Optimization of Osmotic Dehydration Process for Aonla (Emblica officinalis Gaertn) Pieces with Salt Solution and Spices by Response Surface Methodology

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Abstract: The optimization of osmotic dehydration process of aonla (Emblica officinalis Gaertn) slices in brine solution containing spices (cumin powder, fenugreek powder, fresh ginger extract) was carried out using response surface methodology. The independent process variables for osmotic dehydration are salt concentration in water (4-12%), spices concentration in the brine solution (3-9%), solution to fruit ratio (3-5) and duration of 60-90 minutes at room temperature. The osmotic dehydration process was optimized for maximum water loss, solute gain, overall acceptability and minimum acidity and vitamin C loss based on the RSM. The optimum conditions were predicted as 12% salt concentration, 7.09 % spices concentration, 4.30 solutions to fruit ratio and 84.15 minutes process time. Among the process variable, salt concentration, process duration and spices concentration have the most significant effect on water loss, solute gain, acidity and overall acceptability; process time has the most effect on vitamin-C loss and acidity whereas solution-to-fruit ratio had significantly lower effect on all the responses. Osmotically dehydrated aonla samples were observed to be less in functional compounds compare to fresh aonla samples due to leaching out of minor compounds to hypertonic solution during osmotic dehydration process.

1. Introduction
Among the fruits, aonla commonly known as Indian Gooseberry (Emblica officinalis Gaertn.) is an important fruit highly valued among indigenous medicines and is thought to be a native of India, Ceylon, Malaysia and China [1]. It finds a special place in India as it has got tremendous medicinal values and is widely used in Ayurvedic medicine. It has been considered as the best by its medicinal property like rejuvenation, because it is an important constituent of Ayurvedic medicine, tri dosaghna. Aonla stimulates the brain to rebalance the three main components of all physiological functions, the water, fire, and air elements within the body [2]. However, there are some in vivo studies indicating that antioxidant activities of aonla cannot be attributed to ascorbic acid alone and that the overall effect is due to other polyphenols such as ellagic acid, gallic acid, tannins, etc. The fresh fruits are generally not consumed as it is highly acidic and astringent in nature [3] and moreover, 17% or more of the produced fruits are lost during
transport, storage and marketing. Therefore, modern technologies are needed to reduce the losses. Hence attention has been focused on the preparation of different value-added products from *aonla*. The common employed methods of extending shelf life are by cold storage, sun drying and conventional drying or by processing to various indigenous products like *murabba*, pickle, juice syrup, squash and dehydrated powder [4]. Among these processes, dehydration offers many advantages, such as reduced weight, inexpensive packaging, shelf stability at room temperature and some negligible quality deterioration may due to enzymatic changes. Osmotic dehydration involves water removal process by soaking fruits and vegetables in a hypertonic solution such as concentrated sugar syrup or brine solution. Two major simultaneous counter-current flows occur during osmotic dehydration; Water flows out of the food into the solution and a simultaneous transfer of solute from the solution into the food [5]. There is also a third flow of natural solutes such as sugars, organic acids, minerals, salts, leaking from the food into the solution. All these mass exchanges may have an effect on the organoleptic and/or nutritional quality of the dehydrated product. Osmotic dehydration is one of the energy efficient means of removing moisture from a food product, as the water doesn’t have to go through a phase change to be released from the product. It is stated that some of the advantages of direct osmosis in comparison with other drying processes include minimized heat damage to color and flavor, and less decolonization of fruit by enzymatic oxidative browning [6]. Osmotically dehydrated *aonla* products are becoming more popular because of high acceptability, minimum volume, higher nutritional value and longer storage life. Plain osmotically dehydrated *aonla* in brine solution have now been incorporated with other readily available health beneficial spices viz cumin, fenugreek, and ginger. Addition of spices not only gives a new flavor and aroma but also enriches the *aonla* with more health benefits.

Cumin (*Cuminum cyminum*), is a remedy for dyspepsia, diarrhea and hoarseness, antimalarial, laxative, and may relieve flatulence and colic. Fenugreek (*Trigonella foenum*) is considered as one of the valuable spices because of its curative effects against dyspepsia, diarrhea, antimicrobial, and laxative and many relative flatulence and colic [7]. Ginger (*Zingiber officinal*) is a tuber that is consumed whole as a delicacy, medicine or spice. It is used as a fresh root extract or powder form. Chemical components in ginger root include 6-gingerol, 8-gingerol, 6-shogaol and 10-gingerol. The gingerols and other compounds (flavonoids) in ginger root extract have been shown to have antioxidant activity [8]. Hence, the purpose of this study was to optimize the osmotic dehydration process of *aonla* in salt solution containing spices using response surface methodology [9] and also to study the effect of osmotic process parameters as salt concentration, time, spice concentration and solution to fruit ratio on quality responses such as water loss, solute gain, acidity, vitamin-C loss and overall acceptability.

Response Surface Methodology (RSM) is a collection of mathematical and statistical techniques that are useful for modeling and analysis of problems in which the response is influenced by several variables. It is reported to be an efficient tool for optimizing a process when the independent variables have the joint effect on the responses [10]. It has been applied in optimizing food-processing operations by several investigators [11-12]. Hence, response surface methodology was used to design the experiments.

2. Materials and methods

2.1. Preparation of *aonla* and spices for osmotic dehydration process

Matured, uniform sized and disease-free fruits were procured from the local market at Tambaram, Tamil Nadu, and India. Fruits were then washed thoroughly under running tap water so that dirt adhered on the surface of the fruits can be cleaned completely. Cumin and fenugreek seeds were grounded; sieved and fine powder was collected. The fresh ginger was washed thoroughly under running tap water and peeled manually. It was then grounded in laboratory mixer grinder and subsequently fresh ginger extract was collected.
2.2. Experimental design

Response Surface Methodology or RSM; is a collection of mathematical and statistical techniques that are useful for modeling and analysis of problems in which the response is influenced by several variables [13]. It is reported to be an efficient tool for optimizing a process when the independent variables have the joint effect on the responses [14]. It has been applied in optimizing food-processing operations by several investigators [15-21]. Hence, response surface methodology [22] was used to design the experiments. The second order Box- Behnken design of four variables and three levels each with three center point combination was used [23]. This design was taken as it fulfills most of the requirements needed for optimization of the pre-treatment process [24]. In the above X1, X2, X3, X4 are the coded independent osmotic process variables which are related to un-coded variables using the following equation (1)

\[ X_i = 2 \left( \frac{x_i - \overline{x_i}}{d_i} \right) \]  

Where \( x_i \) is variable in actual units of the \( i^{th} \) observation, \( \overline{x_i} \) is the mean of the highest and lowest variable value of \( X_i \) and \( d_i \) is the difference between the highest and lowest value of \( x_i \). The process variables and their levels in the form of coded variables for three-factor three level response surface analyses are given in Table 1. The independent process variables were osmotic salt concentration, time, spices concentration and solution to fruit ratio. The low level and high level in the actual (un-coded) form were 4-12 % (w/v), 60-90 min, 3-9% (w/v), 3-5 (v/w) for salt concentration, process duration, spices concentration and solution to fruit ratio respectively.

| Independent variables | Symbols | Coded | Levels | Un-coded |
|-----------------------|---------|-------|--------|----------|
| Salt concentration (%) | X1      | -1    | 4      | 4        |
| (C)                   |         | 0     | 8      | 8        |
| Time (min)            | X2      | -1    | 60     | 60       |
| (t)                   |         | 0     | 75     | 75       |
| Solution to fruit ratio | X3     | -1    | 3      | 3        |
| (STFR)                |         | 0     | 4      | 4        |
| Spices concentration (%) | X4    | -1    | 60     | 60       |
| (SC)                  |         | 0     | 75     | 75       |

2.3. Osmotic dehydration of aonla

Fresh aonla fruits bought from local market were sorted for uniform size, color and with no physical damage; washed with fresh water then wiped with muslin cloth. The initial moisture content of aonla was 82%. The brine solution of different concentrations - (4%, 8%, 12%) was prepared in a glass bottle to which different concentrations (3%, 6%, and 9%) of spices (fine powder of cumin, fenugreek and fresh ginger extract) were added. All the spices were taken in equal ratio by weight. The aonla fruit was cut into pieces along the ridges. These pieces were added to the prepared osmotic solution and the glass was covered with aluminum foil. The ratio of aonla pieces to osmotic solution was 3:1, 4:1 and 5:1. The glasses were left undisturbed at room temperature and osmotic dehydration continued. During
experimentation, it was assumed that the amount of solid leaching out of cut aonla pieces during osmosis as negligible [25-26]. After the specified process time, the aonla pieces were removed from the glass and the excess solution that is adhering to the aonla pieces were wiped with a blotting paper. The change in weight of aonla pieces before and after osmotic dehydration was noted. After osmotic dehydration, a portion of pretreated aonla (20-25 g) were used to determine the dry matter by oven method [27]. The remaining portion of the pretreated aonla samples were used to determine the percentage of vitamin C loss, percentage of acidity and overall acceptability. The optimized pretreated aonla sample was dried by vacuum freeze drier and tray drier to 10±0.5 % moisture content on wet basis.

2.4. Calculation of dependent variables
The mass transfer parameters i.e. water loss and solute gains reflecting as one of the quality attributes of aonla were calculated by the following equations (2 and 3).

\[
\% \ WL = \frac{\text{water loss}}{100g} = \frac{[W_0 - W_t] + (S_t - S_0) \times 100}{W_0} \quad (2)
\]

\[
\% \ SG = \frac{\text{solute gain}}{100g} = \frac{(S_t - S_0) \times 100}{W_0} \quad (3)
\]

Where W0 is the initial weight of fruit taken for osmotic dehydration (g), Wt is the weight of fruit after osmotic dehydration at any time t (g), S0 is the initial dry matter of fruit (g), St is the dry matter of fruit after osmotic dehydration and FF is the fresh fruit. The other quality parameters such as moisture content, titrable acidity and ascorbic acid were determined according to A.O.A.C. 2000 method. Overall acceptability of the product was determined using nine-point hedonic scale based [28].

2.5. Optimization of osmotic parameters
Response surface methodology was applied to the experimental data using a commercial statistical package, Design-Expert version 8.0.5 (Stat-ease Inc, Minneapolis, USA, Trial version). The same software was used for the generation of response surface plots, contour plots and optimization of process variables. The response surface and contour plots were generated for different interaction for any two independent variables, while holding the value of other two variables as constant (at the central value). Such three-dimensional surfaces could give accurate geometrical representation and provide useful information about the behavior of the system within the experimental design [29-30]. The optimization of the osmotic dehydration process aimed at finding the levels of independent variables viz. salt concentration, spices concentration, time and solution to fruit ratio, which could give maximum possible water loss (WL), overall acceptability (OA), solute gain (SG), minimum percentage of acidity and vitamin- C loss (VCL).

3. Results and discussions

3.1. Proximate composition analysis of aonla
The moisture content, Vitamin, acidity, total sugars, proteins and tannin content of aonla were found to be 82%, 443.42mg/100g, 2.3%, 3.13%, 0.67% and 0.28% respectively. The results obtained were in close conformity with the observations made by Tripathi et al [31]. The polyphenols content of aonla was 0.15% which was in agreement with the observation made by Abishek Abraham et al [32].

3.2. The values of various responses at different experimental conditions
The values of various responses at different experimental combination for coded variables were given in Table 2. A wide variation in all the responses were observed for different experimental combinations i.e., 5.12 to 12.14% for water loss, 0.48 to 4.67% for solute gain, 10.02 to 22.09 % for vitamin-C loss, 1.02 to 2.13 % for acidity and 6.94 to 8.84 for overall acceptability. The maximum consumer acceptance was
witnessed for the sample pretreated at experimental condition of 12% salt concentration, 90 min process duration, 5 STFR and 6% of spices concentration. The data was analyzed employing multiple regression technique to develop a response surface model. A linear model and a second order model with and without interaction terms were tested for their adequacies to describe the response surface and R² values were calculated. A second order polynomial shown in equation (4) was fitted to the data of all the responses and results are given in Table 2.

\[ y = \beta_0 + \sum_{i=1}^{n} \beta_i x_i + \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} \beta_{ij} x_i x_j \]  

Where, \( \beta_i, \beta_{ij} \) are constant coefficients, \( x_i, x_j \) are coded independent variables.

All the five models were tested for their adequacy using ANOVA technique. F-values for the lack of fit were found non-significant (p < 0.01) for all the models confirming the validity of the models. Further, the analysis of experimental values for responses revealed that water loss, solute gain, vitamin-C loss, acidity and overall acceptability could be treated with 0.876, 0.8523, 0.6837, 0.8984 and 0.7964 coefficient of determination, respectively. Table 2 shows that the combined effect of all the process variables which are significant at linear level (p < 0.01) for water loss and solute gain. At quadratic level (p < 0.01) vitamin C loss and acidity were also significant. Whereas, overall acceptability of the sample was significant at linear and quadratic levels in the p < 0.01 level. Further statistical analysis for overall effect of the process variables on all the responses was performed. In simple terms, the values obtained gives factor wise analysis of variance i.e. the contribution of each independent variable to the total sum of squares. The results revealed that the salt concentration showed significant effect (p < 0.01) on water loss, solute gain, acidity and overall acceptability and process duration has also showed significant effect on overall acceptability at (p < 0.01) level whereas spices concentration and STFR do not have any significant effect in all the response.

3.2.1. Effect of process variables on water loss

From the figure 1 the salt concentration, process time and spices concentration have positive effects on water loss where as STFR showed negative effects on water loss witnessing decrease in water loss with increase in STFR. Similar results were obtained by Zhang X et al [33] for carrot soaked in salt. The maximum water loss 12.14% was recorded at experimental combination of 12% salt concentration, 75 min process time, 4 as STFR and 9% spices concentration. Among the process variables studied, the salt concentration witnessed maximum effect on water loss (Table 3) but the water loss was not significantly affected by time and STFR individually (p < 0.01). It was inferred from Table 2 that the quadratic and interaction terms also do not have significant effect on water loss. The model for water loss of aonla pieces was significant at p< 0.2 is displayed in the equation (4). Weight loss of the aonla pieces has direct correlation with solid gain, Vitamin C loss, titratable acidity, protein content with 1.058, 0.222, 0.118 and 0.283 respectively, whereas change in brix of OD solution, total phenol content and total carbohydrate content of aonla pieces have negative correlation with weight loss of aonla pieces during osmotic dehydration process as 0.474, 0.892 and 0.173 respectively. It was also observed that solid gain is significantly differ at p< 0.05 for weight loss. From this model for weight loss of aonla pieces during osmotic dehydration process, it was observed that weight loss have significant effect on changes in solid gain (p=0.016) at R² as 0.576. Each unit increase in solid gain increases 1.058 of weight loss. It is
observed that weight loss of the *aonla* pieces during OD processing did not influenced OD process of *aonla* pieces with spices.

**Figure 1.** Effect of salt concentration and process time on water loss at STFR 4 and Spices concentration 6%

3.2.2. Effect of process variables on solute gain

It was observed from the figure 2 that the salt concentration, process time and spices concentration have positive effect on solute gain where as STFR had mixed effects on solute gain. Similar results were obtained for radish soaked in salt solution by Manivannan P and Rajasimman [19]. The maximum solute gain 4.67% was recorded at experimental combination 12% salt concentration, 90 min process time, STFR 4 and 6 % spices concentration (table 2). The overall statistical analysis showed that salt concentration has higher effects on solute gain whereas solute gain was not significantly affected by process time, and spices concentration individually (p < 0.01) (Table 3). It can also be seen from Table 2 that solute gain was found to be significantly (p < 0.01) affected by salt concentration individually followed by the interaction of salt concentration and time (p < 0.01).
3.2.3. Effect of process variables on vitamin C loss
The Figure 3 reveals that all the process variables had positive effect on vitamin C loss. With increase in process variables, the loss of vitamin C also observed to be increased.

Figure 2. Effect of salt concentration and process time on solute gain at STFR 4 and spices concentration 6%

Figure 3. Effect of salt concentration and time on vitamin C loss at STFR 4 and spices concentration at 6% level.
Similar results were obtained by Alam Md and Alam MS [21& 34] where aonla with added salt during osmotic dehydration process Conducted. The maximum vitamin C loss 22.91% was recorded at experimental conditions 8% salt concentration, 90 min process time, STFR 4 and 9% spices concentration. The overall statistical analysis of process variables reveals that process time has significant effect on vitamin C loss (Table 3). From Table 2, it can be seen that vitamin C loss is significantly (p < 0.01) affected by time. Vitamin C loss of aonla pieces during OD is related to solid gain, changes in brix, weight loss, titrable acidity, total phenol content, protein content and total carbohydrate content of the product.

### 3.2.4. Effect of process variables on acidity

The Figure 4 indicates that all the process variables have negative effect on acidity. With increase in process variable there is a decrease in the acidity. The minimum acidity of 1.02% was recorded at experimental conditions 12% salt concentration, 75 min process time, STFR 4 and 9% spices concentration. Similar results were obtained by Bhagya S et al [35]. The overall statistical analysis revealed that salt concentration had significant (p < 0.01) effect on acidity (Table 3). From Table 4, it can be observed that acidity is significantly (p < 0.01) affected by salt concentration.

![Design-Expert® Software](image)

**Figure 4.** Effect of salt concentration and time on acidity at STFR 4 and spices concentration 6%
3.2.5. Effect of process variables on overall acceptability

The overall acceptability of the dehydrated product increased with increase in all the process variables (figure 5). The maximum overall acceptability 8.84 was recorded at experimental conditions 12% salt concentration, 90 min process time, STFR 4 and 6% spices concentration. The overall statistical analysis from Table 3 revealed that the time followed by salt concentration had significant (p<0.05) effect on overall acceptability. It is clear from Table 4 that time (p<0.01) followed by salt concentration significantly (p< 0.05) affected the overall acceptability of the product. Overall acceptability of the product is a major parameter which needs to be studied for food products. Multiple regression model of OAA developed for aonla pieces with spices during OD process depends on all the parameters taken for this study such as solid gain, brix, weight loss, vitamin C loss, titrable acidity, total phenol content, total carbohydrate content and protein content.

![Effect of salt concentration and time on overall acceptability at STFR 4 and spices concentration 6%; (salt conc: salt concentration)](Figure 5)

3.3. Optimization of the process parameters

Graphical multi-response optimization technique was adopted to determine the workable optimum conditions for the osmotic dehydration of aonla pieces. The main criteria for constraints optimization were maximum possible water loss as well as overall acceptability and solute gain [21 & 31 34], minimum acidity [35] and minimum vitamin-C loss [36]. In order to optimize the process conditions for osmotic dehydration process by numerical optimization technique, equal importance of ‘3’ was given to all the four process parameters (salt concentration, time, solution to fruit ratio and spices concentration) and responses (i.e. water loss, solute gain, vitamin-C loss, acidity and overall acceptability).

![Design-Expert® Software](Diagram 1)
**Table 2.** Experimental data for the four-factor three level response surface analysis

| Coded Process | Un-Coded Process | Responses |
|---------------|------------------|-----------|
| X1 | X2 | X3 | X4 | C (%) | t (min) | STFR | SC (%) | WL (Y1) | SG (Y2) | VCL (Y3) | A (Y4) | OA (Y5) |
| -1 | -1 | 0 | 0 | 4 | 60 | 4 | 6 | 5.61 | 0.48 | 10.02 | 2.13 | 6.94 |
| 1 | -1 | 0 | 0 | 12 | 60 | 4 | 6 | 7.62 | 1.72 | 12.93 | 2.02 | 7.96 |
| -1 | 1 | 0 | 0 | 4 | 90 | 4 | 6 | 6.32 | 0.61 | 11.42 | 2.11 | 7.97 |
| 1 | 1 | 0 | 0 | 12 | 90 | 4 | 6 | 11.21 | 4.67 | 15.12 | 1.03 | 8.84 |
| 0 | 0 | -1 | -1 | 8 | 75 | 3 | 3 | 6.08 | 0.97 | 13.45 | 1.33 | 8.45 |
| 0 | 0 | 1 | -1 | 8 | 75 | 5 | 3 | 7.59 | 1.16 | 13.68 | 1.34 | 8.83 |
| 0 | 0 | -1 | 1 | 8 | 75 | 3 | 9 | 8.86 | 1.21 | 14.06 | 1.32 | 8.45 |
| 0 | 0 | 1 | 1 | 8 | 75 | 5 | 9 | 8.04 | 1.43 | 14.33 | 1.34 | 8.83 |
| -1 | 0 | 0 | -3 | 4 | 75 | 4 | 3 | 5.81 | 0.57 | 12.45 | 2.07 | 8.5 |
| 1 | 0 | 0 | -3 | 12 | 75 | 4 | 3 | 9.51 | 1.93 | 13.16 | 1.06 | 8.68 |
| -1 | 0 | 0 | 1 | 4 | 75 | 4 | 9 | 6.01 | 0.69 | 14.16 | 2.09 | 8.62 |
| 1 | 0 | 0 | 1 | 12 | 75 | 4 | 9 | 12.14 | 3.11 | 13.67 | 1.02 | 8.72 |
| 0 | -1 | -1 | 0 | 8 | 60 | 3 | 6 | 8.17 | 1.35 | 15.78 | 1.36 | 7.81 |
| 0 | 1 | -1 | 0 | 8 | 90 | 3 | 6 | 8.65 | 1.22 | 21.43 | 1.31 | 8.23 |
| 0 | -1 | 1 | 0 | 8 | 60 | 5 | 6 | 8.92 | 1.18 | 19.33 | 1.34 | 7.89 |
| 0 | 1 | 1 | 0 | 8 | 90 | 5 | 6 | 7.13 | 2.26 | 20.12 | 1.33 | 8.82 |
| -1 | 0 | -1 | 0 | 4 | 75 | 3 | 6 | 6.16 | 0.88 | 13.81 | 2.07 | 8.34 |
| 1 | 0 | -1 | 0 | 12 | 75 | 3 | 6 | 10.89 | 3.83 | 14.63 | 1.04 | 8.61 |
| -1 | 0 | 1 | 0 | 4 | 75 | 5 | 6 | 5.12 | 0.52 | 12.88 | 2.05 | 8.57 |
| 1 | 0 | 1 | 0 | 12 | 75 | 5 | 6 | 10.2 | 3.15 | 11.76 | 1.05 | 8.76 |
| 0 | -1 | 0 | -1 | 8 | 60 | 4 | 3 | 7.94 | 2.04 | 17.05 | 1.37 | 7.63 |
| 0 | 1 | 0 | -1 | 8 | 90 | 4 | 3 | 8.72 | 1.29 | 18.42 | 1.34 | 8.52 |
| 0 | -1 | 0 | 1 | 8 | 60 | 4 | 9 | 8.33 | 1.09 | 20.05 | 1.36 | 7.88 |
| 0 | 1 | 0 | 1 | 8 | 90 | 4 | 9 | 8.1 | 0.92 | 22.91 | 1.35 | 8.57 |
| 0 | -1 | 0 | 0 | 8 | 60 | 4 | 6 | 7.66 | 1.07 | 13.67 | 1.38 | 8.64 |
| 0 | 0 | 0 | 0 | 8 | 75 | 4 | 6 | 8.39 | 1.14 | 14.32 | 1.36 | 8.68 |
| 0 | 1 | 0 | 0 | 8 | 90 | 4 | 6 | 8.57 | 1.18 | 15.34 | 1.32 | 8.71 |

Note: X1, X2, X3, X4 are coded process variables; C=salt concentration (%); t=time (min); STFR=solution to fruit ratio; SC=spices concentration (%); WL=water loss (%); SG=solute gain (%); VCL=vitamin C loss (%); A=Acidity (%); OA=overall acceptability

**Table 3.** Analyses of variance for the overall effect of the process variables on the five responses

| Source                  | df | Water loss % | Solute gain% | Vitamin C loss % | Acidity % | Overall acceptability |
|-------------------------|----|--------------|--------------|------------------|-----------|-----------------------|
| Salt concentration      | 1  | 58.70***     | 17.91***     | 3.55             | 2.34***   | 0.58***               |
| Time                    | 1  | 1.41         | 0.744        | 18.13            | 0.098     | 1.72***               |
| STRF                    | 1  | 0.27         | 4.800E-003   | 0.094            | 3.333E-005| 0.27                 |
| Spices concentration    | 1  | 2.83         | 0.020        | 10.03            | 7.500E-005| 0.018                |

***=Significant at 1% level; **=Significant at 5% level
Table 4. Optimum values of process parameters and responses

| Parameter Process     | Target          | Experimental Range | Importance | Optimum value | Desirability |
|-----------------------|------------------|--------------------|------------|---------------|--------------|
| Salt conc. (%)        | is in range      | 4                  | 12         | 3             | 12           |
| Time (min)            | is in range      | 60                 | 90         | 3             | 84.15        |
| STFR                  | is in range      | 3                  | 5          | 3             | 4.30         |
| Spices conc. (%)      | is in range      | 3                  | 9          | 3             | 7.09         |
| Responses             |                  |                    |            |               |              |
| Water loss            | Maximize         | 5.12               | 12.14      | 3             | 11.11        |
| Solute gain           | Maximize         | 0.48               | 4.67       | 3             | 3.765        |
| Vitamin C loss        | Maximize         | 10.02              | 22.91      | 3             | 13.615       |
| Acidity               | minimize         | 1.02               | 2.13       | 3             | 1.01         |
| Overall acceptability | Maximize         | 6.94               | 8.84       | 3             | 8.89         |

The optimum operating condition for salt concentration, time, solution to fruit ratio and spices concentration was 12%, 84.15 min, 4.30 and 7.09 %, respectively. Corresponding to these values of process variables, the value of water loss is 11.11 g water/ 100g fresh fruit, solute gain 3.76 g/100g fresh fruit, vitamin-C loss 13.615 %, acidity 1.01 % and overall acceptability 8.89 % (Table 4). The overall desirability was 0.864. The conditions were experimentally verified with a deviation of +0.1%. The spices incorporated aonla pieces are produced at experimental conditions of 12% salt concentration, 84.15 min process duration, 4.30 STFR and 7.09 % spices concentration. The vitamin C, acidity, total sugars, tannin and total polyphenol content of aonla pieces after osmotic dehydration are 339.90 mg/100g, 1.16%, 2.76%, 0.22% and 0.19% respectively.

4. Conclusion
Response surface methodology was effective in optimizing process parameters for osmotic dehydration of aonla in osmotic solution of salt having concentration in the range of 4 to 12%, spices concentration 3 to 9%, solution to fruit ratio 3 to 5 and process time 60 to 90 minutes. The regression equations obtained in this study can be used for optimum conditions for desired responses within the range of conditions applied in this study. Graphical techniques, in connection with RSM, aided in locating optimum operating conditions, which were experimentally verified and proven to be adequately reproducible. Optimum solutions by numerical optimization obtained was 12% salt concentration, 84.15 min process duration, 4.30 v/w solution to fruit ratio spices concentration 7.09% to get maximum possible water loss, solute gain and overall acceptability gain minimum vitamin-C loss and acidity. The optimized aonla pieces contain 339.90 mg/100g of vitamin C, 1.16% acidity, 2.76% total sugars, 0.22% tannins and 0.19 % total polyphenols. Higher functional compounds retention was observed in the osmotically dehydrated aonla compare to other dried aonla samples.

Nomenclature

\[ x_i \] variable in actual units of the \( i^{th} \) observation
\[ \bar{x}_i \] the mean of the highest and lowest variable value of \( x_i \)
\[ d_i \] the difference between the highest and lowest value of \( x_i \)
\[ W_0 \] the initial weight of fruit taken for osmotic dehydration (g)
\[ W_t \] the weight of fruit after osmotic dehydration at any time \( t \) (g)
S0 the initial dry matter of fruit (g)
St the dry matter of fruit after osmotic dehydration and FF is the fresh fruit (g)
C Salt concentration (%)
T time (min)
STFR solution to fruit ratio
SC Spices concentration (%)
WL Water loss (%)
SG Solute gain (%)
VCL Vitamin C loss (%)
A Acidity (%)
OA overall acceptability
xi variable in actual units of the ith observation
x̄ the mean of the highest and lowest variable value of xi
di the difference between the highest and lowest value of xi
W0 the initial weight of fruit taken for osmotic dehydration (g)
Wt the weight of fruit after osmotic dehydration at any time t (g)
S0 the initial dry matter of fruit (g)

References
[1] Rajkumar N V, Theresa and Kuttan M 2001 Pharmaceutical Biology 39 375-380
[2] Bhattacharya A, Chatterjee A, Ghosal S and Bhattacharya S K 1999 Indian Journal of Experimental Biology 37 676–680
[3] Kumar S and Nath V 1993 Journal of Food Science and Technology 30 202-203
[4] Kalra C L 1988 A resume Indian Food Packer July-August p 67-82
[5] Azoubel P M and Murr F E X 2004 Journal of Food Engineering 61 291-295
[6] Krokida M K and Marinos D 2003 Journal of Food Engineering 57 1-7
[7] Nicola S I Pietro L C and Felice 2005 Journal of Agricultural Food Chemistry 53 57-61
[8] Zhang G F, Yang Z B, Wang Y, Yang W R, Jiang S Z and Gai G S 2009 Poultry Science 88 2159-2166
[9] Orhan G, Hapci G and Orgul K 2011 International Journal of Electrochemical Science 6 3966 – 3981
[10] Mudahar G S, Toledo R T, Floros J D and Jen J J 1989 Journal of Food Science 54 714-719
[11] Floros J D and Chinnan M 1987 Transactions of American Society of Agricultural Engineers 30 560-565
[12] Madamba P S and Lopez R I 2002 Drying Technology 20 1227- 1242
[13] Kadijani J A, Narimani E and Kadijani H A 2015 Korean J. Chem. Eng. 33 1286–1295
[14] Mudahar G S, Toledo R T, Floros J D and Jen. J J 1989 Journal of Food Science 54 714-719
[15] Floros J D and Chinnan M 1987 Transactions of American Society of Agricultural Engineers 30 560-565
[16] Madamba P S and Lopez R I 2002 Drying Technology 20 1227- 1242
[17] Ramos A Q, Bourne M C, Barnard J and Morales A A 1998 Journal of Food Science 63 519-522
[18] Dhingra D and Shashi P 2005 Journal of Food Science and Technology 42 348-352
[19] Manivannan P and Rajasimman 2009 International Journal of Food Engineering 5 1-22.
[20] Rastogi N K and Raghavaran K S M S 1995 Journal of Food Process Engineering 18 187-193.
[21] Shafi A M Q, Amarjit S and Sawhney B K 2010 Journal of Food Sciences and Technology 47 47-54
[22] Said K A M and Amin M A M 2015 Journal of Applied Science and Process Engineering 2 2289 – 7771.
[23] Box G E and Behnken D W 1960 *Technometric* 2 455-475.
[24] Verma R C and Gupta A 1996 *Agricultural Engineering Journal* 51 63–69.
[25] Biswal R N and Bozorgmehr K 1992 *Transactions of American Society of Agricultural Engineers* 35 257-262
[26] Lazarides H N, Katsanidis E and Nickolaides 1995 *Journal of Food Engineering* 35 151-166
[27] A.O. A. C. 2000 Official Methods of Analysis (984.25). 17th Edn. (Association of Official Analytical Chemistry. Maryland) p 14
[28] Ranganna S 1997 Handbook of analysis and quality control for fruit and vegetable products. 2nd edition (Tata Mc Graw- Hill Publishing Company Ltd)
[29] Cox G M and Cochran W G 1964 Experimental designs (New York: John Wiley and Sons, Inc)
[30] Montgomery D C 2004 Designs and analysis of experiments (New York: John Wiley and Sons)
[31] Tripathi V K, Singh M B and Singh S 1988 *Indian Food Packer* 42 60–66.
[32] Abraham P A G, Nagamaniammai G and Ramasamy K 2010 *African Journal of Food Science* 4 744 – 747
[33] Zhang X, Zhou J, Fu W, Li Z, Zhong J, Yang J, Xiao L and Tan H 2010 Electronic Journal of Biotechnology 13
[34] Alam M S, Sharma S R and Nidhi 2002 Studies on drying of aonla (Phyllanthus Emblica). In Paper presented in (XXXVI annual convention of ISAE, IIT Kharagpur) doi: January 28–30.
[35] Bhagya S, Shedamec M and Patil N B 2009 *International Journal of Agricultural Engineering* 2 18-23
[36] Ade Omowaye B I O, Rastogi N K, Angersbach A and Knorr D 2002 *Journal of Food Science* 67 1790-1796.