Optimisation of process parameters for vacuum concentration and foaming behaviour of *Aloe vera* (*Aloe barbadensis* Miller) gel

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Abstract: This study on *Aloe vera* gel was conducted to investigate the optimum condition for vacuum concentration in relation to its physicochemical properties and optimum foaming condition of the concentrated products which was used as raw material of foam mat drying in order to maximize the retention of valuable components. Twenty experiments were conducted with different combinations of concentration temperature and time using factorial design for numerical optimisation of the independent variables. Solutions obtained for numerical optimisation of vacuum concentration covering the criteria as temperature 55°C and time 60 min were- ascorbic acid 4.095 mg/100 g, total soluble solids 3.6 °Bx, total solids 3.7%, acidity 0.0698% (as malic acid) and pH 4.97. For optimising the foaming behavior of concentrated Aloe vera gel, 16 experiments were conducted using different selected additives and their proportionate mixtures [*viz.* pectin, glycerol monosterate and methyl cellulose (1:1), egg albumin and methyl cellulose (1:1), pectin and methyl cellulose (1:1)] in the concentration range of 0.25 to 1% (w/w). The optimum foaming conditions were obtained numerically in relation to foaming density (0.39 g cm^{-3}), drainage volume (0.15 mL) and expansion volume (122.53%) covering the criteria as pectin and methyl cellulose (1:1) with concentration of 1% (w/w). The experimental values during validation of responses were found at par with the numerical solutions (p<0.001) and it showed that the valuable components of fresh Aloe vera gel can be preserved optimally before foam mat drying by concentrating up to 3.8 °Bx under vacuum and converting the same into stable foam which exhibited foaming density of 0.42 g cm^{-3}, drainage volume of 0.00 mL and expansion volume of 123.21%.

Keywords: optimisation, *Aloe vera* gel, vacuum concentration, temperature, time, foam expansion, foam stability

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1 Introduction

Aloe vera (*Aloe barbadensis* Miller) is widely used and popular medicinal plant belongs to the *Liliacea* family. The fresh aloe vera gel is a transparent mucilaginous material which is found in thick walled parenchyma cells of the leaves. It does not possess any specific colour, odour but it contains several natural beneficial substances (Ramachandra and Rao, 2008; Chandegara and Varshney, 2013). Aloe vera is widely used in food industry as functional component for foods like health drinks, aloe beverages and tablets (Eshun and He, 2004; Ramachandra and Rao, 2008; Ahlawat and Khatkar, 2011). Aloe vera has certain applications as flavouring agent and preservative in few food products (Christaki and Florou-Paneri, 2010).

Fresh Aloe vera gel is converted into various products like powder, flakes etc. by heating, concentration, drying and grinding (Ramachandra and Rao, 2008) to increase the stability as well as to use the products effectively in different applications. The freshly extracted gel is highly perishable and proper technologies with great care during processing are required to improve its stability and functionality (Swami Hulle et al., 2014; Chandegara and Varshney, 2013). Improper processing may cause permanent changes to the biologically active chemical constituents and affect their original structures. These may alter the proposed physiological and medicinal

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properties of those biologically active compounds (Eshun and He, 2004; Chang et al., 2006).

For producing powder or flakes from fresh Aloe vera gel several dehydration methods like-freeze drying (Waller et al., 1978; Ratti, 2001), spray drying (Krokida et al., 2011; Garcia-Cruz et al., 2013; Cervantes-Martínez et al., 2014), osmo-drying (Simal et al., 2000; Vega et al., 2007; Garcia-Segovia et al., 2009; Pisalkar et al., 2011) etc. have been reported earlier. Although spray drying and freeze drying techniques are known for producing excellent product with good rehydration properties and colour, but excessive production and installation costs restrict for use in large scale commercial applications (Ratti, 2001; Hsu et al., 2003; Asokapandian et al., 2015).

Foam mat drying has been identified as an important economical alternative to drum, vacuum, spray and freeze-drying for the production of food powders (Kadam et al., 2010; Asokapandian et al., 2015). This is one of the simple and effective method for drying of heat sensitive liquid foods (Morgan et al., 1961; Karim and Wai, 1999a; Kudra and Ratti, 2006; Kandasamy et al., 2014).

In foam mat drying liquid juice is concentrated firstly (if total solid concentration is not suitable for foam formation) and suitable foaming agents in appropriate proportions are incorporated into that. The mixture is then whipped using special type of mechanical device for stable foam formation. This is dried in the form of a mat or thin layer (Karim and Wai, 1999a; Ratti and Kudra, 2006). So, good quality foam and appropriate foaming process is extremely important for producing high quality dehydrated product by foam mat drying. The rate of drying also depends on gas-liquid interface created during foaming (Kudra and Ratti, 2006; Thirupathi et al., 2008). So, the addition of foaming agent in appropriate quantity is required to form good quality stable foam which ultimately helps to produce a good quality product (Rajkumar et al., 2007). The finished product is superior than the drum dried and spray dried product because of its honeycomb structure, better rehydration properties, controlled density and better retention of volatiles that would be lost during the drying of non-foamed materials (Morgan et al., 1961; Kudra and Ratti, 2006; Thirupathi et al., 2008).

Actually, foaming of fresh Aloe vera gel is difficult because it is mainly composed of water (98%-99%). Major portion (more than 60%) of its dry matter is composed of polysaccharides (McAnalley, 1993; Femenia et al., 1999, Garcia-Segovia et al., 2009). This low soluble solid content in the fresh Aloe vera gel sample has strong influence on the foaming behavior especially foam stability which can be improved by adding suitable amounts of foaming agent and stabilizer (Karim and Wai, 1999b). However, before foaming, the concentration of the gel is also important step to decrease the water content in gel. The behavior of foam prepared from concentrated Aloe vera gel is important for producing desired quality dried product. Freeze concentration, though an ideal method for concentrating fruit juices has major problems of loss of soluble solids of juice in the separated ice. Bioactive substances including polysaccharide and barbaloin are sensitive towards heat treatment and shows maximum stability at around 70℃ which may decease at either higher or lower temperatures (Chang et al., 2006). Hence, vacuum concentration was proposed in this study. It has been found in literature that, systematic study on vacuum concentration and foaming of fresh Aloe vera gel is nonexistent.

The aim of this study was to optimize the process variables for vacuum concentration of *Aloe vera* gel at different temperature-time combinations and to optimize foaming behaviour by studying the effect of different additives on foaming characteristics of *Aloe vera* gel for maximum foam expansion (FE) and stability.

2 Materials and methods

2.1 Sample preparation

Mature leaves of *Aloe barbadensis* Miller variety were collected from Indian Institute of Technology, Agriculture farm as required for the experiments. Efforts were made to maintain uniformity in leaves used in all experiments. The leaves were washed under running water. The *Aloe barbadensis* Miller leaves were processed by traditional hand filleted technique. In this method, the lower 1inch of the leaf base, 2-4 inch of the tapered leaf top along with the short sharp spines which were located along the leaf margins were removed by a

sharp stainless steel knife. Then the knife was introduced carefully into the mucilage layer to remove top and bottom rind (Choudhary et al., 2014). Along with the bottom rind some amount of attached mucilage was also discarded. Pulping of washed fillet and collection of mucilage were done for further processing. The fillet was then ground to a liquid and the gel was removed.

2.2 Concentration experiment

The extracted *Aloe vera* gel (0.9 °Bx) was subjected to concentration at different temperature (*viz.* 45°C, 50°C, 55°C and 60°C)and time (*viz.* 0, 15, 30, 45 and 60 min) combinations using a batch scale laboratory model (superfit) rotary vacuum evaporator (750 mL batch^{-1}). The vacuum was created inside by the rotary vacuum evaporator which was initially at 760 mm Hg abs. and increased up to 50 mm Hg abs. as time elapsed. The effect of concentration time and temperature on different physico-chemical properties of the juice was studied.

2.3 Optimisation for concentration

Since ascorbic acid (AA) is considered to be the most heat labile component in the products of plant origin (Labuza and Riboh, 1982; Johnson et al., 1995), its maximum retention in the concentrate was taken as criteria for optimisation of the concentration process variables. It was assumed that the process parameters retaining maximum AA will also preserve the other components maximally. Numerical optimisation was carried out for the two independent variables (*viz.* temperature and time) and five dependent variables [*viz.* AA fraction, total soluble solids (TSS), total solids (TS), acidity and pH] by using Design-Expert program 7.0 of the stat-Ease software. Constraints set for numerical solution of optimum concentration conditions are shown in Table 1 below.

Table 1 Constraints set for numerical solution of optimum concentration conditions

Process parameter/response	Constraints
AA, mg/100 g	Maximum
TSS, °Bx	Maximum
TS, %	Maximum
Acidity, %	In range
pH	In range

2.4 Foaming experiment

2.4.1 Continuous foaming device

The laboratory scale continuous foaming device, consisting of four main parts with mixing jar, motor, peristaltic pump and a compressor has been developed by modification of a kitchen grinder (Bag et. al., 2011). The continuous foaming device was made up with the principle of volume displacement method. The mixing jar consists of material inlet, material outlet and three air inlets. The air inlets were made with 3 copper valve pins. The material inlet was made with a copper tube having 10 mm outer diameter. The material outlet was made up with aluminum sheet (thickness 2 mm) and developed in such a way that the inside width 90 mm and height 17 mm and the outward length of 50 mm. All the inlets and outlets were fixed with synthetic adhesive (Araldite). The outlet was placed at such a position so that the gel must have sufficient residence time (2 min). A stainless steel whipping blade was used for agitating the material in the jar. A pre-calibrated rotameter was installed for monitoring compressed air flow rate, and a stroboscope (Strobotac, 1531AB, G R Co., Concord Massachusetts, USA) was used to measure the rotational speed of the whipping blade (Bag et. al., 2011).

2.4.2 Foaming trials

Measured quantity (400 mL) of concentrated *Aloe vera* gel samples of varied TSS content (°Bx) was taken into the vessel of the foaming device. A pre-determined quantity of foaming agent [*viz.* pectin, glycerol monostearate (GMS) and methyl cellulose (MC) (1:1), egg albumin (EA) and methyl cellulose (MC) (1:1), pectin and methyl cellulose (MC) (1:1)] dispersed in *Aloe vera* gel (suspension). Then the material was sucked at a constant flow rate (100 mL min^{-1}) into the whipping jar by a peristaltic pump. Compressed air was then allowed to pass through three sides of the vessel at a constant rate (10 L min^{-1}) and the whipping blade also rotating at a constant speed (3400 rpm). The air flow and the rotation of the whipping blade were stopped simultaneously after the desired time period. The foamed gel samples were gradually escaped out of the foaming device after a particular residence time (2 min) and analyzed. All the experiments were done at controlled room temperature which varied between 25℃-29℃. The foaming properties, viz., foam expansion (FE) and stability were determined

by measuring foam density (FD) and drainage volume (DV) respectively.

2.4.3 Optimisation for foaming

Numerical optimisation was carried out for the process parameters for foaming of *Aloe vera* gel concentrate to obtain the best result. The results of experimental data were confirmed by deriving numerical solution. Design-Expert program 7.0 of stat-Ease software was used to perform numerical operation and simultaneous optimisation of the multiple responses. Constraints set for numerical solution of optimum foaming conditions are shown in Table 2 below.

Table 2 Constraints set for numerical solution of optimum foaming conditions

Process parameter/response	Constraints
FD, g cm^{-3}	Minimum
DV, mL	Minimum
FE, %	Maximum

2.5 Quality parameters for analysis

2.5.1 FD

50 mL of the foam was weighed and filled in a graduated measuring cylinder (50 mL). Foam was transferred to cylinder without destroying the foam structure and avoided trapping of voids (Karim and Wai, 1999a). The experiments were performed in triplicate to minimize error for each batch of foam preparation and average values were noted.

2.5.2 DV

The method for foam drainage was earlier described by Sauter and Montoure (1972) and later on by Raju and Pal (2009). In the present experiment slight modification to that method has been done and used to measure foam DV for testing the foam stability. In this, the foam filled into a Buchner filter (80 mm) was placed on a 25 mL graduated cylinder. The liquid juice (mL) which separated from the foam as a result of drainage was collected in a measuring cylinder. The amount of juice collected in the cylinder after an hour time was recorded as DV (Bag et al., 2011).

2.5.3 FE

The percent FE was calculated from the height/depth of material in the vessel before and after whipping using following Equation (1).

$$PE(\%) = \frac{\text{Height of material after foaming} - \text{Initial height of the material}}{\text{Initial height of the material}} \times 100 \quad (1)$$

2.5.4 Moisture content

Vacuum oven drying method as described by Ranganna (1995) was used to determine the moisture content. Samples (3-5 g) in triplicate were dried to an apparent dryness in a vacuum oven at 70°C at vacuum level not exceeding 450 mm Hg abs. The loss of weight was expressed as percent wet basis (wb).

2.5.5 TS and TSS

TS content was calculated by subtracting the moisture content from 100. Contents of TSS in *Aloe vera* gel samples were determined by hand refractometer having range 0-32 °Bx.

2.5.6 Acidity

Acidity of *Aloe vera* gel was measured Ranganna (1995) and expressed in terms of malic acid. Known weight of the pulp was transferred to 50 mL conical flask for preparation of sample solution. Then the *Aloe vera* gel was filtered to remove the solid materials. 10 mL of this solution was taken; few drops of phenolphthalein indicator were added to it and titrated against 0.1 N NaOH solutions till the colour of end point of pale pink. Acidity was expressed as per cent malic acid using the following Equation (2).

$$\text{Acidity as anhydrous malic acid}(\%) = \frac{\text{Titre} \times \text{Normality of alkali} \times \text{Equivalent weight of acid} \times 100}{\text{Volume of filtrate taken for titration} \times \text{weight of sample} \times 1000} \quad (2)$$

In this equation, the equivalent weight of malic acid is 67.

2.5.7 AA

AA was determined by the 2, 6-dichlorophenol indophenols visual titration method (AOAC, 1984). Five to seven grams of juice was dissolved in 100 mL of 3% metaphosphoric acid. Known quantity of this solution was titrated with the standard dye solution and AA as mg/100 g of sample was calculated as Equation (3):

$$\text{AA (mg/100 g)} = \frac{\text{Titre value} \times \text{dye factor} \times \text{volume made up} \times 100}{\text{Aliquot of extract taken for titration} \times \text{weight or volume of sample}} \quad (3)$$

Dye factor is mg of AA per mL of dye. This was estimated by standardizing the dye before titration with standard AA solution (AOAC, 1984).

3 Results and discussions

3.1 Vacuum concentration of fresh *Aloe vera* gel

Fresh *Aloe vera* gel extracted by hand filleting technique was taken for vacuum concentration. The experiments for vacuum concentration were carried out at different temperature (*viz*. 45°C, 50°C, 55°C and 60°C) and time (*viz*. 0, 15, 30, 45 and 60 min) combinations.

3.1.1 Effect of process variables on physico-chemical properties during vacuum concentration

3.1.1.1 TSS

The effect of temperature and time on TSS content of *Aloe vera* gel juice during concentration has been shown below in Figure 1. The increase in TSS followed a linear relationship for greater part of the time except at the end of the cycle where its rate of increase was very low. At 45°C the gel juice could be concentrated up to 2.5 °Bx# only, whereas it was possible to concentrate up to 4.5 °Bx# at 60°C. The time required for achieving juice concentration of 2.5 °Bx at 45°C and 4.5 °Bx#at 60°C were one hour each. Beyond this period, the rate of increase in concentration was very small. Moreover, the material started sticking to the vessel surface and could not be agitated easily.

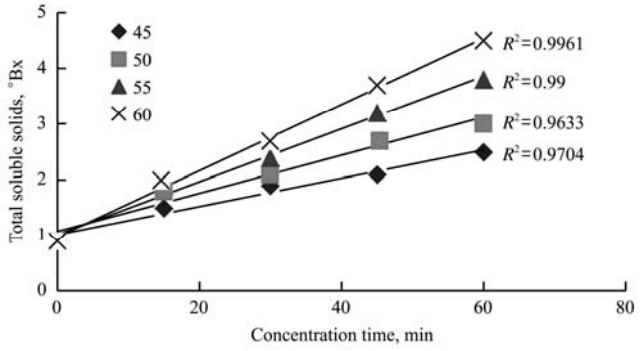

Figure 1 Effect of concentration temperature and time on TSS (°Bx) of *Aloe vera* gel

3.1.1.2 pH and acidity

The pH of *Aloe vera* gel juice concentrate ranged from 5.30 to 5.35. A slight decrease in pH was observed during the concentration process at all concentration temperatures. The acidity of the *Aloe vera* gel juice (0.0268% as malic acid, TS basis) increased slightly with concentration process.

3.1.1.3 AA

The effect of process time and temperature on retention of AA during concentration of *Aloe vera* gel juice is shown in Figure 2. Destruction of AA was influenced by both temperature and time of processing. The destruction rate of AA increased with increase in temperature. At 45°C and 50°C, it followed a linear relationship for greater part of the concentration cycle, while at 55°C and 60°C the relationship is nonlinear.

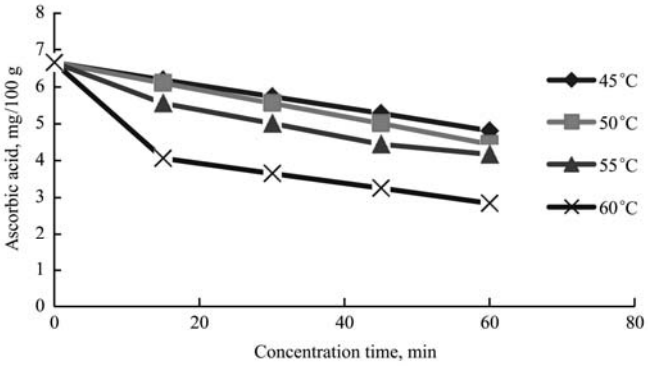

Figure 2 Effect of concentration temperature and time on AA fraction

3.1.2 Optimisation of process variables

Since AA is considered to be the most heat labile component in the products of plant origin (Labuza and Riboh, 1982; Johnson et al., 1995), its maximum retention in the concentrate was taken as criteria for optimisation of the concentration process variables. It was assumed that the process parameters retaining maximum AA will also preserve the other components maximally.

Design-Expert program 7.0 of the stat-Ease software was utilized and was used to perform numerical operation and simultaneous optimisation of the multiple responses. The desired goals for each variable and responses were chosen (Table 3) to get the different desirability function. Table 4 shows that software generated five optimum conditions of independent variables with predicted values of responses. Solution No.1, having the maximum desirability value was selected as the optimum conditions for concentration of *Aloe vera* gel juice. The solution was obtained for the optimum concentration condition covering the criteria as temperature 55°C and 60 min time of concentration, AA 4.095 mg/100 g, TSS 3.6 °Bx, TS 3.7%, acidity 0.0698% (as malic acid) and pH 4.97. The analysis of variance (ANOVA) data are presented below.

Three trails were conducted at optimum conditions to validate the responses and the experimental values at temperature 55°C and time 60 min for concentration were ascorbic acid 4.167 mg/100g , total soluble solids 3.8 °Bx, total solids 4.0%, acidity 0.0737% (as malic acid) and pH 4.96. The retention of ascorbic acid indicates that factorial model was appropriate.

Table 3 ANOVA data for the effect of process variables on all responses during concentration of *Aloe vera* gel juice

ANOVA Data	Source	Sum of squares	*df*	Mean square	*F* value	*p*-value Prob.> *F*	R^2
AA	Model	24.30	7	3.47	19.78	<0.0001***	0.920
	A-Temp	8.13	3	2.71	15.44	0.0002***	
	B-Time	16.17	4	4.04	23.03	<0.0001***	
	Residual	2.11	12	0.18			
	Cor. Total	26.40	19				
TSS	Model	18.37	7	2.62	20.25	<0.0001***	0.922
	A-Temp	2.69	3	0.90	6.92	0.0059**	
	B-Time	15.68	4	3.92	30.25	<0.0001***	
	Residual	1.56	12	0.13			
	Cor. Total	19.92	19				
Acidity	Model	0.00559	7	0.0008	39.91	<0.0001***	0.959
	A-Temp	0.00023	3	0.00008	3.87	0.0380*	
	B-Time	0.00536	4	0.00134	66.94	<0.0001***	
	Residual	0.00024	12	0.00002			
	Cor. Total	0.00583	19				
TS	Model	17.93	7	2.56	20.05	<0.0001***	0.921
	A-Temp	2.79	3	0.93	7.28	0.0049**	
	B-Time	15.14	4	3.79	29.63	<0.0001***	
	Residual	1.53	12	0.13			
	Cor. Total	19.47	19				
pH	Model	0.441	7	0.063	25.98	<0.0001***	0.938
	A-Temp	0.051	3	0.017	7.01	0.0056**	
	B-Time	0.390	4	0.098	40.21	<0.0001***	
	Residual	0.029	12	0.002			
	Cor. Total	0.470	19				

Notes: *** $p<0.001$; ** $p<0.01$; * $p<0.05$; ns=Not-significant.

Table 4 Numerical solutions for concentration of *Aloe vera* gel juice

Sl. No.	Temp, °C	Time, min	AA, mg/100 g	TSS, °Bx	Acidity,%	TS,%	pH	Desirability
1	55	60	4.095	3.6	0.0698	3.7	4.97	0.571
2	50	60	4.484	3.3	0.0733	3.4	4.93	0.571
3	55	45	4.521	3.1	0.0581	3.3	5.06	0.549
4	50	45	4.669	3.0	0.0693	3.1	4.96	0.537
5	45	60	4.910	2.8	0.0616	2.9	5.02	0.526

3.2 Foaming of *Aloe vera* gel concentrate

Investigations were carried out to check the performance of *Aloe vera* gel concentrate for foam production in the developed continuous foaming device, determination of optimum operating and machine parameters for maximum FE and to check the effect of foaming additives on foaming properties of *Aloe vera* gel concentrate.

3.2.1 Effect of additives on foaming properties of *Aloe vera* gel concentrate

Samples of *Aloe vera* gel concentrate were subjected to whipping. It was observed, during preliminary experiment, that whipping of *Aloe vera* gel without any foaming agent produce very little foam which collapsed completely within short time at room temperature. When whipped with foaming agent, an appreciable FE was obtained, which remained stable over a period of time. This necessitated the use of a suitable foaming agent and foaming stabiliser for the formation of stable foam.

3.2.2 Selection of suitable foaming agent

Different chemicals *viz.* GMS and MC (1:1), EA and MC (1:1) and pectin and MC (1:1) were evaluated as

foaming additives for *Aloe vera* gel concentrate. The effect of these additives and their concentration on FE and DV of *Aloe vera* gel concentrate (3.8 °Bx) are presented in Figure 3 and Figure 4 respectively. The FE depended on the type of foaming additives and its concentration in *Aloe vera* gel. From Figure 3, it can be observed that foam expansion increased with the increase in concentration of GMS and MC (1:1), EA and MC (1:1), pectin and MC (1:1) from concentration range 0.25% (w/w) to 1% (w/w).

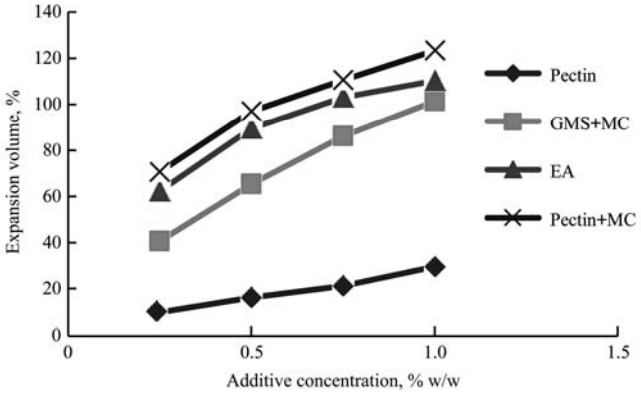

Figure 3 Effect of type of foaming additives and their concentration on FE or expansion volume of *Aloe vera* gel concentrate (3.8 °Bx)

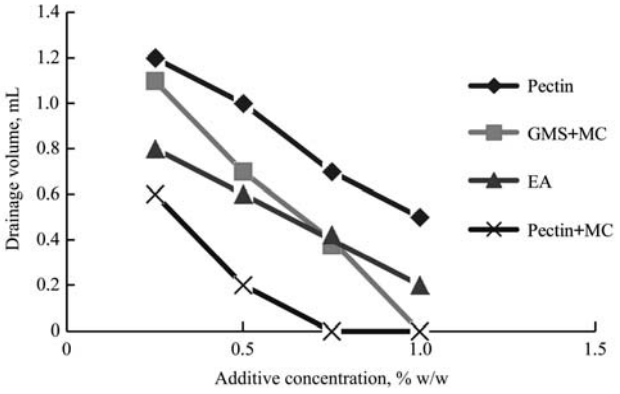

Figure 4 Effect of type of foaming additives and their concentration on DV of *Aloe vera* gel concentrate (3.8 °Bx)

DV reflects the water holding capacity of foam. It is one way to check the foam stability and measured by the volume of liquid juice drains from the foam over a specific time period (Kampf et al., 2003). The liquid in foams distributed between thin films and plateau borders. The difference is known as plateau border suction, leads to drainage of liquid from thin films to the neighboring plateau border. Finally, all liquid in the plateau border of foams are subjected to drain of the liquid from between the bubbles caused by the action of gravity (Narsimhan, 1991**)**. Drainage is accompanied by a progressive thinning of lamellae and may, therefore, enhance the probability of film collapse. The stable foam structure is desirable for rapid drying and ease of removing the dried material from the tray. If foams break or drain excessively, drying time is increased, reducing product quality (Bag et al., 2011). DV of the foam during the experiment varied from 0.0 mL to 1.2 mL. DV decreased with the increase in additive concentration irrespective of the type of chemical. Maximum DV obtained using pectin at concentration of 0.25% (w/w). While minimum DV was found using pectin and MC (1:1) at concentration of 0.75% (w/w) and 1% (w/w). DV decreased with the increase in additive concentration irrespective of the type of chemical (Figure 4).

FD is an important property for determining the whipping ability of a mixture. This is also related to amount of air incorporated during whipping process, because the higher the amount of air incorporated during whipping, the lower the FD will be and the foam will have higher whippability **(**Falade et al., 2003), which is desirable for good quality foam. FD in this experiment varied from 0.42 to 0.94 g cm^{-3}. Maximum FD obtained using pectin at concentration of 0.25% (w/w). While minimum FD was found using pectin and MC (1:1) at concentration of 0.25% (w/w). This indicates that the pectin and MC (1:1) helps to reduce the intermolecular tension on the surface and interfacial tension of the foam to a level which is sufficient to form the interfacial film that exceeds the critical thickness (Bag et al., 2011). Probably at lower concentration of pectin and MC (1:1) the air bubbles were collapsed because critical thickness required for interfacial film could not be formed (Karim and Wai, 1999b). The concentration of pectin and MC increased till a lowest value of FD is reached at 1% concentration of pectin and MC. At this concentration the FD was least. However, increasing the pectin and MC concentration beyond 1% (w/w), there was increase in FD. Because beyond that concentration viscosity increases, probably exceeds the limiting value (maximum air incorporation is possible at this viscosity) and it has negative influence in the incorporation of air during whipping or mechanical mixing (Bikerman, 1973). This

results in reduction of FE or increases FD. Similar findings have been noted from the study of foam density of star fruit (Karim and Wai, 1999a; 1999b). For the additive GMS and MC the FD decreases from 0.76 to 0.46 g cm^{-3}. But for pectin and MC, the FD decreases from 0.56 to 0.42 g cm^{-3}. The reasons can be explained as described for the mixture of pectin and MC (1:1). In Figure 5, there is decrease in foam density with increase in additive concentration.

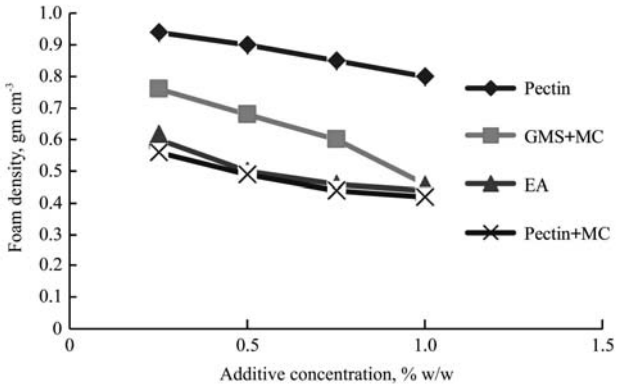

Figure 5 Effect of type of foaming additives and their concentration on Foam density of *Aloe vera* gel concentrate (3.8 °Bx)

3.2.3 Optimisation of foaming process variables

The selected factorial model was used for the statistical significance of the experimental design and desirability functions were used for optimum solutions. The desired goals for each variable and response were chosen (Table 5) to get the different desirability function. Table 6 shows that software generated five optimum conditions of independent variables with predicted values of responses. The ANOVA data are presented in the Table 5. In analysis of variance the model F-values (49.56, 57.04 and 26.38 for FE, FD and DV respectively) showed that all the models are highly significant ($p<$ 0.001) for all the responses. There exists a 0.01% chance that a "Model F-Value" this large could occur due to noise (Asokapandian et al., 2015). The co-efficient of determination (R^2) values for the responses of FE, FD and DV were 0.971, 0.974 and 0.946 indicating high proportion of variability was explained by the data and models of factorial design were adequate. It means that the values of FE, FD and DV were significant as a response for varying foaming conditions. From the above data, it can be interpreted that the selected models can help us to optimise the conditions for foaming with significant relationship among the parameters chosen. The overall desirability value covering the optimum conditions was 0.998. At this condition, the solution which had the highest concentration *i.e*. 1% (w/w) to get lowest FD, DV, and highest FE values were selected. The solution for optimum foaming condition covered the criteria as pectin and MC concentration (1:1) 1% (w/w). The predicted (theoretical) values were for FD 0.39 g cm^{-3}, DV 0.15 mL and expansion volume 122.53% respectively. The observed values (mean of three measurements) at these optimum conditions for FD, DV and expansion volume were 0.42 g cm^{-3}, 0.00 mL and 123.21% respectively. This indicates the suitability of the factorial model for foaming of Aloe vera gel.

Table 5 ANOVA data for effect of process variables on all responses during foaming of *Aloe vera* gel concentrate

ANOVA Data	Source	Sum of squares	*Df*	Mean square	*F* value	*p*-value Prob > *F*	R^2
FD	Model	0.469	6	0.078	57.04	<0.0001***	0.974
	A-Add type	0.394	3	0.131	95.88	<0.0001***	
	B-Add conc.	0.075	3	0.025	18.19	0.0004***	
	Residual	0.012	9	0.001			
	Cor. Total	0.481	15				
DV	Model	2.11	6	0.352	26.38	<0.0001***	0.946
	A-Add type	0.85	3	0.283	21.25	0.0002***	
	B-Add conc.	1.26	3	0.420	31.50	<0.0001***	
	Residual	0.12	9	0.013			
	Cor. Total	2.23	15				
Expansion volume or FE	Model	20387.8	6	3397.9	49.56	<0.0001***	0.971
	A-Add type	15827.7	3	5275.9	76.95	<0.0001***	
	B-Add conc.	4560.10	3	1520.0	22.17	0.0002***	
	Residual	617.04	9	68.56			
	Cor. Total	21004.9	15				

Notes: *** $p<0.001$; ** $p<0.01$; * $p<0.05$; ns=not-significant.

Table 6 Numerical solutions for foaming of *Aloe vera* gel concentrate

Sl. No.	Additive type	Additive conc., %	FD, g cm^{-3}	DV, mL	Expansion volume or FE, %	Desirability
1	Pectin+MC	1	0.39	0.15	122.53	0.998
2	Pectin+MC	0.75	0.41	0.15	113.52	0.928
3	EA+MC	1	0.45	0.05	106.46	0.919
4	EA+MC	0.75	0.47	0.35	97.44	0.792
5	Pectin+MC	0.5	0.51	0.3	95.15	0.779

4 Conclusions

The study indicated that the extracted *Aloe vera* gel (0.9 °Bx) was vacuum concentrated to 3.8 °Bx and successfully converted into stable foam (123.21% expansion volume and 0.00 mL DV) using numerically optimized parameters in relation to several quality attributes using pectin and MC (1:1) as foaming agent (1%, w/w). So, the optimized numerical solutions for vacuum concentration and stable foam formation can be used to produce good quality *Aloe vera* gel powder by foam mat drying.

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