Application of soy protein isolate and cassava starch based film solutions as matrix for ionic encapsulation of carrot powders

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Abstract Research into characterization and storage stability of carrot powders encapsulated in soy protein isolate and cassava starch based film solutions via ionic gelation method was performed. Carotene a major antioxidant presents in carrot powders plays a beneficial role in preventing some health problems such as cancer, and cardiovascular/coronary heart diseases. Consequently, the carotene contains a hydrocarbon with an unsaturated double bond or its oxygen derivatives, which makes it unstable and sensitive to moisture, heat, oxygen, light, and acid. There is therefore the need for encapsulation of this nutritive and healthy component of carrot powders to extend its stability. Film solutions required for encapsulation of the carrot powders were prepared from soy protein isolate, cassava starch and their combinations, and were as well categorized into plasticized and non-plasticized using glycerol in combination with sorbitol as plasticizer. Ionic encapsulation was achieved using sodium alginate for gelation of carrot powder beads in 5% calcium chloride solution for curing. Distinction in gelation features of the film solutions as a result of blend compositions as well as the addition of plasticizers substantially influenced the quality criteria of encapsulated carrot powder beads such as encapsulation efficiency, encapsulation yield, moisture content, hygroscopicity, particle size, and also their sensory qualities. Their values varied between 70.93–82.59%, 70.35–75.35%, 9.88–13.04%, 40.00–49.00 g/100 g, and

2.18–2.64 mm respectively. 100% soy protein isolate based film solution performed much better than 100% cassava starch based film solutions in preventing degradation of carotene content of the encapsulated carrot powder beads. Plasticization of the membrane solutions caused greater carotene degradation. Combination of soy-protein isolate (50%) and cassava starch (50%) composite based film solutions gave the best protection for carotene degradation having shelf life of 106 days while plasticized cassava starch based was the least with the shelf life of 13 days which is closed to that of the control (carrot powders).

Keywords Ionic gelation · Encapsulation · Carrot powders · Membrane · Stability

Introduction

Carrot (*Daucuscarota* L) is one of the important nutritious root vegetables grown in the northern part of Nigeria (Ibidapo et al. 2017). It is usually orange, with a crisp texture and when turned into powders, its surface area and porosity significantly increase, and the product dispersivity, solubility and functionality noticeably strengthened, which makes it easily digested and absorbed in human bodies (Zhang and Xia 2006; Ma et al. 2008; Gong et al. 2006; Yuanjuan et al. 2015). Carrots have high nutritional and medical values. It is a rich source of carotenoids and other vitamins, like thiamine, riboflavin, vitamin B-complex and minerals (Yuanjuan et al. 2015). Carrot is also an excellent source of calcium pectate; an extraordinary pectin fiber that has the cholesterol lowering properties. Carotenoids content of carrot especially β -carotene a pro-vitamin (A) may be beneficial in preventing major health problems such as

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cancer, and cardiovascular/coronary heart diseases due to their antioxidant activity (Yeum and Russell 2002; Yogesh et al. 2015). Carotenoids are also effective in physiological roles such as cell-to-cell communication, immuno-modulatory effect, and UV skin protection (Yogesh et al. 2015).

Carotenoid contains a hydrocarbon with an unsaturated double bond or its oxygen derivatives, which makes it unstable and sensitive to moisture, heat, oxygen, light, and acid (Yuanjuan et al. 2015). Encapsulation of this healthy and nutritive compound could be the best way for its shelf life extension.

Encapsulation refers to a technology in which sensitive component of food (cores) are completely enveloped, covered and protected by a physical barrier (matrix) without any protrusion (Desai and Park 2005). Carotenoid content of carrot powders which have been characterized by rapid degradation would profit from the encapsulation procedure, since encapsulation slows down the degradation processes (Prüsse et al. 2008). Though, there are several methods for encapsulation process (fluidized bed, freeze drying, freeze cooling, lyophilization, coacervation, etc.), the choice for ionic gelation (extrusion) method in this research work is due to its simplicity, availability of technology involved and its better performance in shelf life extension. Gouin (2004) reported that ionic gelation method had the longest shelf life of the core compare to other methods of encapsulation due to its provision of an almost impermeable barrier against oxygen.

In ionic gelation technique, alginate is usually used as matrix for the encapsulation of the core. This method presents a major limitation such as loss of active ingredients (core) during bead preparation. The active ingredients losses are majorly favored by the presence of macrospores in the alginate matrix (Niken and Yhulia 2016). However, some researchers were able to solve this problem by mixing alginate with other polymers such as starch, chitosan, cellulose, pectin, protein, among others, and this had been reported to significantly improve encapsulation parameters of the beads (Chen and Xu 2007; Niken and Yhulia 2016). However, application of soy-protein isolate and cassava starch composite as matrix material in this manner had not been examined, especially for the encapsulation of carrot powders. Studies carried out by Kamaldeen et al. (2019) showed that soy protein isolate based films unlike cassava starch based films had poor water vapour barrier but had better mechanical properties than cassava starch based films. Kamaldeen et al. (2019) combined blends (soy-protein isolate and cassava starch) and plasticizers (glycerol and sorbitol) as a composite to develop films which were resulted into improved mechanical and barrier properties of the films. They thereafter recommended that solution of these composite films be used for encapsulation of food

micro nutrients. This was expected to significantly increase shelf life of the food micro nutrients.

There is a need to study environmental effect on shelf life of the food micro nutrients encapsulated in soy protein isolate and cassava starch based film solutions. Environmental factors such as temperature and humidity can promote undesirable chemical reactions and degrade the nutritive and healthy compounds of the food product during storage due to the low stability of these bioactive compounds (Camila et al. 2017). There is therefore the need to study shelf life of carotene content of the encapsulated carrot powders in storage. Studies on the shelf life of the products can be very time consuming and costly, and therefore, accelerated stability tests are often used (Corrigan et al. 2012). During these tests, the product is subjected to adverse storage conditions and one or more accelerating factors (such as temperature, relative humidity and water activity) higher than normal, so that the degradation is faster, resulting in a shorter shelf life. Thus, knowledge of kinetic and thermodynamic parameters will allow understanding the changes occurring during the storage (Kechinski et al. 2010). The aim of this research is to apply solution of the soy protein isolates and cassava starch based films for encapsulation of carrot powders and determine effect of the blend and plasticizer compositions on characterization and stability of the encapsulated carrot powders beads through ionic gelation method.

Materials and methods

Source of raw materials and equipment

Fresh sweet cassava tubers (TMS 30,470) and carrots (Red-orange chantenay) were procured from a local market “Yankaba” in Kano State Nigeria. Soy protein isolate powders (natural) containing 90% protein with light yellow appearance was purchased from puritan’s pride at shop online: www.puritan.com and delivered by Konga (Kano branch). Equipment used for the experiment includes: (1) UV/VIS spectrometer T-80 by PG Instruments LTD, Lut-terworth, United Kingdom (2) Digital weighing balance JA-2003 by Pharmao Industries Co. LTD Liaoning, China (3) Magnetic stirrer IC-0966 by Gallenkamp and Co. LTD England (4) Experimental dryer/Oven UL-50780184, by Memmert, Büchenbach, Germany (5) Heating incubator GHP-9052 by Remilab World, Mumbai, India.

Preparation of cassava starch

A wet extraction method as described by Ihekoronye and Ngoddy (1985) was used for cassava starch extraction. 3 kg of fresh cassava tuber was manually peeled, washed

with clean water and crushed to produce slurries. The slurries were mixed with distilled water and sieved through a mesh (0.45 mm); the fibrous materials were removed leaving the starch solution. Starch solution was left for 5 h until the settled starch gave a firm, dense deposit on the bottom and was substantially free of fine fibre. The starch was recovered by decantation/filtration and dried at 55 °C for 12 h, and milled into powder. Proximate compositions of the produced cassava starch include: moisture content (9.21%), protein (0.46%), fat (0.21%), ash (0.38%), fiber (0.18%) and carbohydrate (80.56%).

Preparation of carrot powder

Preparation of carrot powder was produced as prescribed by Ibadapo et al. (2017). Fresh carrots were trimmed, scraped washed and cut into Two mm rings. The carrot rings were blanched in a water bath at 60 °C for 15 min, in a solution of 2% calcium chloride, and 0.2% sodium meta bi-sulphate which is dissolved in distilled water. Immediately after blanching, the carrot rings were soaked in distilled water, which contained ice cubes (0 °C for 15 min) to stop further cooking. The blanched carrot rings were dried at 60 °C for 18 h using vacuum oven. The dried carrot rings were cooled and ground using blender, then the milled carrots were sieved through 75 µm sieve to obtain finer powders. Chemical properties of the produced carrot powders include: moisture content (8.81%), protein (6.28%), fat (2.14%), ash (4.02%), crude fiber (78.75%) and carotene content (5093.33 µg/100 g).

Encapsulation of carrot powders

Encapsulation of carrot powders was prepared by ionic gelation method as described by Donthidi et al. (2010) with slight modification. Blend solutions were prepared by addition of 3 g of each blend compositions into 200 ml of distilled water separately making it 1.5% (w/v) of the water. The blend solution is divided into plasticized and non-plasticized. 0.6 ml of each plasticizer composition was added to the plasticized blend solutions. These solutions were then heated to gel and cool to 30 °C to form the membrane coatings. 12 g of carrot powders was added to the membrane coatings and mixed homogeneously. 3 g of sodium alginate was then added to the mixture, and then mix together to form dispersion. The dispersion was extruded drop wise through 10 ml syringe tubes (internal diameter 0.64 mm) into 5% (w/v) of CaCl₂ solution. The CaCl₂ solution was continuously stirred at a uniform speed using the magnetic stirrer. After 30 min of curing of the beads in the CaCl₂ solution, the solution was drained and the beads was washed twice with distilled water to remove unbounded and excess CaCl₂ on the surface of the beads.

The carrot powders beads were then dried at 55 °C for 18 h, cooled and packaged in a polythene bag for further analysis. Table 1 shows percentage ratio of the blend and plasticizer compositions used for encapsulation of the carrot powders.

Carotene content determination

Carotene content of the encapsulated beads was determined using method described by Biswas et al. (2011). For extraction from the samples, 1 g of each sample was ground and placed in a glass test tube. Then 5 ml of acetone was added to it, and the tube was held for 15 min with occasional shaking, and finally centrifuged at 1370 g for 10 min. Supernatant was collected into a separate test tube, and the compound was re-extracted with 5 ml of an acetone followed by centrifugation once again as above. Both of the supernatants were pooled together. Absorbance of the supernatant was determined at the wavelength of 452 nm by the UV/VIS spectrophotometer and the concentration of carotene was calculated using Beer-Lambert law as follows:

$$\beta - \text{Carotene} \left(\frac{\mu\text{g}}{100\text{g}} \right) = \frac{A \times V}{E_{1\text{cm}}^{1\%} \times W} \times 10^6 \quad (1)$$

where, A = Absorbance, V = Total volume of extract (ml), W = Weight of sample (g), $E_{1\text{cm}}^{1\%}$ (100 ml g⁻¹ cm⁻¹) = Specific extinction coefficient which is 2500 in acetone at 449 nm wavelength.

Characterization of the encapsulated carrot powder beads

Characteristics such as encapsulation yield, encapsulation efficiency, particle size, moisture content, hygroscopicity, and sensory attributes of the beads were evaluated.

Encapsulation yield (E.Y)

Encapsulation yield defines the recovered weight of dried beads obtained as compared to weight of solid raw materials used for the encapsulation. E.Y was determined using the equation given by Yoo et al. (2006) as:

$$E.Y = \frac{W_3}{W_4} \times 100 \quad (2)$$

where W_3 (Kg) = Total weight of the beads obtained after encapsulation and dehydration W_4 (Kg) = Total weight of total solids before encapsulation.

Table 1 Percentage ratios for the matrix compositions

Blend compositions soy protein isolate: cassava starch (%)	Plasticizers composition glycerol: sorbitol (%)
100:0	–
90:10	–
80:20	–
70:30	–
60:40	–
50:50	–
0:100	–
100:0	P ₁ (100:0)
100:0	P ₂ (80:20)
100:0	P ₃ (60:40)
0:100	P ₁ (100:0)
0:100	P ₂ (80:20)
0:100	P ₃ (60:40)
70:30	P ₁ (100:0)
70:30	P ₂ (80:20)
70:30	P ₃ (60:40)

Encapsulation efficiency (E.E)

Encapsulation efficiency was calculated as the amount of carotene present in the beads compared to the carotene present in the carrot powders initially used for encapsulation. To quantify the amount of carotene in the beads, and that of the carrot powder, method described by Biswas et al. (2011) was used. Encapsulation efficiency was determined using the equation given by Silva et al. (2011) as:

$$E.E\% = \frac{C_1}{C_2} \times 100 \quad (3)$$

where C_1 ($\mu\text{g}/100\text{g}$) = Carotene content of the beads C_2 ($\mu\text{g}/100\text{g}$) = Carotene content of the carrot powders initially mixed with membrane solution.

Particle size of the carrot beads

Size of the dried carrot powder beads were measured using the digital slide caliper by inserting the micro-particles in between the space of two metallic plates. Diameter of the beads were displayed in the digital screen of the previously calibrated equipment. The average size was then calculated by measuring the size of 3 sets of 20 beads from each batch.

Determination of moisture content of the beads

The moisture (dry basis moisture content) was determined gravimetrically by drying in a vacuum oven at 70 °C until

constant weight (AOAC 2005). The moisture content was expressed as:

$$M.C = \frac{\text{initial}(\text{moisture}) - \text{final}(\text{moisture})}{\text{initial}(\text{moisture})} \quad (4)$$

Hygroscopicity of the carrot powder beads

For the measurement of hygroscopicity, 2 g of each sample of the beads was placed over a saturated solution of sodium chloride (75% relative humidity) in a desiccator, and the desiccator was placed at 25 °C in an oven. The samples were weighed daily until constant weight was obtained. Hygroscopicity was calculated as g of moisture absorbed per 100 g dry solids (g/100 g) (Cai and Corke 2000; Sahar et al. 2015; Silva et al. 2011).

Sensory evaluation

The method of Ihekoronye and Ngoddy (1985) was adopted with slight modification as described by (Stone and Sidel 1993). A twenty-member panel was used for sensory evaluation of the carrot powder beads using carrot powders as control. All panel members were trained by the open discussion method prior to sensory tests. Samples (Carrot capsules and control) was provided in coded white plastic plates. The order of the presentation of samples to the panel was randomized. The samples were evaluated for appearance, taste, aroma and acceptability. Appearance was evaluated by visual observation, Aroma was evaluated by smelling with nose and taste of the sample was evaluated with the tongue. Cups with water and crackers were provided for panelists to use during the test to minimize the residual effect of the samples in the mouth. Each sensory attribute was rated on a 9-point Hedonic scale (1 = disliked extremely while 9 = liked extremely).

Stability of the encapsulated carrot powder beads

Stability of the encapsulated carrot powders beads including the control was determined through accelerated storage stability test method. The accelerated storage stability test was carried out as prescribed by Camila et al. (2017) with slight modification. The samples were contained in polythene and then placed in desiccators. Study was conducted under a constant relative humidity and temperature of 75% and 60 °C respectively. Relative humidity was controlled in the desiccators containing saturated solutions of sodium chloride ($a_w = 0.75$). Temperature was kept constant by placing the desiccators in an electric oven at 60 °C. The samples were stored for 49 days, and removed every 7 days for analyses of carotene degradation.

Analysis of kinetic properties of the encapsulated carrot powder beads

The experimental data of the carotene degradation during storage were adjusted by the first order kinetics since several recent research works reported that degradation of carotene followed first order kinetics (Aurlie et al. 2010; Thakur et al. 2017; Song et al. 2017; Przybysz et al. 2018; Liu et al. 2019). The First order kinetic model can be expressed as (Awagu et al. 2017; Camila et al. 2017):

First order model ($n = 1$)

$$\ln(Q) = \ln(Q_0) - kt \quad (5a)$$

$$t_{1/2} = \ln(2)/k \quad (5b)$$

where Q = amount of carotene degraded at time (t), Q_0 = amount of carotene content at the starting period, k = rate constant, $t_{1/2}$ = half-life of the carotene concentration

Statistical analyzes

IBM SPSS statistics (20) software was used for statistical analysis such as characteristics of the beads as well as kinetic modelling of the storage data. Data from characteristics of the encapsulated beads were analysed using one-way analysis of variance (ANOVA) and mean values were compared with Duncan (post hoc) at 95% probability. Each analysis was repeated three times and final data presented as a mean ($\pm$ SD).

Results and discussion

Encapsulation efficiency and encapsulation yield of the carrot micro-particles

Results of the encapsulation efficiency and yield are presented in Table 2. The encapsulation efficiency and encapsulation yield are within the range of (70.93–82.59%) and (70.35–75.35%) respectively. From the results, it can be seen that addition of cassava starch to soy-protein isolate based film solutions, significantly ($p < 0.05$) increase the encapsulation efficiency within the range of 0.3–0.6% depending upon the level of included cassava starch. The increased encapsulation efficiency with the increment of cassava starch amount in the soy-protein isolate based film solutions may be due to increase in viscosity of the solutions which might have facilitated faster solidification of beads and therefore minimized carrot powders leaching to the cross-linking solution (CaCl₂) at the time of curing. Venkata et al. (2010) reported that interaction between matrix of different film materials led to increased viscosity

of the film solution and delayed the drug diffusion within the polymer droplets during curing. High viscosity led to fast solidification of the dispersed phase which reduced porosity of the micro-particles (Schlicher et al. 1997; Venkata et al. 2010). It can be seen as well from the results that addition of cassava starch to soy-protein isolate based film solutions, significantly ($p < 0.05$) increase the encapsulation yield within the range of 1–3% depending upon the amount of added cassava starch. This increased encapsulation yield with the increment of cassava starch amount in the soy-protein isolate based film solutions may be due to strong interaction between protein and starch that led to the formation of a denser (heavier) matrix. This suggests that weight of each of the soy protein isolate and cassava starch that form the composite matrix reflected in the recovered weight of beads. The finding is in support of the results reported by Niken and Yhulia (2016); Malakar et al. (2013). They reported that increase in viscosity of the matrix solution in ionic gelation method significantly enhanced yield.

The results from Table 2 additionally indicates that encapsulation efficiency of the non-plasticized film solutions, and that of the plasticized film solutions are statistically the same for 100% soy-protein isolate including combination of soy-protein isolate and cassava starch composite based film solutions. But considering 100% cassava starch regarding encapsulation efficiency, non-plasticized cassava starch based film solution is significantly ($P < 0.05$) higher than that of the plasticized based. This may be attributed to the greater availability of active calcium binding sites in the non-plasticized cassava starch based films than that of the plasticized films thereby establishing greater degree of cross-linking (Belgamwar and Surana 2010). That simply showed that plasticization of cassava starch based film affects efficiency of the encapsulated beads. Concerning encapsulation yield, addition of plasticizer to the film solution enhance the yield of the carrot beads. This is expected since the molecular weight of the plasticizers will reflect in the overall weight thereby leading to higher weight of the recovered beads.

Physical properties of the carrot powder beads

Results of the physical properties such as the moisture content, particle size and hygroscopicity of encapsulated carrot powder beads are presented in Table 3

Moisture content of the carrot powder beads

Moisture content of the carrot powder beads is an important property which is related to the drying efficiency and storage stability (Nayak et al. 2010). The moisture content of the beads varied between 9.88 and 13.04%. Data of

Table 2 Encapsulation efficiency and yield of the carrot powder beads

Blend compositions soy protein: cassava starch	Plasticizers glycerol: sorbitol	Encapsulation yield (%)	Encapsulation efficiency (%)
100:0	0:0	70.35 ^h ± 0.04	74.28 ^g ± 0.23
90:10	0:0	71.34 ^g ± 0.04	74.61 ^f ± 0.31
80:20	0:0	72.55 ^e ± 0.01	74.57 ^e ± 0.35
70:30	0:0	72.63 ^{de} ± 0.02	74.79 ^d ± 0.45
60:40	0:0	72.72 ^d ± 0.02	74.99 ^d ± 0.44
50:50	0:0	73.25 ^c ± 0.02	74.55 ^e ± 0.82
0:100	0:0	74.23 ^b ± 0.02	82.59 ^a ± 1.67
100:0	P ₁ (100:0)	72.39 ^f ± 0.01	73.68 ^{gh} ± 0.40
100:0	P ₂ (80:20)	73.26 ^c ± 0.03	74.40 ^g ± 0.25
100:0	P ₃ (60:40)	73.22 ^c ± 0.01	73.42 ^h ± 0.02
0:100	P ₁ (100:0)	75.25 ^a ± 0.01	71.44 ⁱ ± 0.87
0:100	P ₂ (80:20)	75.32 ^a ± 0.01	70.93 ^j ± 0.16
0:100	P ₃ (60:40)	75.35 ^a ± 0.01	73.25 ^h ± 0.30
70:30	P ₁ (100:0)	74.23 ^b ± 0.02	75.77 ^b ± 0.35
70:30	P ₂ (80:20)	74.23 ^b ± 0.02	75.34 ^c ± 0.42
70:30	P ₃ (60:40)	74.25 ^b ± 0.03	74.25 ^g ± 0.55
Sig.		0.001	0.003

Mean and standard deviation of triplicate determination. Mean values not followed by the same superscript in a column within a membrane composition are significantly ($P < 0.05$) different

moisture content in this study were similar with the results of moisture content (10.57–13.63%) previously reported by Niken and Yhulia (2016). They used oxidized tapioca and alginate as matrix for the encapsulation of oxidants from coffee residue.

Particle size of the carrot powder beads

The particle size of the carrot powder beads varied between 2.18 and 2.64 mm. From the results, increase in the size of micro-particles was found with the increase of the amount of cassava starch added into soy-protein isolate based film solution. Similarly, plasticization of the film solution significantly ($p < 0.05$) increased carrot powder beads. The increase in bead particle size due to addition of cassava starch to soy-protein isolate based film solution and plasticization of the film solution could be as a result, the increase in viscosity of the film–blend compositions which in turn increased the droplet size during extrusion of the carrot-film blends to the cross-linking solution. Venkata et al. (2010) reported that interaction between blends of different film materials provides a high concentration gradient of the film solutions throughout the phase boundary, leading to fast solidification of their micro-particles in curing solution. Due to the fast solidification of the carrot-film solution, particle size increased with the increasing volume of the continuous phase. This finding is in line with the results reported by Malakar et al. (2013) who reported

that difference in viscosity of the matrix solution as a result of blend compositions significantly affect the particle size of tolbutamide beads developed from starch-alginate based matrix.

Hygroscopicity of the carrot powder beads

Hygroscopicity of the carrot powder beads varied between 40.00 and 49.00 g/100 g. From the results, increase in the hygroscopicity of carrot powder beads was found with increase in the amount of cassava starch added to soy-protein isolate based film solution. Similarly, plasticization of the film solution also significantly increased the hygroscopicity. This difference in water adsorption may be attributed to difference in molecular weight of the cassava starch and that of the soy protein that formed the matrix of the encapsulated carrot powder beads. Cai and Corke (2000) reported that the difference in the molecular weight of the matrix constituents significantly affect their hygroscopicity. Addition of plasticization to the film solutions are expected to increase the film hygroscopicity since plasticizer induces higher free volume, and molecular mobility within the films which consequently increases the film water absorption (Sothornvit and Krochta 2005).

Table 3 Physical properties of the carrot powder beads

Blend compositions soy protein: cassava starch	Plasticizers glycerol: sorbitol	Residual moisture (%)	Particle size (mm)	Hygroscopicity (g/100 g)
100:0	0:0	11.72 ^e ± 0.08	2.24 ^f ± 0.01	40.00 ^e ± 1.00
90:10	0:0	11.28 ^g ± 0.05	2.25 ^f ± 0.01	42.00 ^e ± 1.00
80:20	0:0	10.73 ⁱ ± 0.07	2.31 ^e ± 0.01	41.00 ^e ± 1.00
70:30	0:0	10.72 ⁱ ± 0.06	2.28 ^{ef} ± 0.01	43.00 ^{de} ± 1.00
60:40	0:0	10.00 ^j ± 0.03	2.33 ^{de} ± 0.02	44.00 ^{cd} ± 1.00
50:50	0:0	10.73 ⁱ ± 0.05	2.35 ^{de} ± 0.03	45.00 ^{cd} ± 1.00
0:100	0:0	9.88 ^k ± 0.02	2.18 ^g ± 0.01	46.00 ^{bc} ± 1.00
100:0	P ₁ (100:0)	12.40 ^c ± 0.20	2.29 ^{ef} ± 0.01	49.00 ^a ± 1.00
100:0	P ₂ (80:20)	12.83 ^b ± 0.04	2.42 ^c ± 0.01	42.00 ^e ± 1.00
100:0	P ₃ (60:40)	13.04 ^a ± 0.04	2.31 ^e ± 0.01	40.00 ^e ± 1.00
0:100	P ₁ (100:0)	12.24 ^d ± 0.07	2.37 ^d ± 0.02	47.00 ^b ± 1.00
0:100	P ₂ (80:20)	12.36 ^{cd} ± 0.19	2.23 ^f ± 0.01	43.00 ^{de} ± 1.00
0:100	P ₃ (60:40)	12.51 ^c ± 0.09	2.37 ^d ± 0.02	47.00 ^b ± 1.00
70:30	P ₁ (100:0)	11.47 ^f ± 0.02	2.47 ^b ± 0.03	44.00 ^{cd} ± 1.00
70:30	P ₂ (80:20)	11.03 ^h ± 0.05	2.35 ^{de} ± 0.01	43.00 ^{de} ± 1.00
70:30	P ₃ (60:40)	11.82 ^e ± 0.12	2.64 ^a ± 0.01	43.00 ^{de} ± 1.00
Sig.		0.001	0.001	0.001

Mean and standard deviation of triplicate determination. Mean values not followed by the same superscript in a column within a membrane composition are significantly ($P < 0.05$) different

Sensory properties of encapsulated carrot powder beads

Sensory properties of the soy-protein isolate and cassava starch based carrot powder beads are presented in Table 4. The beads' appearance varied between 5.73 and 8.27. 100% soy-protein isolate based carrot beads were opaque and light chocolate brown while that of the 100% cassava starch based beads were transparent reflecting the color of carrot powders. This might be reason the panelists rated 100% cassava starch based carrot beads (8.27) the highest and close to the control which is the carrot powders (8.73) as can be seen from the results. It can be observed from the results that the non-plasticized beads were rated higher than that of the plasticized. Most of the panelists observed that the plasticized beads were not as spherical as that of the non-plasticized beads. This implies that plasticization of the film solution affects the shape of the beads. The taste of the carrot beads varied between 4.13 and 7.07. The panelists observed Traces of calcium chloride taste in the 100% cassava starch based carrot beads with little or no traces of the taste in 100% soy-protein isolate based carrot powder beads including that of their combinations. This is evidence as 100% cassava starch based carrot powder beads were rated the least (4.13). It can be seen from the results that taste of the plasticized carrot powder beads were rated higher by the panelists than that of non-

plasticized beads. The sweet taste of the plasticizers (glycerol and sorbitol) in the plasticized carrot beads might have overridden the salty taste of the calcium chloride. Comparing the encapsulated carrot beads with the control (carrot powders), both plasticized and non-plasticized carrot beads did not have taste of the carrot powders. Similarly, both plasticized and non-plasticized carrot powder beads did not have aroma of the carrot powders. This is expected since encapsulation primarily masks taste and aroma of the core (Prüsse et al. 2008). Ratings of acceptability of the encapsulated carrot powder beads varied between 4.43 and 7.97. Combination of Soy protein isolate (70%) and cassava starch (30%) composite based encapsulated bead was the most acceptable beads followed by 100% cassava starch based beads while the plasticized cassava starch based bead was rated the least concerning the acceptability.

Variations in carotene concentration of the beads during storage

Variations in carotene concentration of the beads during accelerated stability storage at the temperature of 60 °C under 75% relative humidity is presented in Table 5. It can be observed from the results that carotene concentration of the beads decreased steadily with time during storage in all the samples. This confirms the fact that carotene

Table 4 Sensory Properties of the Carrot Powder beads and the control

Blend compositions soy protein: cassava starch	Plasticizers	Appearance	Taste	Aroma	Acceptability
100:0	–	6.47 ^{ij} ± 0.01	5.53 ^j ± 0.02	6.07 ⁱ ± 0.02	6.21 ^h ± 0.01
90:10	–	7.27 ^f ± 0.01	5.67 ⁱ ± 0.01	6.66 ^c ± 0.02	6.27 ^g ± 0.01
80:20	–	6.87 ⁱ ± 0.01	5.93 ^g ± 0.02	6.21 ^g ± 0.02	6.27 ^g ± 0.01
70:30	–	7.07 ^h ± 0.02	5.81 ^h ± 0.02	6.33 ^f ± 0.01	7.97 ^b ± 0.02
60:40	–	7.53 ^d ± 0.01	5.52 ^j ± 0.02	6.33 ^f ± 0.02	6.53 ^c ± 0.01
50:50	–	7.40 ^e ± 0.01	5.06 ^k ± 0.03	6.61 ^d ± 0.02	7.52 ^d ± 0.01
0:100	–	8.27 ^b ± 0.01	4.13 ^l ± 0.03	6.33 ^f ± 0.02	7.71 ^c ± 0.01
100:0	P ₁ (100:0)	5.73 ^k ± 0.01	5.93 ^g ± 0.02	6.21 ^g ± 0.01	6.42 ^f ± 0.01
100:0	P ₂ (80:20)	5.87 ^k ± 0.01	5.86 ^g ± 0.02	6.47 ^e ± 0.02	5.72 ^j ± 0.01
100:0	P ₃ (60:40)	6.21 ^j ± 0.01	6.62 ^e ± 0.02	6.32 ^f ± 0.01	6.54 ^e ± 0.01
0:100	P ₁ (100:0)	8.13 ^c ± 0.01	6.71 ^c ± 0.02	6.85 ^b ± 0.03	4.43 ^m ± 0.01
0:100	P ₂ (80:20)	7.27 ^f ± 0.01	6.46 ^f ± 0.03	6.61 ^d ± 0.01	5.25 ^k ± 0.01
0:100	P ₃ (60:40)	7.07 ^h ± 0.01	6.41 ^f ± 0.01	6.47 ^e ± 0.02	5.13 ^l ± 0.01
70:30	P ₁ (100:0)	7.13 ^g ± 0.01	7.07 ^b ± 0.01	6.13 ^h ± 0.01	5.13 ^l ± 0.01
70:30	P ₂ (80:20)	6.73 ⁱ ± 0.01	6.73 ^d ± 0.01	6.47 ^e ± 0.01	6.42 ^f ± 0.01
70:30	P ₃ (60:40)	6.87 ⁱ ± 0.01	6.73 ^d ± 0.02	6.65 ^c ± 0.03	6.12 ⁱ ± 0.01
Control (carrot powders)	–	8.73 ^a ± 0.02	8.27 ^a ± 0.02	8.05 ^a ± 0.02	8.78 ^a ± 0.02
Sig.		0.001	0.001	0.001	0.001

Mean and standard deviation of triplicate determination. Mean values not followed by the same superscript in a column within a membrane composition are significantly ($P < 0.05$) different

concentrations of the encapsulated carrot powders beads degrade during storage. It can also be observed that the carotene degradation of the encapsulated carrot powders beads occurs in different degrees, depending on the membrane compositions. This is in agreement with the report of earlier researchers (Camila et al. 2017; Burdurlu et al. 2006; Derossi et al. 2010).

Regression parameters of first order kinetics

Regression parameters of the first order kinetics of quality degradation of carrot powder beads

The regression parameters via least square linear regression analysis are provided in Table 6. The correlation coefficient ($R^2 \geq 0.911$) and values of RMSE (0.007–0.192) confirmed the validity and efficacy of this first order kinetic equation in describing degradation of carotene content of the encapsulated carrot powder beads.

Comparison of the first order kinetic parameters and proposed model

Comparison of the carotene first order kinetic degradation parameters for all the samples is presented in Table 7. It can be observed from results that the difference in film compositions affect carotene degradation rate constant. Comparatively, the carotene degradation rate constant of

carrot powders encapsulated in cassava starch based film solution is significantly ($p < 0.05$) higher than those of the soy-protein isolate based film solution while the carotene degradation rate constant of the carrot powders encapsulated in soy-protein isolate based film solution is significantly ($p < 0.05$) higher than those encapsulated in their combinations. Plasticization of the film solutions can also be observed to affect the degradation rate constant. The degradation rate constant of the plasticized carrot powder beads is significantly ($p < 0.05$) higher than those of the non-plasticized beads. Since the magnitude of the rate constant is a reflection of the rate of reaction, the inference is that degradation of carotene occurred faster in 100% cassava starch based carrot powder beads than those of soy-protein isolate based beads, and their combinations. It can also be observed that degradation of carotene occurred faster in plasticized carrot powder beads than those of non-plasticized beads. These trends manifested in the half-life of the samples which gave further credence to this fact. The time at which the concentration of carotene content of the 100% cassava starch based beads reduces to half of its original amount (half-life) was shorter than those of 100% soy-protein isolate based beads. The time at which the concentration of carotene content of 100% soy-protein isolate based beads reduces to half of its original amount (half-life) was shorter than those in the combination of soy-protein isolate and cassava starch based beads. This implies

Table 5 Carotene degradation of carrot powders beads during storage at 60 °C and 75% RH

Sample codes	Storage time (days)									
	S:C	G:S	0	1	2	3	4	5	6	7
100:0	–	–	1.692	1.546	1.193	1.122	1.076	0.936	0.866	0.517
90:10	–	–	1.659	1.501	1.123	1.053	0.994	0.925	0.891	0.720
80:20	–	–	1.689	1.659	1.583	1.466	1.536	1.367	1.282	0.859
70:30	–	–	1.680	1.640	1.558	1.426	1.413	1.391	1.344	1.108
60:40	–	–	1.689	1.610	1.388	1.317	1.284	1.219	1.160	0.866
50:50	–	–	1.691	1.656	1.587	1.566	1.517	1.441	1.402	1.212
0:100	–	–	1.963	1.561	0.691	0.620	0.316	0.282	0.265	0.179
100:0	P ₁ (100:0)	–	1.684	1.417	0.820	0.749	0.582	0.500	0.458	0.252
100:0	P ₂ (80:20)	–	1.696	1.434	0.850	0.779	0.617	0.551	0.518	0.352
100:0	P ₃ (60:40)	–	1.694	1.453	0.908	0.837	0.695	0.577	0.517	0.220
0:100	P ₁ (100:0)	–	1.723	1.403	0.701	0.630	0.410	0.350	0.320	0.170
0:100	P ₂ (80:20)	–	1.717	1.386	0.661	0.590	0.358	0.312	0.288	0.173
0:100	P ₃ (60:40)	–	1.708	1.352	0.578	0.505	0.252	0.225	0.212	0.144
70:30	P ₁ (100:0)	–	1.678	1.482	1.029	0.958	0.862	0.708	0.631	0.247
70:30	P ₂ (80:20)	–	1.691	1.442	0.881	0.810	0.661	0.583	0.545	0.351
70:30	P ₃ (60:40)	–	1.656	1.647	1.566	1.495	1.496	1.364	1.298	0.968
Control	–	–	2.231	1.185	1.149	0.873	0.650	0.539	0.483	0.204

S: C (Soy-protein isolate: Cassava starch), G: S (Glycerol: Sorbitol)

Table 6 Regression parameters of the first order kinetics of quality degradation of carrot powder beads

Sample codes		First order kinetics	
S:C	G:S	R ²	RMSE
100:0	–	0.966	0.046
90:10	–	0.942	0.084
80:20	–	0.942	0.084
70:30	–	0.938	0.091
60:40	–	0.944	0.073
50:50	–	0.933	0.018
0:100	–	0.939	0.035
100:0	P ₁ (100:0)	0.939	0.035
100:0	P ₂ (80:20)	0.948	0.048
100:0	P ₃ (60:40)	0.944	0.032
0:100	P ₁ (100:0)	0.957	0.007
0:100	P ₂ (80:20)	0.920	0.024
0:100	P ₃ (60:40)	0.920	0.024
70:30	P ₁ (100:0)	0.912	0.021
70:30	P ₂ (80:20)	0.921	0.042
70:30	P ₃ (60:40)	0.968	0.156
Control	–	0.911	0.192

that the carrot powders encapsulated in the combination of soy-protein isolate and cassava starch based film solutions will be expected to have longer shelf life than those

encapsulated in 100% cassava starch and that of 100% soy-protein isolate based film solutions. It can therefore be confirmed from these results that synergistic properties of combining soy-protein isolate and cassava starch to form the capsule matrix gave better barrier to heat and moisture and therefore minimize carotene degradation of the encapsulated carrot powder beads. This finding could result from improved interaction between starch and protein, which might have led to increased formation of dense matrix causing a wall with small free volumes, thus minimizing diffusion process (Helena et al. 2013; Cristina et al. 2014; Luiza et al. 2017; Camila et al. 2017; Przybysz et al. 2018). Similarly, the time at which the concentration of carotene content of the plasticized beads reduces to half of its original amount (half-life) was shorter than those of non-plasticized beads. This implies that plasticization of the film solutions affects the barrier properties of the membrane therefore weakling insulating properties of the matrix to thermal oxidation. Several latest researchers mentioned that plasticizer addition to film solution led to increased water vapour permeability and decreased glass transition temperature of the film (Sanyang et al. 2016; Bakry et al. 2017; Almeida et al. 2018, Indrianti et al. 2018; Marvdashti et al. 2019). The increased water vapor permeability of bead matrix as a result of plasticizer addition would possibly facilitate greater interaction between the core (carrot powders) and the water activity ($a_w = 0.75$) within storage system thereby causing higher carotene degradation. Decreased glass transition

Table 7 Kinetic parameters of the degradation of carotene compounds in the carrot powder beads stored at 60° C temperature and 75% relative humidity (RH)

Sample codes		Rate constant K (week ⁻¹)	Half life t _{1/2} (days)	Proposed model
S:C	G:S			
100:0	–	0.143	34	In (C) = In (C ₀)– 0.143t
90:10	–	0.138	35	In (C) = In (C ₀)– 0.138t
80:20	–	0.053	92	In (C) = In (C ₀)– 0.053t
70:30	–	0.078	62	In (C) = In (C ₀)– 0.078t
60:40	–	0.091	53	In (C) = In (C ₀)– 0.091t
50:50	–	0.046	106	In (C) = In (C ₀)–0.046t
0:100	–	0.352	14	In (C) = In (C ₀)–0.352t
100:0	P ₁ (100:0)	0.247	20	In (C) = In (C ₀)–0.247t
100:0	P ₂ (80:20)	0.221	22	In (C) = In (C ₀)–0.221t
100:0	P ₃ (60:40)	0.256	19	In (C) = In (C ₀)–0.256t
0:100	P ₁ (100:0)	0.316	15	In (C) = In (C ₀)–0.316t
0:100	P ₂ (80:20)	0.338	14	In (C) = In (C ₀)–0.338t
0:100	P ₃ (60:40)	0.363	13	In (C) = In (C ₀)–0.363t
70:30	P ₁ (100:0)	0.231	21	In (C) = In (C ₀)–0.231t
70:30	P ₂ (80:20)	0.226	22	In (C) = In (C ₀)–0.226t
70:30	P ₃ (60:40)	0.069	70	In (C) = In (C ₀) – 0.069t
Control	–	0.404	12	In (C) = In (C ₀) – 0.404t

temperature of the bead membrane would possibly as well have an effect on thermal conductivity of the beads' matrix. Carrot powders encapsulated in the combination of soy-protein isolate (50%) and cassava starch (50%) based composite film solutions recorded the longest half-life of 106 days followed by combination of soy protein isolate (70%) and cassava starch (30%) based composite film solution having half-life of 92 days. The plasticized cassava starch based carrot beads had the shortest half-life of 13 days. All the carrot powder beads performed better than the control (carrot powders).

Conclusion

Addition of cassava starch to soy-protein isolate based film solution increased the encapsulation efficiency, encapsulation yield, particle size, and hygroscopicity while the moisture content was reduced. Soy protein isolate based membrane performed better than cassava starch based membrane in extending the shelf life the carotene content of the carrot powders. Addition of plasticizers to film solutions weakened the insulating properties of the beads to thermal oxidation therefore, leading to significant degradation of carotene content. Combination of soy-protein isolate (50%) and cassava starch (50%) based composite film solution was the best in preventing the carotene degradation of the encapsulated carrot powders while plasticized cassava starch based film solution was the least in performance.

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