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Original Research Article

Influence of Spray Drying Technology on the Physical and Nutritional Properties of Guava Powder

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A B S T R A C T

Uniform and repeatable product characteristics are critical in the performance and acceptance of consumer products, and the spray drying process can have a major influence on achieving these characteristics. A study was conducted to produce spray-dried guava powders using three different maltodextrin concentrations (7%, 9.5% and 12%) as the encapsulating agent and three different inlet temperatures (170°C, 180°C and 185°C). The spray-dried guava powders were analyzed for moisture content, dissolution. Results demonstrated that as inlet temperature increased, the moisture content and dissolution decreased. However, there were no significant changes in the water activities of the spray-dried powders for all the inlet temperatures investigated. In this study, the effects of some processing parameters on moisture content, drying yield, bulk density, solubility, of spray dried guava powders were investigated. Inlet air temperature negatively influenced the bulk density due to the increase of powder's porosity. The lower the bulk density, the higher the solubility of powder. With regard to morphology, powders produced with maltodextrin presented the smallest size. The experiment was conducted according to Response Surface Methodology. Higher inlet temperatures favored the desired physical properties of the powders, decreasing their moisture contents and hygroscopicity, and increasing flowability. The drying aids decreased the powder hygroscopicity. The best processing conditions to obtain a free-flowing and least hygroscopic guava powder by spray drying were: inlet temperature above 185°C. From nutritional point of view, guava powder was found rich in protein, fat, ash, fiber. The physical properties studied were: apparent and true density, color (a, b and L parameters), moisture content and solubility. The results showed that the linear model used describing the relation of the independent variables was significant for thetrue density. Nevertheless, the regression for the other responses was not significant, suggesting the need for a quadratic model to consider the interactions with the independent variables.

Keywords

Physical and Nutritional Properties, Guava Powder

Introduction

Among the agricultural processing technologies, drying has a great importance as a post-harvest food preservation technology. Drying is the most ancient and most common type of food preservation. (Perkins and Collins, 2004) Drying of agricultural products helps in reduction of moisture content, weight, and volume and minimizes packaging, storage, and transportation costs. (Edwards et al. 2003; USDA, 2006) Foaming of liquid and semi-liquid materials has long been recognized as one of the methods to shorten drying time.

Spray drying is a highly appropriate process for heat sensitive products such as foods, and has been success- fully employed with many items (coffee, milk, egg, amongst others) (Bhandari et al. 1993; Masters, 1979). The addition of additives such as maltodextrin is necessary to apply this technique to juices, adding amounts not exceeding the operational limits of the equipment (it could increase the viscosity and negatively affect performance) or altering the flavor. Currently maltodextrin is the most widely used additive to obtain fruit juice powders, since it satisfies the demands and is reasonably cheap (Bhandari et al. 1997; Bhandari et al., 1993; Dib Taxi et al. 2000; Figueiredo, 1998; Ribeiro, 1999).

The physical properties of the juice related to ease of reconstitution, include moisture content, apparent density, true density and respective particle porosity, the instantanisation properties (penetration, wetting, disperibility, and solubility), particle size and distribution. These properties are influenced by the nature of the feed (solids content, viscosity and temperature), type of spray dryer, operational speed and pressure and air inlet and outlet temperatures (Hall & Iglesias, 1997; King et al. 1984; Nath & Satpathy, 1998). Previous studies by Borges et al. (2002) with powdered passion fruit and pineapple juices showed that in a mini spray dryer, operating with aspersion nozzles, an increase in maltodextrin concentration increased the apparent density of the products, and the outlet temperature had a variable effect on this property. The effect of the interaction of these variables and the individual effects of each were not significant with respect to true density or the other properties related to the reconstitution of the powder. Increases in the atomization speed resulted in a reduction in particle size and air incorporation in the feed, resulting in porous products of low apparent density (Pisecky, 1978), making rehydration more difficult (Maia & Golgher, 1983). During spray drying, this property can be affected by the air conditions (temperature and flow rate), feed conditions (enzyme inactivation, additives and feed rate), and atomization speed, amongst other factors (Cai & Corke, 2000; Desobry et al. 1997; Masters, 1979).

Little recent information can be found in the literature with respect to the influence of the concentration of a specific additive and the atomization speed, on the color. In 1974, Kalil and Sial studied the effect of these aspects with respect to the spray drying of mango juice, and showed that the atomization speed (40,000–500,000 rpm) had little effect on the color, although an increase in the concentration of the additives (sodium alginate and glycerin monostearate) had a negative effect on product color. According to Desobry et al. (1997), conditions favoring a high surface/volume ratio or a larger number of smaller particles tend to favor pigment oxidation. In the case of spray drying, these conditions are favored by high temperatures and atomization speeds (Masters, 1979).

Due to a lack of studies on the influence of the process variables on the physical properties of guava powder, the objective of this research was to verify the effects of maltodextrin concentration on such properties in guava powder.

Materials and Methods

Spray drying of guava slurry was carried out at the Centre of Food Sceince and Technology, Institute of Agricultural Sciences, Banaras Hindu University, (India).

Powder Physical Properties

Considering that in a very simplistic sense powder flow dynamics of non-cohesive is affected by powder properties as represented by the relationship:

Flow dynamics = f (particle density particle size particle shape, bulk density composition).

Some physical and chemical properties of the powders were measured to provide an understanding of the effect of their variation on powder delivery through a feeder system. Property measurements were made in triplicate except for the bulk densities, which were measured from eight independent samples Fig 1.

Moisture and Fat Content

Moisture and fat are chemical components of powders and granular materials that can cause cohesion between powder particles and are therefore related to flow behavior. Both these powder compositional components were determined using AOAC standard methods (Cai & Corke, 2000). Moisture content was determined by drying under vacuum for 4 hr at 102°C. Fat content was determined by first placing a 1g sample in an Erlenmeyer flask and adding1 mL of sulfuric acid and 4 mL of water. The contents were then mixed gently. After 60 min the contents of the flask were transferred to a 60 mL separatory funnel using 25 mL of dichloromethane methanol solution (1:1). After another 15 min., the bottom layer, which contains the lipid, was drained into a weighing pan and the solvent evaporated. The amount of fat was then calculated as a percent of the original sample weight.

Density Determination

Both loose and tap bulk density of the test materials were determined. The loose bulk density of all test materials was determined by dividing the weight of powder delivered freely by gravity into a 200-mL stainless steel cylinder by its volume. (Desobry et al, 1997) Tap bulk densities were calculated from the weight of powder contained in the cylinder after being hand tapped 100 times at roughly 60 taps per minute. The foregoing test cylinder had a removable extension that was carefully removed after the tapping, leaving a 100-mL volume for tap density calculation. In both cases excess powder was scraped from the top of the fixed volume container by sliding a wooden straight edge in a zigzag fashion across the container rim so that the material surface was flush with the container rim. Care was taken so as not to disturb or compact the settled powder. All bulk density measurements were made in triplicate. Compaction of the powders was described by the "Hausner ratio," the ratio of the tap bulk density to the loose bulk density. The Hausner ratio is frequently used as a relative flowability index. Apparent particle density was determined with an air pycnometer (Model VM-100, Horiba Inc., Irvine, Calif., USA). Apparent particle density, simply referred to, as particle density in this report, is the mass of a particle divided by its volume, excluding only the open pores.

Angle of Repose

Angle of repose was measured by the

pouring method. (Adhikari et al. 2004) Fayed and Otten (Goula et al. 2004) defined angle of repose in general as "the angle formed between the horizontal plane and a slope line extending along the face of a heap formed by pouring material onto a horizontal surface." Powder was allowed to flow through a conical funnel having a spout diameter of 20 mm. The angle of repose was calculated from the base angle formed by the heap powder. (Nollet, 200) According to Wouters and Geldart, (Abadio et al. 2004) the angle of repose can provide the process engineer quickly with valuable information. Therefore, since the tests can be performed in the plant, the angle of repose is taken as a predictor of possible flow difficulties later in industrial applications. Barbosa-Canovas et al. also forwarded that the angle of repose can be used as a rough flowability indicator. In fact, they noted that it is the actual measurement applied by food industry quality control in order to evaluate flowability.

Tap density: After observing the initial volume, the cylinder was mechanically tapped, and volume was recorded until reached to constant volume. The tap density is calculated by the following formula

$$Tap\ density = \frac{Mass\ of\ powder}{Final\ tapped\ volume}$$

Hausner ratio and Carr index:

Hausner ratio is a number that is correlated to the flowability of a powder or granular material (Hausner, 1967). It is calculated by the formula below:

$$Hausner\ ratio\ (HR) = \frac{\rho T}{\rho B}$$

where, ρ T =the tapped density, ρ B =the bulk density. Difference range for HR in defining the flowability is as below (Tsai et al. 2007).

(i) 1.0<HR<1.1, free flowing powder; (ii) 1.1<HR< 1.25, medium flowing powder; (iii) 1.25<HR<1.4, difficult flowing powder; and (iv) HR>1.4, very difficult flowing powder.

Carr index represents the compressibility of a powder (Pereira et al, 2008). It is calculated by the following formula:

$$Carr\ index\ (CI) = 100 \times \frac{\rho T - \rho B}{\rho T}$$

where, ρ T =the tapped density; ρ B =the bulk density. According to Carr (Carr 1965), an excellent flowability can be expected if the CI is within 5 to 15%. If value of CI is above 25%, it generally indicates as poor flowability.

Chemical Properties Determination

Total sugar

Estimation of total sugars was done using a phenol sulphuric acid method. (Adhikari et al. 2003). A reconstituted sample was appropriately diluted from which 0.1 ml was further diluted to 1 mlwith distilled water. To this, 0.5 ml of 5% phenol was added followed by the addition of 5 ml of H_2 SO_4 after 10 min. Test tubes were incubated at 37°C for 30 min and absorbance was read at 490 nm against reagent blank on an UV visible spectrophotometer (Elico SL-164, Elico Ltd., Hyderabad, Andhra Pradesh, India). The percentage of total carbohydrates was worked out from the standard curve of glucose and calculated as:

$$Total\ sugar\ (\%) = \frac{Sugar\ value\ from\ the\ graph\ (\mu g) \times total\ volume\ of\ extract\ (ml)}{Aliquot\ of\ the\ sample\ used\ (ml) \times Volume\ of\ sample \times 1000}$$

Ascorbic Acid

Ascorbic acid of spray dried guava powder was estimated using a 2, 6 dichlorophenol-indophenol visual titration method. (Adhikari et al. 2003) An aliquot of the reconstituted sample was removed. After removing the powder, the outlined paper circle was cut and weighed. The radius was calculated and the angle of repose estimated.

$\tan \theta = h/(r - ½ a)$

Where,

θ = Angle of repose,

h = Height of stem base (2 mm),

r = Radius of the base of powder heap, and

a = diameter of funnel stem.

Solubility index: Fourteen grams of the powder was reconstituted in a 100 ml of distilled water. The sediment obtained from 50 ml by centrifugation of reconstituted product was measured and results expressed in milliliters.

Wettability: A piece of satin-fabric measuring 10 x 10 cm was stretched over one end of the metallic can (open at both ends with 6.5 cm dia and 4.5 cm height) and fastened in position by a rubber band. Another one end can (5 cm dia and 7 cm height) was placed centrally on the cloth. The tray was filled with distilled water at 40 ± 1°C to a height of 2.5 cm. A triangle made out of 0.4 cm thick glass rod with sides measuring 8 cm long was placed in the dish and served to prevent close contact of the cloth with the bottom of the dish. With the two cans assembled, and cloth resting on outer can, 1 g of powder was transferred to the inner can and spread over the 6 cm circle of the cloth as evenly as possible with a soft sable hair brush. The inner can was then removed and the outer can lowered into the tray onto the glass triangle and held in place, until the water level in the can ceased to rise. A stopwatch was clicked as soon as the cloth touched the water and stopped when the powder got completely wet. The time taken for complete wetting of powder was recorded in seconds.

Sinkability: In this test, 3.5 ml of distilled water at 20°C was taken in the Spectrophotometer cuvette and 10 mg sample of powder was then dusted on the surface of water and the percentage transmittance was measured at 760 nm in a Spectrophotometer. The readings were recorded after 2, 4 and 6 min intervals. The mean of three replicate values was taken as the percentage transmittance.

Statistical Analysis

Physicochemical properties and nutritional properties evaluations were carried out to check the effect of treatments and safety of food quality in terms of fungal and bacterial loads. Data was analyzed using two-way ANOVA to get the best treatment.

Results and Discussion

Titratable Acidity

The titratable acidity of reconstituted dried powder ranges from 0.28 to 0.54% as compared to the fresh sample (0.40%). The concentration did not make any significant ($P < 0.05$) effect at 65°C on titratable acidity. However, at 75 and 85°C the concentrations were significant ($P < 0.01$). Control (0%) samples had the highest values of titratable acidity in the case of milk and egg white. Various researches with peanuts, (Stefanovich and Karel, 1982), apples, (Regier, 2005) and tomatoes (MacEvoy, 2005) reported similar results of titratable acidity decline.

pH

Guava samples pH was about 5.70 and the pH of spray dried guava powder ranged between 5.29 and 5.57. The pH showed an increasing trend with the increasing concentration levels of foaming agents (Table 1). The effect of different foaming agents as well as different concentration levels was highly significant ($P < 0.01$) at all temperatures (Table 1). A low pH range of the spray dried sample was significant from a safety point of view.

Sugar Content

Sugar content of guava powder was about 4%. Generally sugar content increased on increasing the percentage of foaming agents (Table 1). This increase in sugar content with increasing foaming agent concentration may be because the inherent content of foaming agents used to the total sugar content of the sample, and the sample with a higher concentration of foaming agent underwent heat treatment for less time and due to better foaming and foam stabilization they took less time for drying. However, overall there was a decrease in the sugar content, which could be attributed to the Maillard reaction. (Cai and Corke, 2000) From Table 1, it is clear that treatment of foaming agents showed a significant variation ($p < 0.01$) from each other. Mean comparison by LSD showed that foaming agent CMC at 1% was found to be best. (Desobry et al. 1997) reported a similar decline in sugar content during the preparation of dehydrated chips.

Ascorbic Acid

Ascorbic acid content guava powder was about 998 mg/100 mg. There was a linear trend in ascorbic acid content with respect to different foaming agents. At three different drying air temperatures, the foaming agents were significant ($p < 0.05$). LSD interaction between foaming agents and their concentration levels at different temperatures were non-significant except at 85◦C where milk at 3% was significant. Milk and egg white were found to be best at 65 and 75◦C, whereas milk and CMC were best at 85◦C. The decrease in ascorbic acid content of foam mat dried tomato powder could be due to its heat sensitive nature. Similar decline in ascorbic acid content was noticed in other studies with potato, (Desobry et al. 1997) pulses, (Adhikari et al, 2004), muskmelon, (Goula et al. 2004), cauliflower, (Nollet, 2000) and onion (Abadio et al 2004) following heat treatment.

Moisture content and water activity shows the moisture content of the guava powder that produced at different inlet temperatures and maltodextrin concentrations. The guava powder produced by spray drying obtained moisture content below 10%. This water content is sufficient to make food powder microbiologically safe. The moisture content powder of the in relation to different drying temperatures and maltodextrin concentrations showed no specific relation. At 12% maltodextrin in feed, moisture content decreased with increasing drying temperature. In the case of 9.5% maltodextrin in feed, being slightly decreased initially moisture content of powder was eventually increased with increasing temperature beyond 185 °C. According to Quek et al. (1997) at higher inlet temperature the rate of heat transfer to the particle is greater, which provides a great driving force for moisture evaporation. Finally the powders with reduced moisture content are formed. Therefore, results concerning inlet temperature effects at 7% maltodextrin concentration were consistent with this statement. Moisture content of spray-dried powder was also affected by the content of maltodextrin. Due to the increase of the total soluble solids with the increasing of maltodextrin concentration, moisture content of produced powder decreased (Abadio et al. 2004). It might be the reason of initial slight decreased of moisture content of powder containing 30%

maltodextrin. The moisture content of powder produced with 30% maltodextrin was increased gradually with increasing temperature from 185°C. Zaini showed that the excess addition of maltodextrin and spray dried at high inlet temperature would cause the powder become sticky and thus the moisture content increased. This would be the explanation of the increasing moisture content at inlet temperature of 170 to 185 °C with 7% maltodextrin in feed.

The water activity was slightly affected by both the inlet temperature and the maltodextrin addition. Powder produced with 12% maltodextrin possessed slightly lower water activity. According to the previous reports at higher total solids content, a rapid drying was occurred and powder with low water activity was produced (Porrarud and Pranee 2007). Guava powder produced by 185°C inlet temperature and 7% maltodextrin concentration possessed higher water activity which is unexpected. But it is noticeable that the replication of spray drying at this condition (9.5% maltodextrin concentration and 185 °C inlet temperature) resulted in a larger error bar. So spray drying at this condition possessed higher experimental error, which either from sample preparation or drying process or something else. However, the water activities of the powders produced in the current work was between 0.3 to 0.35. This range indicated that the powders were micro-biologically safe. Generally, food with water activity around 0.3 are stable both from microbiologically and chemically (Porrarud and Pranee 2007).

Nutrition

A well rich nutrient content of a natural colorant is the major advantages of using it over synthetic colorant. Guava fruit powder produced using 185 °C inlet temperature and 7% maltodextrin was analyzed for its proximate compositions (Table 4). As shown in Table 5, guava powder contained protein, fat, fiber, and ash. Among them, crude fiber content in the guava powder was the highest (55.31%). It is believed that natural colorant have many potential health benefits that are arose from antioxidant activity of polyphenol and color compounds (Wybraniec and Mizrahi 2002). Wu et al. (2006) reported that the antioxidant activity of dried red pitaya flesh measured by the DPPH method at IC 50 was 22.4±0.29. The low value of antioxidant in guava powder might be due to the presence of large amount of bulky materials in the powder-like maltodextrin. It is also noted that Wu et al. (2006) determined antioxidant of freeze dried extract of pitaya flesh and peels extracted by organic solvent. It is well-known that organic solvent gives relatively pure extract. Therefore, the concentration of antioxidant in freeze dried extract should much higher than that of spray dried whole fruit powder containing quite large amount of bulk materials. It is also not ignorable that the loss of antioxidant including betacyanins is relatively higher during spray drying than that of freeze drying.

Proximate analysis

Results of proximate analysis on spray dried powders are found in Table 5. All powders were dried to an acceptable level below 5 g water/100 g and no differences (p40.05) in moisture content existed between spray drying treatments. Starch content was higher in the spray dried samples containing maltodextrin (Table 2). The higher starch value in the maltodextrin samples can be attributed to the added maltodextrin, a starch hydrolysate (Woolfe, 1992). However, when guava are heated, the natural amylases become active and degrade the starch molecules into dextrins and sugars until the enzymes are inactivated.

Table.1 Physicochemical properties of the studied guava juice

Total soluble solids (◦Brix)	12.10
pH	05.79
Total Sugar (mg/mL) %	03.88
Fibres %	55.31
Moisture (%)	90.40
Vitamin C mg/g	998
Fat %	2%
Protein %	07.50%
Tirable acidity	00.40 %

Table.2 The experimental data for response surface analysis of the effect of processing conditions on the quality of guava powder

		Factor 1 A:	Factor 2 B:
Std	Run	Maltodextrin	Inlet Temp
1	1	7	170
9	2	9.5	177.5
13	3	9.5	177.5
7	4	9.5	166.89
2	5	12	170
12	6	9.5	177.5
5	7	5.96	177.5
11	8	9.5	177.5
4	9	12	185
8	10	9.5	188.11
10	11	9.5	177.5
6	12	13.03	177.5
3	13	7	185

Table.3 Shows the significant level of guava powder parameters

	Moisture %	Solubility %	Disperasibility %	Vitamin C mg/100g %
Model	0.0001	0.004	0.0001	0.0002
A-maltodextrin	0.9358	0.8185	0.773	0.8087
B-inlet temp	< 0.0001	0.0004	< 0.0001	< 0.0001
AB	-	0.4256	0.5948	0.8038
A^2	-	0.0521	0.0012	0.0002
B^2	-	0.037	0.008	0.4767
Lack of Fit	0.253	0.6462	0.4068	0.2899

p-value Prob > F

Fig.1 Process flow chart for development of Guava powder

Guava
⇩
Washing
⇩
Blanching
⇩
Cutting into small pieces using fruit mill
⇩
Pulping using hexacolidal fruit juice extractor
⇩
Pasteurization of guava slurry (75˚C, 30 min)
⇩
Addition of water and maltodextrins as drying aid
⇩
Blending (Maltodextrin)
⇩
Guava slurry
⇩
Spray drying (Inlet air temperature: 180 – 185˚C) (Outlet air temperature: 80-85˚C)
(Feed rate: 18-20 rpm) (Air pressure: 4 kg/cm^2)
⇩
Guava powder
⇩
Packing

Table.4 Physical properties of the spray-dried guava powder

Malto dextrin	inlet temperature (°C)	outlet temperature (°C)	Bulk density g/ml	Tap density g/ml	True density g/ml	Carr index (%)	Hausner's Ratio	Wettability (s)	sinkability min	solubility ml
7	170	75	0.78	0.93	1.24	41	1.723	31	23	1.23
9.5	180	75	0.76	0.91	1.18	44	1.734	34	25	1.35
12	185	80	0.75	0.88	1.13	46	1.8	36	28	1.48

Table.5 Proximate analysis of spray dried guava powder

Maltodextrin %	Inlet temperature (°C)	Outlet temperature (°C)	Moisture %	Vitamin C mg/100g	total sugar %	Ash %	Fat %	Protein %
7	170	75	2.82	996	14	1.5	1.7	4
9.5	180	75	3.42	856	13	3.2	1.9	3.4
12	185	80	3.91	813	11	3.3	2	3

Walter and Purcell (1976) reported a decrease in starch concentration and increase in maltose and dextrins in dehydrated sweetpotato flakes as the length of time the puree was exposed to enzyme activity prior to drying was increased. Truong, Biermann, and Marlett (1986) reported a 4–14% decrease in starch content when sweetpotatoes were cooked for 30 min. Arthur and McLemore (1955) reported starch values of 33–43 g/100 g raw roots which decreased to between 2 and 10 g/100 g (db) dehydrated flakes. Thus, the starch content was expected to be lower in spray dried powder pretreated with amylase for viscosity reduction. The amylase treatment does indeed have the lowest starch content, but this treatment does not significantly reduce the starch compared to the control powder. Total sugar content of the spray dried powders was similar to the values reported for dehydrated flakes (32–45 g/100 g db) (Arthur & McLemore, 1955). Each powder sample had a higher sugar content compared to the puree except for the maltodextrin sample where the total sugar content was diluted by the addition of maltodextrin.

The addition of maltodextrin increased the amount of guava solids in the powder samples which in turn lowered the fiber, protein, and ash content of the maltodextrin - added powders. The fiber content of the powder samples ranges from 53-57% and was lower, but not significantly different, than the fiber content of the puree except for the afore mentioned added maltodextrin differences. Protein values of the spray dried powders were also lower than that of the puree. The Maillard reaction is a complex set of reactions initiated by reaction of an amine group of a protein and a carbonyl group of a reducing sugar at elevated temperatures.

During these reactions, lysine becomes biologically unavailable and also may further degrade by participating in the Strecker degradation reaction (Damodaran, 1996). The lipid content of the powders was significantly lower than that of the puree. Similarly, greatly increasing the surface area through spray drying exposes more area in guava powders for oxidation and degradation to take place, thus reducing the lipid concentration.

Vitamin C and minerals

Vitamin C activity of the puree was significantly reduced by spray drying (Table 3). Again, addition of the maltodextrin increased the overall guava solids and thus the amount of vitamin C in those powders. Raw sweetpotatoes contain between 17 and 35 mg/100 g of vitamin C on a fresh weight basis (fwb) (Bradbury & Singh, 1986; Purcell et al., 1989; Woolfe, 1992).

However, these levels are significantly reduced by thermal processing. The vitamin C values for the spray dried powders and the puree in the current study are much lower than these previously reported values. In addition to thermal treatments, some oxidation and hydrolysis over storage time could account for these low values.

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