of a plurality of factors, has grown in food researches (Maxino *et al.,* 1984, Robert, 2003). Such tests have become more sophisticated and costly. This has posed a generally felt problem of looking for an optimal testing plan, and the issue of optimization of a testing plan is inherently related to the procedures of generating the result of the testing, and is resolved by scientific planning of an experiment, which is a new trend in mathematical statistics (Maxino *et al.,* 1984, Zivorad, 2004). Factorial design method is a scientific procedure of conducting multiple-factor tests. In this paper, factorial design methodology is employed in determining the effects of storage temperature, total soluble solid (brix value), pH, level of dissolved oxygen and the duration of storage on the ascorbic acid level of orange, mango and pineapple juices under ambient storage and distribution conditions. Mathematical models of juice quality based on these deterioration factors were developed.

EXPERIMENTAL TECHNIQUES

Experimental Materials

Samples of orange, mango and pineapple juices were manually extracted from fruits obtained from experimental plots of National Horticultural Research Institute (NIHORT), Ibadan. These juice samples are representation of the Nigeria fruit juice market with respect to the variety and cultural conditions. The fresh fruit juice samples and their properties of juices extracted are presented in Table 1 (Olorunsogo, 1998).

Table 1: Experimental Sample and Their Properties

Experimental Samples	Variety/source	Properties of freshly extracted Juice		
		Ascorbic acid	Brix value	pH
Orange Juice	Agege 1	36.15mg/100ml	100 Brix	3.2
Mango Juice	Arumanis	30.79mg/100ml	100 Brix	3.3
Pineapple Juice	Smooth cayene	5.76mg/100ml	140 Brix	3.5

Experimental Design Method

A five-variable two-level factorial design ($N=2^5$) provides the framework for the juice variable experiments. With five variable and two levels, an orthogonalized design leads to a total of thirty two experimental

runs. In the 2^5 full factorial experiment, the low and high levels of the factors were coded as minus (-) and plus (+) respectively (Douglas, 1991; Douglas, *et al.,* 2003).

Conduct of Experiment and Data Presentation

Data were drawn from 2^5 full factorial experiments conducted in randomized order in three replicates according to the design matrix (Table. 2). The values of the varying factors and their coded levels are presented in Table 3. The data generated, which consists of the values of ascorbic acid for the juice experiments, are presented in Table 4. (Olorunsogo, 1998).

Table 2: Design Matrix for a 2^5 Full Factorial Experiment (FFE)

Run	X_o b_o	X_1 b_1	X_2 b_2	X_3 b_3	X_4 b_4	X_5 b_5
1	+	-	-	-	-	-
2	+	+	-	-	-	-
3	+	-	+	-	-	-
4	+	+	+	-	-	-
5	+	-	-	+	-	-
6	+	+	-	+	-	-
7	+	-	+	+	-	-
8	+	+	+	+	-	-
9	+	-	-	-	+	-
10	+	+	-	-	+	-
11	+	-	+	-	+	-
12	+	+	+	-	+	-
13	+	-	-	+	+	-
14	+	+	-	+	+	-
15	+	-	+	+	+	-
16	+	+	+	+	+	-
17	+	-	-	-	-	=
18	+	+	-	-	-	+
19	+	-	+	-	-	+
20	+	+	+	-	-	+
21	+	-	-	+	-	+
22	+	+	-	+	-	+
23	+	-	+	+	-	+
24	+	+	+	+	-	+
25	+	-	-	-	+	+
26	+	+	-	-	+	+
27	+	-	+	-	+	+
28	+	+	+	-	+	+
29	+	-	-	+	+	+
30	+	+	-	+	+	+
31	+	-	+	+	+	+
32	+	+	+	+	+	+

STATISTICAL ANALYSIS AND MODEL SIMULATION

Multivariate regression analysis was used in relating the variables (Douglas, *et al.,* 2003; Klaus *et al.,* 2005; Robert *et al.,* 2003; Zivorad, 2004). The mean of the replicated observations were given by:

Table 3: Factors and Their Coded Levels

Level of factors	Code	Juice sample	Independent variables				
			X1	X2	X3	X4	X5
Base level	0	Orange	300C	100 Brix	3.2	0.08g/l	12days
		Mango	300C	100 Brix	3.3	0.08g/l	12days
		Pineapple	300C	140 Brix	3.5	0.08g/l	12days
Interval of variation	Dxi	Orange	100C	30 Brix	1.0	0.025g/l	4days
		Mango	100C	30 Brix	1.0	0.025g/l	4days
		Pineapple	100C	40 Brix	1.0	0.025g/l	4days
High level	+1	Orange	400C	130 Brix	4.2	0.1g/l	16days
		Mango	400C	130 Brix	4.3	0.1g/l	16days
		Pineapple	400C	130 Brix	4.5	0.1g/l	16days
Low level	-1	Orange	200C	70 Brix	2.2	0.05g/l	8days
		Mango	200C	70 Brix	2.3	0.05g/l	8days
		Pineapple	200C	100 Brix	2.5	0.05g/l	8days

(where x_1 = storage temperature, x_2 = brix value, x_3 = pH, x_4 = quantity of antioxidant, x_5 = duration of storage)

$$\bar{y}_u = \frac{1}{r}\sum_{u=1}^{r} y_{uv} \quad \text{..... (1)}$$

where r is replication of the trial, y_{uv} is the value in the u-th repeat of the r-th.
The dispersion (variance) of the replicated observation were given as:

$$S_u^2 = \frac{1}{r-1} \sum_{v=1}^{r} (y_{uv} - \bar{y}_u)^2 \quad \text{.....(2)}$$

$$\textit{The sum of the dispersion} = \sum_{u=1}^{N} S_u \quad \text{.....(3)}$$

where, N = number of experimented runs (u =1,2,…..…., 32).

The maximum dispersion is designated as $S^2_{u\max}$. The homogeneity of dispersion of the replicate experiments were verified using the cochran G-criteria (G-test). The calculated G – Value is given as:

Table 4: Ascorbic Acid Level Data For Juices mg/100ml

Run No	Orange Juice				Mango Juice				Pineapple Juice			
	Replicates			$\bar{y}_u$	Replicates			$\bar{y}_u$	Replicates			$\bar{y}_u$
	yu_1	yu_2	yu_3		yu_1	yu_2	yu_3		yu_1	yu_2	yu_3	
1	12.16	12.80	12.61	12.52	17.60	18.88	18.19	18.22	6.44	6.40	6.45	8.43
2.	22.40	22.40	22.50	22.43	20.16	20.48	21.02	20.55	1.60	1.60	1.63	1.61
3.	12.80	12.48	12.51	12.60	20.80	20.16	20.51	20.49	4.80	4.80	4.63	4.74
4.	1.92	2.24	2.28	2.15	26.56	25.92	26.17	26.22	4.16	3.20	3.77	3.71
5.	23.36	23.26	23.12	23.25	13.78	12.80	13.62	13.40	6.40	5.12	5.85	5.79
6.	13.44	14.08	14.11	13.88	13.12	13.76	13.51	13.46	3.52	3.52	3.49	3.51
7.	18.56	18.41	18.42	18.40	20.80	19.84	20.77	20.47	4.80	4.16	4.51	4.49
8.	21.76	21.65	21.61	21.67	15.36	14.80	15.20	15.12	4.16	4.16	4.20	4.17
9.	15.36	15.21	15.11	15.23	18.24	18.24	18.42	18.30	3.84	3.52	3.62	3.66
10.	8.96	8.32	8.67	8.65	19.84	20.48	20.33	20.22	2.24	2.24	2.21	2.23
11.	9.60	8.64	9.32	9.19	20.80	21.12	21.42	21.11	5.12	4.16	4.79	4.69
12.	1.92	2.24	2.09	2.08	23.92	25.48	24.81	24.74	4.48	3.52	4.21	2.07
13.	12.48	13.12	13.09	12.90	13.76	15.04	14.70	14.50	3.52	3.52	3.60	3.55
14.	19.52	19.20	19.49	19.40	12.48	12.16	12.20	12.28	3.20	3.20	3.16	3.19
15.	21.30	20.80	21.41	21.17	17.92	18.24	18.19	18.12	5.12	4.80	5.03	4.98
16.	16.00	17.288	17.10	16.79	17.04	16.60	17.34	17.00	4.48	4.16	4.23	4.29
17	12.16	11.84	12.10	12.03	14.72	15.04	15.01	14.92	5.12	4.80	5.12	5.01
18	3.20	2.56	3.01	2.92	13.76	14.40	1393	14.03	2.24	1.92	2.24	2.13
19	13.40	13.12	13.62	13.38	24.00	23.78	23.61	23.80	5.12	4.48	4.96	4.85
20	5.12	4.16	4.71	4.66	16.96	17.03	17.13	17.04	2.56	1.60	2.56	2.24
21	5.12	4.80	5.01	4.98	15.22	15.04	15.35	15.20	11.52	11.59	11.61	11.57
22	1.60	1.92	1.74	1.75	10.24	9.83	10.41	10.16	4.21	5.08	4.48	4.59
23	22.85	22.72	22.92	22.82	10.24	10.88	11.04	10.72	4.16	3.20	3.94	3.77
24	9.28	7.68	8.41	8.46	16.32	16.00	16.14	16.24	4.48	4.48	4.66	4.54
25	7.68	7.36	7.40	7.48	23.36	22.16	22.68	22.60	3.20	2.56	2.87	2.88
26	3.52	3.52	3.60	3.55	17.60	17.28	17.53	17.47	4.48	3.20	4.18	3.95
27	22.72	21.76	21,84	22.11	19.52	19.20	19.48	19.40	6.13	6.72	6.27	6.37
28	4.16	4.45	4.20	4.28	26.88	26.24	26.53	26.55	1.92	2.56	2.48	2.32
29	4.80	6.08	5.21	5.36	13.44	13.44	13.47	13.45	5.44	5.44	5.32	5.40
30	3.52	3.52	3.63	3.56	12.80	11.94	12.56	12.43	1.92	2.24	2.12	2.09
31	23.00	22.19	21.37	22.19	1.87	2.13	2.04	2.01	12.16	11.20	11.60	11.65
32	4.48	4.16	4.40	4.35	19.52	19.84	19.67	19.68	4.48	4.16	4.62	4.42

$$G_{cal} = \frac{S^2_{u_{\max}}}{\sum_{u=1}^{N} S_u^2} \qquad \text{.....(4)}$$

The calculated G – value was compared with an appropriate table value. The condition of homogeneity is given as:

$$G_{cal} < G_{[\alpha, N, (r-1)]} \quad \text{……...……...(5)}$$

where, a = level of significance. If this condition is satisfied then we can proceed with regression analysis. The mean-square-error is given as:

$$S_y^2 = \frac{1}{N}\sum_{u=1}^{N} S_u^2 \quad \text{…….……..……..…….(6)}$$

It is the average sample variance estimate. The experimental error is given as

$$S_y = \sqrt{S_y^2} \quad \text{……..……..(7)}$$

The effects and the sum of squares for each factor were estimated through the contrast associated with effects.

The mean effect was given as:

$$b_o = \frac{1}{N}\sum_{u=1}^{N}(X_o \bar{y}_u); \quad u = 1, 2, …., 32 \quad \text{……...(8)}$$

where Xo are the coded signs in the Xo column of the design matrix.
The main effects were estimated by:

$$b_i = \frac{1}{N}\sum_{u=1}^{N}(X_i \bar{y}_u); \quad i = 1, 2, ….5; \quad u = 1, 2, …., 32\text{……...…..(9)}$$

where Xi are the coded signs in the Xi columns of the design matrix.
The k – factor interactions were estimated by:

$$b_{i,j,....k} = \frac{1}{N}\sum_{u=1}^{N}\left(X_{i,j,\ k}\bar{y}_u\right); \quad i = 1, 2, ...5 \quad i \neq j \neq .... \neq k \quad \text{...…(10)}$$

where Xi, j,….., k are the coded signs in the Xi, j, ….,k columns of the design matrix.

The quantities in brackets in equations (8), (9) and (10) are called contract in the treatment combinations.
Construction of confidence interval and testing of hypothesis about individual regression coefficient were used in assessing their statistical significance. Confidence intervals for the regression coefficients with confidence coefficient a are of the general form:

$$b's \pm t_{[\alpha, N(r-1)]} S'_b s \quad \text{…….(11)}$$

where $S'_b s$ = the estimated standard error in regression coefficients b's,

$t_{[\alpha, N(r-1)]}$ = an appropriate tabulated t – criteria with N(r-1) degree of freedom.

For full-factorial experiments error in each regression coefficient is the same and is determined by:

$$S_{bo} = S_{b_i} = ... = S_{b_{i,\,j,\,....k}} = \frac{S_y}{\sqrt{N \bullet r}} \quad \text{……...…….(12)}$$

where, Sy = the experimental error.

The statistical significance of the regression coefficients are tested by:

$$t_{i,\,j,\,.....k} = \frac{\left|b_{i,\,j,....k}\right|}{S_{b_{i,\,j\,.....k}}} \quad \text{……..(13)}$$

where, $\left|b_{i,\,j,...k}\right|$ is the absolute value of the estimate of the coefficient being checked. The calculated t-values were compared with the appropriate critical value found from standard t -tables, A coefficient is considered significant if:

$$t_{cal} > t_{[\alpha, N(r-1)]} \quad \text{……...…….(14)}$$

For any coefficient that was statistically insignificant, such a coefficient was left out of the regression models.

The summary of the estimated effects, confidence interval and the t-values are presented in Table 5. Using only the statistical regression coefficients, the fitted models were then used to generated the predicted values, and the residuals which are used to examine the adequacy of the models.

The adequacy of the fitted models were evaluated using the null hypothesis (Ho:bi,….. k-=0) on the individual regression coefficients. The analysis of variance (ANOVA) was used in confirming the significance of the coefficients. In the 2k factorial design with replicates, the regression sum of squares for any effect is determined by:

$$SS_{b_{i.....k}} = \frac{r}{N}(contrast)^2 \quad \text{…….(15)}$$

Table 5: The Estimated Effects, Confidence Interval and t-Value

Regression Coefficient	Estimated effects			Confidence interval			Calculated t-value		
	Orange	Mango	Pineapple	Orange	Mango	Pineapple	Orange	Mango	Pineapple
b0	11.76	17.18	4.47	+0.07	+0.07	+0.05	294.00	429/50	149.00
b1	-2.97	0.39	-1.15	+0.07	+0.07	+0.05	74.25	9.75	38.33
b2	1.14	1.49	0.24	+0.07	+0.07	+0.05	28.50	37.25	8.00
b3	2.05	-3.04	2.66	+0.07	+0.07	+0.05	51.25	76.00	22.00
b4	-0.61	0.30	-0.11	+0.07	+0.07	+0.05	15.25	7.50	3.67
b5	-2.76	-1.10	0.40	+0.07	+0.07	+0.05	69.00	27.50	13.33
b12	-1.87	1.02	0.16	+0.07	+0.07	+0.05	46.75	25.50	5.33
b13	0.04	-0.008	-0.13	+0.07	+0.07	+0.05	10.00	0.20	4.33
b14	-0.34	0.66	0.11	+0.07	+0.07	+0.05	8.50	16.50	3.67
b15	-1.83	0.08	-0.43	+0.07	+0.07	+0.05	45.75	2.00	13.33
b23	2.04	-0.45	-0.08	+0.07	+0.07	+0.05	51.00	11.25	2.67
b24	0.49	-0.27	0.75	+0.07	+0.07	+0.05	12.25	6.75	25.00
b25	2.65	-0.41	-0.08	+0.07	+0.07	+0.05	66.25	10.25	2.67
b34	0.02	-0.52	-0.07	+0.07	+0.07	+0.05	-0.50*	13.00	2.33
b35	-1.86	-0.20	0.51	+0.07	+0.07	+0.05	46.50	5.00	17.00
b45	0.73	0.41	0.13	+0.07	+0.07	+0.05	18.25	10.25	4.33
b123	0.28	0.30	0.18	+0.07	+0.07	+0.05	7.00	7.50	6.00
b124	-0.72	.085	-0.70	+0.07	+0.07	+0.05	18.00	21.25	23.33
b125	-0.67	0.96	-0.23	+0.07	+0.07	+0.05	16.75	24.00	7.67
b134	0.70	0.22	-0.28	+0.07	+0.07	+0.05	17.50	5.50	9.33
b135	-0.28	1.28	-0.39	+0.07	+0.07	+0.05	7.00	32.00	3.00
b145	-0.0013	0.70	-0.22	+0.07	+0.07	+0.05	0.033*	17.50	7.33
b234	-0.78	0.016	0.48	+0.07	+0.07	+0.05	19.50	0.40*	16.00
b235	-0.55	--0.57	0.01	+0.07	+0.07	+0.05	13.75	14.25	0.33*
b245	-0.16	-0.22	0.40	+0.07	+0.07	+0.05	4.00	5.50	13.33
b345	-0,46	-0.67	-0.07	+0.07	+0.07	+0.05	11.50	16.75	2.33
b1234	-1.06	-0.18	-0.18	+0.07	+0.07	+0.05	26.50	4.50	6.00
b1235	1.14	0.76	0.36	+0.07	+0.07	+0.05	28.50	19.00	12.00
b1245	-0.48	0.67	-0.37	+0.07	+0.07	+0.05	12.00	16.75	12.33
b1345	0.61	0.07	-0.14	+0.07	+0.07	+0.05	15.25	1.75	4.67
b2345	-0.45	0.12	0.43	+0.07	+0.07	+0.05	11.25	3.00	14.33
b12345	1.65	-0.70	-0.22	+0.07	+0.07	+0.05	41.25	17.50	7.33

* Statistically insignificant

and has a single degree freedom. The regression sums of squares for the models is the summation of the sums of squares for the individual effects:

$$SS_R = SS_{b_i} + SS_{b_j} + \ldots\ldots\ldots\ldots\ldots + SS_{b_{i\ldots\ldots k}} \quad \ldots\ldots\ldots\ldots(16)$$

The total sum of squares were calculated by:

$$SS_T = \sum_{u=1}^{N} y_{uv}^2 - \frac{\left(\sum_{u=1}^{N} y_{uv}\right)^2}{N \cdot r}$$

The error sums of squares were given as

$$SS_E = SS_T - \sum SS_{b_{i\ldots k}} = SS_T - SS_R \quad \ldots\ldots\ldots\ldots(18)$$

Testing the significance of individual regression coefficient was carried out by the Fisher's test (F-test)

$$F_{cal} = \frac{MS_R}{MS_E} = \frac{SS_R / dF_R}{SS_E / dF_E} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(19)$$

where, dFR = the degree of Freedom regression =1, dFE = the degree of Freedom error = N(r-1)

The calculated F-values are compared with the appropriate critical table value. The null hypothesis was rejected if:

$$F_{cal} > F_{[\alpha, dF_R, N(r-1)]} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(20)$$

with the conclusion that the coefficient contributes significantly to the regression

The adequacy of the models was further validated by calculating the dispersion of adequacy for the replicated experiments and comparing the magnitudes with the variance estimates given by the mean squared error. The dispersion of adequacy is given by:

$$SS_{ad}^2 = \frac{r}{N - \lambda} \sum_{u=1}^{N} \left(\bar{y}_u - \hat{y}_u\right)^2 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(21)$$

where l = number of inadequate regression coefficients. The adequacy of the models is confirmed by the Fisher's test:

$$F_{cal} = \frac{SS_{ad}^2}{S_y^2} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(22)$$

where s_y^2 = variance estimate given by the mean squared error (i.e. eqn 6).
The calculated F-values were then compared with the appropriate table values.
The condition of adequacy is

$$F_{cal} \leq F_{[\alpha, N-\lambda, N(r-1)]} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(23)$$

If this condition is satisfied then we conclude that the fitted models are adequate.

Applying eqns (1) – (23) to the ascorbic acid level data for the fruit juices (Table 4), the fitted models were found to be:

(a). For orange Juice:

$$\left.\begin{aligned}\widehat{y}_u = {} & 11.76 - 2.97X_1 + 1.14X_2 + 2.05X_3 - 0.61X_5 - 2.76X_5 - 1.87X_{12} + 0.04X_3 \\ & - 0.43X_{14} - 1{,}83X_{15} + 2.04X_{23} + 0.49X_{24} + 2.65X_{25} - 1.86X_{35} - 0.73X_{45} \\ & + 0.28X_{123} - 0.72X_{124} - 0.67X_{125} + 0.70X_{134} - 0.28X_{135} - 0.78X_{234} - 0.55X_{235} \\ & - 0.16X_{245} - 0.46X_{345} - 1.06X_{1234} + 1.14X_{1235} - 0.48X_{1245} + 0.61X_{1345} \\ & + 0.45X_{2345} - 1.65X_{12345}\end{aligned}\right\} \quad - \quad 24$$

(b). For Mango Juice

$$\left.\begin{aligned}\widehat{y}_u = {} & 17.18 + 1.49X_2 - 3.04X_3 - 1.10X_5 + 1.02X_{12} - 0.66X_{14} - 0.52X_{34} + 0.85X_{124} \\ & + 0.96X_{125} + 1.28X_{135} + 0.70X_{145} - 0.57X_{235} - 0.67X_{345} + 0.76X_{1235} + 0.67X_{1245} \\ & + 0.70X_{12345}\end{aligned}\right\} \quad - \quad 25$$

(c). For Pineapple Juice

$$\left.\begin{aligned}\widehat{y}_u = {} & 4.47 - 1.15X_1 + 0.24X_2 + 0.66X_3 - 0.11X_4 - 0.40X_5 - 0.16X_{12} + 0.13X_{13} \\ & - 0.11X_{14} - 0.43X_{15} + 0.08X_{23} + 0.75X_{24} + 0.08X_{25} - 0.07X_{34} + 0.51X_{35} + 0.13X_{45} \\ & + 0.18X_{123} - 0.70X_{124} - 0.23X_{125} + 0.28X_{134} - 0.39X_{135} - 0.22X_{145} + 0.48X_{234} \\ & + 0.40X_{245} - 0.07X_{345} - 0.18X_{1234} + 0.36X_{1235} - 0.37X_{1245} + 0.14X_{1345} \\ & + 0.43X_{2345} - 0.22X_{12345}\end{aligned}\right\} \quad - \quad 26$$

The complete analyses of variance (ANOVA) are summarize in Tables 6, 7, and 8.

Table 6: ANOVA for Replicated 2^5 Factorial Orange Juice Experiment

Source of variation	Effect	Sum of Squares (SS)	Degree of freedom (df)	Mean squares (MS)	F-ratio
b1	-2.91	846.81	1	846.81	7698.27
b2	1.14	124.35	1	124.35	1130.46
b3	2.05	404.43	1	404.43	3676.64
b4	-0.61	36.09	1	36.09	328.09
b5	-2.76	732.95	1	732.95	6663.18
b12	-1.87	335.48	1	335.48	3049.82
b13	0.40	14.88	1	14.88	135.27
b14	-0.34	11.14	1	11.14	101.27
b15	-1.83	372.15	1	322.15	2928.64
b23	2.04	397.80	1	397.80	3616.36
b24	0.49	22.93	1	22.93	208.46
b25	2.65	674.80	1	674.80	6134.55
b34	0.02	0.036	1	0.036	0.3273
b35	-1.86	322.35	1	322.35	3021.36
b45	0.73	51.16	1	51.16	465.09
b123	0.28	7.56	1	7.56	68.73
b124	-0.72	49.08	1	49.08	446.18
b125	-0.67	43.58	1	43.58	396.18
b134	0.70	46.45	1	46.45	422.27
b135	-0.28	7.43	1	7.43	67.55
b145	-0.0013	0.00015	1	0.00015	0.0014*
b234	-0.78	58.97	1	58.97	536.09
b235	-0.55	29.31	1	29.31	266.46
b245	-0.16	2.33	1	2.33	21.18
b345	-0.46	19.98	1	19.98	181.64
b1234	-0.06	108.12	1	108.12	982.91
b1235	-1.14	123.67	1	123.67	1124.27
b1245	-0.48	22.52	1	22.52	204.73
b1345	-0.61	35.58	1	35.58	323.46
b2345	-0.45	19.28	1	19.28	175.27
b12345	-1.65	260.77	1	260.77	2370.64
Error		7.04	64	0.110	
Total		5149.03	95		

*Insignificant at 5 percent

Table 7: ANOVA For Replicated 2^5 Factorial Mango Juice Experiment

Source of variation	Effect	Sum of Squares (SS)	Degree of freedom (df)	Mean squares (MS)	F-ratio
b1	0.39	14.60	1	14.60	2.49*
b2	14.49	212.40	1	212.40	36.18
b3	-3.04	891.21	1	891.21	151.82
b4	0.30	8.89	1	8.89	1.51*
b5	-1.10	111.07	1	111.07	18.92
b12	1.02	99.27	1	99.27	16.91
b13	-0.008	0.006	1	0.006	0.001*
b14	0.66	42.06	1	42.06	7.17
b15	0.08	0.63	1	0.63	0.11*
b23	-0.45	19.66	1	19.66	3.35*
b24	-0.27	7.13	1	7.13	1.22*
b25	-0.41	16.43	1	16.43	2.80*
b34	-0.52	25.52	1	25.52	4.35
b35	-0.20	3.77	1	3.77	0.64*
b45	0.41	16.38	1	16.38	2.80*
b123	0.30	8.46	1	8.46	1.44*
b124	0.85	69.26	1	69.26	11.80
b125	0.96	88.82	1	88.82	15.13
b134	0.22	4.44	1	4.44	0.76*
b135	1.28	158.21	1	158.21	26.95
b145	0.70	47.38	1	47.38	8.07
b234	0.016	0.03	1	0.03	0.01*
b235	-0.57	31.19	1	31.19	5.31
b245	-0.22	4.43	1	4.43	0.75*
b345	-0.67	43.17	1	43.17	7.35
b1234	-0.18	3.09	1	3.09	0.53*
b1235	0.76	54.81	1	54.81	9.34
b1245	0.67	42.85	1	42.85	7.30
b1345	0.07	0.42	1	0.42	0.07*
b2345	-0.12	1.44	1	1.44	0.25*
b12345	0.07	46.62	1	46.62	7.94
Error		375.97	64	5.87	
Total		2449.62	95		

*Insignificant at 5 percent.

Table 8: ANOVA For Replicated 2^5 Factorial Pineapple Juice Experiment

Source of variation	Effect	Sum of Squares (SS)	Degree of freedom (df)	Mean squares (MS)	F-ratio
b1	-1.15	126.75	1	126.75	2018.31
b2	0.24	5.57	1	5.57	88.69
b3	0.66	41.78	1	41.78	665.29
b4	-0.11	1.09	1	1.09	17.36
b5	0.40	15.05	1	15.05	239.65
b12	0.16	2.55	1	2.55	40.61
b13	-0.13	1.52	1	1.52	24.20
b14	0.11	1.17	1	1.17	18.63
b15	-0.43	17.52	1	17.52	278.98
b23	-0.08	0.57	1	0.57	9.08
b24	0.75	53.87	1	53.87	857.80
b25	-0.08	0.65	1	0.65	10.35
b34	-0.07	0.50	1	0.50	7.96
b35	0.51	25.37	1	25.37	403.98
b45	0.13	1.63	1	1.63	25.96
b123	0.18	3.06	1	3.06	48.73
b124	-0.70	46.7	1	46.5	744.43
b125	-0.23	4.93	1	4.93	78.50
b134	-0.28	7.75	1	7.75	123.41
b135	-0.39	14.72	1	14.72	234.40
b145	-0.22	4.82	1	4.82	76.75
b234	0.48	21.75	1	21.75	346.34
b235	0.01	0.009	1	0.009	0.143*
b245	0.40	15.15	1	15.15	241.24
b345	-0.07	0.41	1	0.41	6.53
b1234	-0.18	2.93	1	2.93	46.66
b1235	0.36	12.72	1	12.72	202.55
b1245	-0.37	13.03	1	13.03	207.48
b1345	-0.14	1.98	1	1.98	31.52
b2345	0.43	17.88	1	17.88	284.71
b12345	-0.22	4.54	1	4.56	72.29
Error		4.02	64	0.0628	
Total			95		

* Insignificant at 5 percent

DISCUSSIONS AND INTERPRETATION OF MODELS

Equations (24), (25) and (26) express the fitted models for predicting ascorbic acid levels in orange, mango and pineapple juices respectively under non-refrigerated storage and distribution conditions. However, the regression analysis confirmed the mango juice model to be inadequate.

Orange Juice Model

From the statistical analysis of orange juice experimental data, all the main effects and the interactions have significant influence on the level of ascorbic acid of orange juice. However, storage temperature (with coefficient b1 = - 2.97), duration of storage (with coefficient b5 = -2.76) and pH (with coefficient b3 = -2.05), have higher detrimental influences. High level of each of these factors will lead to drastic reduction in the ascorbic acid level of the juice. On the other hand, the interactions, brix value/duration, of storage (with coefficient b25 = 2.65) and brix value/pH (with coefficient b23 = 2.04) both enhance the retention of ascorbic acid. Furthermore, maintaining the juice at 20^0C storage temperature 13^0 brix value, a pH of 4.2 and using 0.5g/litre of antioxidant gives the optimum ascorbic acid level (under non -refrigerated storage and distribution condition) for a maximum storage duration of 16 days.

Mango Juice Model

The pH (with coefficient b3 = -3.04) has the highest influence on the ascorbic acid level of mango juice. A high pH value will lead to drastic reduction in the ascorbic acid level of the juice. However, analysis showed that the model is inadequate.

Pineapple Juice Model

Statistical analysis of the pineapple juice experimental data reveals that the entire main effects and interactions in the model have significant influence on the level of the ascorbic acid of the juice. However, storage temperature (with coefficient b1= -1.15) has the highest detrimental influence. High level of temperature will lead to drastic reduction in the ascorbic acid level of the juice. However, to maintain a high ascorbic acid level under non-refrigeration storage and distribution, the analysis of the data reveals that the juice must be kept under the following conditions: 20^0C storage temperature, 18 brix value, a pH of 4.5, 0.1g/litre of antioxidant for a maximum storage duration of 16 days.

CONCLUSION

The use of factorial design, a scientific procedure of conducting multi-factor test has been presented. A multiple case of linear regression function has been considered. With this method, it has been shown how to methodically eliminate insignificant variables and obtain adequate parametric model for physical phenomenon.

The result of the experiments and the developed models confirm that storage temperatures, brix value, pH, quantity of antioxidant and duration of storage all govern the shelf-life and are important for characterizing the quality of orange and pineapple juices.

The developed models are valid only for values of factors that fall within intervals of values used in producing them. The models are mainly for non-refrigeration storage and distribution conditions.

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