Effect of temperature and relative humidity on the water vapour permeability and mechanical properties of cassava starch and soy protein concentrate based edible films

C. E. Chinma · C. C. Ariahu · J. S. Alakali

Revised: 20 November 2013 / Accepted: 26 November 2013 / Published online: 11 December 2013
© Association of Food Scientists & Technologists (India) 2013

Abstract The effect of temperature and relative humidity on the water vapour permeability (WVP) and mechanical properties of cassava starch and soy protein concentrate (SPC) based edible films containing 20 % glycerol level were studied. Tensile strength and elastic modulus of edible films increased with increase in temperature and decreased with increase in relative humidity, while elongation at break decreased. Water vapour permeability of the films increased (2.6–4.3 g.mm/m².day.kPa) with increase in temperature and relative humidity. The temperature dependence of water vapour permeation of cassava starch-soy protein concentrate films followed Arrhenius relationship. Activation energy (E_a) of water vapour permeation of cassava starch-soy protein concentrate edible films ranged from 1.9 to 5.3 kJ/mol ($R^2 \geq 0.93$) and increased with increase in SPC addition. The E_a values were lower for the bio-films than for polyvinylidene chloride, polypropylene and polyethylene which are an indication of low water vapour permeability of the developed biofilms compared to those synthetic films.

Keywords Cassava starch-soy protein films · Mechanical properties · Water vapour permeability · Activation energy

Introduction

Edible films are flexible materials used in food coating and packaging (Regalado et al. 2006). Earlier studies (Parra et al.

2004; Kokoszka et al. 2010) have shown that the films can extend the shelf -life of foods through the inhibition of the migration of moisture, oxygen, carbon dioxide and aroma. Several workers have characterized the properties of starch based films (Mali et al. 2008, 2005; Bertuzzi et al. 2007; Parra et al. 2004; Arvanitoyannis and Biliaderis 1998; Arvanitoyannis et al. 1997) and soy protein based films (Kokoszka et al. 2010; Cho and Rhee 2002; Rhim et al. 2000; Were et al. 1999).

The main properties of edible films are their barrier properties and mechanical properties. The mechanical properties of edible films provides information on the mechanical strength required to maintain structural integrity and barrier properties during its application and subsequent distribution and handling of the food (Bourtoom and Chinnan 2008). Barrier properties are studied to generate information about interaction between edible films and moisture/gases during processing and storage. Also, barrier properties such as water vapour permeability can be useful to understand possible mass transfer mechanisms and solute and polymer interactions in edible films (Bertuzzi et al. 2007).

Edible films like other foods when exposed to certain environmental conditions or during storage may undergo both physical and chemical changes, may suffer biological, chemical and physical deterioration during storage and distribution; several interactions, including those with oxygen and moisture, exposure to light, which may catalyze certain reactions, and mechanical abuse account for the majority of deterioration sources (Hong and Krotcha 2006). It has been reported that temperature and relative humidity induce physical and chemical changes in edible films that cause structural changes in films resulting to alterations in the barrier and mechanical properties of films (Akbari et al. 2007).

Edible films have been successfully produced using cassava starch and soybean protein concentrates (Chinma et al. 2012) and moisture sorption isotherms and thermodynamic

C. E. Chinma (✉)
Department of Food Science and Nutrition, Federal University of
Technology, P. M.B. 65 Minna, Nigeria
e-mail: chinmachiemela@yahoo.com

C. C. Ariahu · J. S. Alakali
Department of Food Science and Technology, University of
Agriculture, P.M.B. 2373 Makurdi, Nigeria

properties of the biofilms were studied (Chinma et al. 2013). However, information regarding the effect of temperature and relative humidity on water vapour permeability and mechanical properties of cassava starch-soy protein concentrate based edible films is lacking in literature. Such information is important for handling, distribution and storage of cassava starch-soy protein concentrate based edible films. The objective of the study was to determine the effect of temperature and relative humidity on water vapour permeability and mechanical properties of cassava starch and soy protein concentrate edible films.

Materials and method

Source of raw material

Fresh sweet cassava (Cultivar TMS 30470) tubers and soybean (Cultivar TGX 1448-2E) seeds were procured from Crop Production department, Federal University of Technology, Minna, Nigeria.

Cassava starch extraction

The wet method of Ihekoronye and Ngoddy (1985) as earlier reported in our previous study (Chinma et al. 2012) was used for cassava starch isolation. In this method, 2 kg of fresh cassava tuber was manually peeled, washed with clean tap water and milled into slurries. In addition, the slurries were suspended in cold (12 °C) deionized water and sieved to remove the fibrous materials leaving the starch in solution. The starch layer was suspended in deionized water and centrifuged 6–7 times, until the settled starch gave a firm, dense deposit. The final sediment was suspended in cold deionized water and screened through 150 µm screen to keep the cell wall off the starch slurry. Then the residue was amassed and deposited quietly for 6 h. The starch suspension obtained was dried in an air draft oven (model T12h, Genlab) at 50 °C until constant weight was achieved. The dried material was milled and sieved with a 75 µm screen to obtain the starch.

Preparation of soy protein concentrates

The isoelectric precipitation method described by Nasri and El Tinay (2007) was used in the preparation of soy protein concentrate. Defatted soybean samples were extracted by blending with 1 M NaCl using flour to solvent ratio of 1:10. The slurry (pH 9.0) was centrifuged at 12,000 g for 30 min. The extract was precipitated isoelectrically at pH 4.5 by addition of 0.1 N HCl. The protein was allowed to dry in open air at room temperature for 24 h and then ground in an electric blender (Moulinex) to pass through a 75 µm screen and stored at 4 °C until used.

Blend formulation

Cassava starch and soy protein concentrate were mixed at different proportions (100: 0 %; 90: 10 %; 80: 20 %; 70: 30 %; 60:40 % and 50: 50 %) (Chinma et al. 2012). A Kenwood mixer (Kenwood Ltd., Hampshire, United Kingdom) was used for mixing to achieve uniform blending.

Preparation of edible films

The method of Phan et al. (2009) was used for the preparation of cassava starch and soy protein concentrate films using casting method. Edible films were prepared using different blends of cassava starch and soy protein concentrate. Glycerol concentration of 20 % was weighed and dissolved into distilled water and followed with addition of composite blends to obtain film forming suspension, in which starch concentration was 5 % (w/w) of overall water content independently of plasticizer concentration. The pH of the film forming suspension was adjusted to 9.98 (with 1 M NaOH) using a pH meter (DELTA 320). The film forming suspension was heated in a heating flask in a hot plate over 90 °C for 5 min with continuous stirring using a glass rod to obtain the film forming solution. The film forming solution (40 mL) was cooled in ice water casted onto flat, leveled, non-stick trays (15×25 cm) to set. Once set, the trays were held overnight in an oven at 35 °C before peeling the films off the plates.

Film conditioning

Test films were conditioned prior to test. Edible film samples were conditioned at 52 % relative humidity and 25 °C using 39.50 % sulphuric acid solution. Edible films were sealed to glass dish containing distilled water using silicone adhesive to give good seal; the glass dish was placed in a desiccator maintained at 25 °C and 52 % relative humidity using saturated sulphuric acid solution (Ruegg 1980; Chinma et al. 2012). The concentrations of sulphuric acid solution for obtaining 50 % relative humidity at 10, 20, 30 and 40 °C were 38.75, 38.82, 38.89 and 38.90 %, respectively. At 80 % relative humidity, the concentrations of sulphuric acid at 10, 20, 30 and 40 °C were 24.60, 24.86, 24.94 and 24.98 % respectively (Ariahu et al 2006; Ruegg 1980).

Mechanical properties of edible films

An Instron universal testing machine (Model 4465, High Wycombe, England) with a 0.1-kN static load cell was used to measure Young's modulus (slope of stress–strain curve at low values of strain), tensile strength (maximum force used during measurement) and elongation at break (ratio of

Table 1 Effects of temperature and relative humidity on the tensile strength (MPa) of edible films prepared from cassava starch and soy protein concentrate blends

Cassava starch: soy protein	Temperature							
	10 °C		20 °C		30 °C		40 °C	
	Relative humidity		Relative humidity		Relative humidity		Relative humidity	
	50 %	80 %	50 %	80 %	50 %	80 %	50 %	80 %
Ratio								
100:0	23.4 ^a ±0.52	22.5 ^a ±0.19	23.6 ^a ±0.43	22.9 ^a ±0.36	23.9 ^c ±0.11	23.1 ^b ±0.67	24.5 ^b ±0.92	23.7 ^b ±0.95
90:10	20.1 ^f ±0.39	19.4 ^f ±0.61	20.5 ^f ±0.88	19.6 ^f ±0.73	21.3 ^d ±0.95	19.9 ^d ±0.15	21.9 ^c ±0.24	20.2 ^d ±0.11
80:20	21.5 ^e ±0.76	20.2 ^e ±0.58	21.8 ^e ±0.25	21.0 ^e ±0.90	21.9 ^d ±0.49	21.2 ^c ±0.30	22.3 ^c ±0.51	21.3 ^c ±0.67
70:30	21.9 ^d ±0.43	20.8 ^d ±0.20	22.3 ^d ±0.79	21.7 ^d ±0.84	22.7 ^c ±0.22	21.5 ^c ±0.91	23.1 ^b ±0.27	21.9 ^c ±0.50
60:40	22.6 ^c ±0.58	21.2 ^c ±0.77	22.9 ^c ±0.53	22.1 ^c ±0.37	23.3 ^b ±0.38	22.7 ^b ±0.74	23.8 ^b ±0.90	22.4 ^b ±0.43
50:50	23.5 ^b ±0.25	22.7 ^b ±0.34	23.9 ^b ±0.48	22.7 ^b ±0.21	24.4 ^a ±0.74	23.9 ^a ±0.36	24.9 ^a ±0.63	23.2 ^a ±0.32

Mean and standard deviation of triplicate determination

Mean values not followed by the same superscript in a column are significantly ($p \leq 0.05$) different

elongation to original length of sample) of film stripes length (150 mm) and width (10 mm). The thickness of the films was determined using a manual micrometer (Mitutoyo, São Paulo, Brazil) at five random positions for each film sample.

Determination of water vapour permeability

The method of Bertuzzi et al. (2007) was used for determination of water vapour permeability. The conditioned films were sealed to glass dish containing distilled water using silicone adhesive to give good seal. The glass dish was placed in a desiccator maintained at 25 °C and 52 % relative humidity using saturated sulphuric acid solution. The water vapors transferred through the films were determined by measuring the weight changes periodically until constant weight was

reached for about 6 h. Weight loss was plotted over time to obtain a straight line graph. The water vapour permeability was calculated from the slope of the linear regression of weight loss versus time. Water vapour permeability (WVP) was calculated from the following equation:

$$WVP = \frac{CX}{A\Delta P}$$

X is the film thickness (m), A is area of the exposed film (m²), ΔP is the water vapor pressure differential across the film (Pa), and C is the slope of the weight gain of the dish, to the 0.0001 g, versus time.

Table 2 Effects of temperature and relative humidity on the elastic modulus (MPa) prepared from cassava of edible films starch and soy protein concentrate blends

Cassava starch: soy protein	Temperature							
	10 °C		20 °C		30 °C		40 °C	
	Relative humidity		Relative humidity		Relative humidity		Relative humidity	
	50 %	80 %	50 %	80 %	50 %	80 %	50 %	80 %
Ratio								
100:0	40.8 ^f ±0.20	39.1 ^f ±0.63	41.1 ^f ±0.41	40.3 ^f ±0.50	42.9 ^f ±0.20	41.3 ^f ±0.38	45.2 ^f ±0.76	41.9 ^f ±0.65
90:10	43.2 ^e ±0.31	42.4 ^e ±0.24	43.9 ^e ±0.30	42.6 ^e ±0.19	44.1 ^e ±0.46	42.8 ^e ±0.61	46.9 ^e ±0.43	43.1 ^e ±0.14
80:20	45.4 ^d ±0.11	44.0 ^d ±0.15	45.8 ^d ±0.91	43.3 ^d ±0.34	46.2 ^d ±0.32	43.7 ^d ±0.25	47.73 ^d ±0.90	43.9 ^d ±0.23
70:30	48.2 ^c ±0.50	48.4 ^c ±0.56	48.5 ^c ±0.35	47.6 ^c ±0.54	48.9 ^c ±0.10	44.4 ^c ±0.72	49.1 ^c ±0.38	45.7 ^c ±0.59
60:40	57.6 ^b ±0.77	56.8 ^b ±0.32	57.9 ^b ±0.17	57.2 ^b ±0.29	58.0 ^b ±0.73	56.5 ^b ±0.14	58.9 ^b ±0.20	56.8 ^b ±0.27
50:50	65.1 ^a ±0.29	63.4 ^a ±0.25	65.7 ^a ±0.21	63.7 ^a ±0.13	66.3 ^a ±0.44	65.4 ^a ±0.37	66.7 ^a ±0.18	64.4 ^a ±0.61

Mean and standard deviation of triplicate determination

Mean values not followed by the same superscript in a column are significantly ($p \leq 0.05$) different

Table 3 effects of temperature and relative humidity on elongation at break (%) of edible films prepared from cassava starch and soy protein concentrate blends

Cassava starch: soy protein	Temperature							
	10 °C		20 °C		30 °C		40 °C	
	Relative humidity		Relative humidity		Relative humidity		Relative humidity	
	50 %	80 %	50 %	80 %	50 %	80 %	50 %	80 %
Ratio								
100:0	7.9 ^d ±0.52	7.6 ^c ±0.19	7.8 ^d ±0.43	7.4 ^c ±0.36	7.6 ^c ±0.11	7.3 ^d ±0.67	7.3 ^c ±0.25	7.1 ^d ±0.47
90:10	9.0 ^c ±0.39	8.9 ^d ±0.61	8.8 ^c ±0.88	8.5 ^b ±0.73	7.9 ^c ±0.95	8.20 ^c ±0.15	7.7 ^c ±0.24	7.8 ^c ±0.18
80:20	10.3 ^b ±0.76	9.7 ^c ±0.58	9.9 ^b ±0.25	9.5 ^{ab} ±0.90	9.7 ^b ±0.49	9.3 ^b ±0.30	9.3 ^b ±0.51	8.9 ^b ±0.67
70:30	10.8 ^b ±0.43	10.5 ^b ±0.20	10.6 ^a ±0.79	10.2 ^a ±0.84	10.2 ^a ±0.22	9.9 ^{ab} ±0.91	9.9 ^{ab} ±0.27	9.5 ^{ab} ±0.50
60:40	11.1 ^{ab} ±0.58	10.9 ^{ab} ±0.77	10.7 ^a ±0.53	10.5 ^a ±0.37	10.5 ^a ±0.38	10.2 ^a ±0.74	10.2 ^a ±0.90	9.8 ^a ±0.43
50:50	11.5 ^a ±0.25	11.2 ^a ±0.34	10.9 ^a ±0.48	10.6 ^a ±0.21	10.7 ^a ±0.74	10.5 ^a ±0.36	10.3 ^a ±0.63	10.2 ^a ±0.32

Mean and standard deviation of triplicate determination

Mean values not followed by the same superscript in a column are significantly ($p \leq 0.05$) different

The temperature dependency of WVP of the edible films was evaluated using an Arrhenius relationship (Equation 10) described by Bertuzzi et al. (2007).

$$\text{WVP} = \text{WVP}_0 \exp(-E_P/RT)$$

where WVP is water vapour permeability coefficient, WVP_0 is a constant, E_P is the activation energy (J/mol) of permeation, R is the universal gas constant 8.314 J/mol. K and T is the absolute temperature (Kelvin). Logarithmic transformation of the above equation gave:

$$\ln(\text{WVP}) = \ln(\text{WVP}_0) - (E_P/R) (1/T)$$

From the slope of the fitted regression line, the apparent activation energy (E_P) of cassava starch and soy protein concentrate films was determined at test temperatures.

Statistical analysis

Data were analyzed by analysis of variance (Steel and Torrie 1980). The difference between mean values was determined by the least significant difference (LSD) test. Significance was accepted at 5 % probability level (Ihekoronye and Ngoddy 1985). All the data reported in the tables are average values of triplicate determinations.

Table 4 Effects of temperature and relative humidity on the water vapour permeability (g.mm/m².day.kPa) of edible films prepared from cassava starch and soy protein concentrate blends

Cassava starch: soy protein	Temperature							
	10 °C		20 °C		30 °C		40 °C	
	Relative humidity		Relative humidity		Relative humidity		Relative humidity	
	50 %	80 %	50 %	80 %	50 %	80 %	50 %	80 %
Ratio								
100:0	3.9 ^a ±0.11	4.1 ^a ±0.08	4.0 ^a ±0.05	4.3 ^a ±0.24	4.1 ^a ±0.03	4.4 ^a ±0.02	4.3 ^a ±0.09	4.6 ^a ±0.11
90:10	3.1 ^b ±0.07	3.4 ^b ±0.13	3.3 ^b ±0.03	3.5 ^b ±0.19	3.5 ^b ±0.17	3.7 ^a ±0.11	3.8 ^a ±0.02	3.9 ^a ±0.08
80:20	2.9 ^b ±0.03	3.1 ^b ±0.01	3.2 ^b ±0.01	3.4 ^b ±0.07	3.4 ^b ±0.09	3.7 ^a ±0.03	3.8 ^a ±0.01	3.8 ^a ±0.05
70:30	2.8 ^b ±0.08	2.9 ^b ±0.04	3.1 ^b ±0.04	3.3 ^b ±0.02	3.3 ^b ±0.11	3.5 ^{ab} ±0.00	3.6 ^{ab} ±0.04	3.7 ^a ±0.01
60:40	2.7 ^b ±0.01	2.8 ^{bc} ±0.02	2.8 ^b ±0.02	3.0 ^b ±0.00	3.1 ^b ±0.05	3.3 ^{ab} ±0.01	3.4 ^{ab} ±0.00	3.6 ^a ±0.00
50:50	2.6 ^b ±0.05	2.4 ^c ±0.01	2.6 ^b ±0.01	2.9 ^b ±0.10	2.9 ^b ±0.00	3.0 ^b ±0.01	3.2 ^b ±0.01	3.4 ^a ±0.01

Mean and standard deviation of triplicate determination

Mean values not followed by the same superscript in a column are significantly ($p \leq 0.05$) different

Results and discussion

Effects of temperature and relative humidity on the water vapour permeability and mechanical properties of cassava starch-soy protein edible films

Variation in quality characteristics of edible films prepared from cassava starch and soy protein blends at different temperatures and relative humidities is shown in Tables 1, 2 and 3. The mechanical properties of edible films prepared from cassava starch and soy protein concentrate were temperature and relative humidity dependent. At 50 % relative humidity and temperature range between 10 and 40 °C; tensile, elastic modulus and elongation at break of film values ranged from 20.1 to 24.9 MPa, 40.8 to 66.7 MPa and 7.3 to 11.5 % respectively while at 80 % relative humidity, the tensile strength, elastic modulus and elongation at break ranged from 19.4 to 23.9 MPa, 39.1 to 65.4 MPa and 7.1 to 11.2 % respectively (Tables 1, 2 and 3). Tensile strength increased slightly with increase in temperature at a constant relative humidity but decreased with increase in relative humidity (Table 1). Higher elastic modulus was obtained at higher temperature and low relative humidity. Elongation at break increased with higher relative humidity and lower temperature. On the other hand, tensile strength and elastic modulus increased slightly with increase in temperature at a constant relative humidity while elongation at break decreased. The decrease in tensile strength and elastic modulus of edible films with increase in relative humidity could be attributed to increased film moisture content with relative humidity. Films exposed to higher relative humidity contain higher amount of water than films at lower relative humidity due to moisture adsorption. According to Ashley (1985), absorbed moisture has a plasticizing effect on films prepared with proteins thereby reducing tensile strength and increasing film flexibility. The decrease in elongation at break could be due to increased starch crystallinity induced by high relative humidity in starch films (Van Soest et al. 1996). On the other hand, tensile strength and elastic modulus increased slightly with increase in temperature at a constant relative humidity while elongation at break decreased. This behavior could be attributed to film moisture content. According to Labuza (1984), the amount of water absorbed by food materials at constant relative humidity decreases with increase in temperature. This implies that less water was bound at higher temperatures decreasing film plasticizing and causing less weakening of film structure thereby improving tensile strength and elastic modulus of the films. Also, it could be deduced that increasing temperature, increased the effect of relative humidity on the films. Osés et al. (2009) reported decrease in tensile strength, elastic modulus and increase in elongation at break with increase in relative humidity for soy protein isolate and whey protein films respectively.

Table 5 Regression parameters of temperature dependence of water vapour permeability of edible films prepared from cassava starch and soy protein concentrate blends

Cassava starch: soy protein ratio	Regression parameters			
	Slope	Intercept	Activation energy (kJ/mol)	r ²
100:0	0.2	-2.1	1.9	0.9827
90:10	0.4	-2.7	3.8	0.9960
80:20	0.5	-2.8	4.3	0.9908
70:30	0.5	-2.7	4.3	0.9807
60:40	0.4	-2.6	4.0	0.9964
50:50	0.6	-3.0	5.3	0.9301

The water vapour permeability of the films at experimental conditions ranged from 2.4 to 4.6 g.mm/m².day.kPa (Table 4). Water vapour permeability of the films increased with increase in temperature and relative humidity; with a maximum value at a temperature of 40 °C and 80 % relative humidity of each of the film samples. Water vapour permeability is a phenomenon that implies water solubility and diffusion of the water molecules through the matrix of the film (Osés et al. 2009). The increase in water vapour permeability of edible films prepared from blends of cassava starch and soy protein concentrates with increase in temperature and relative humidity could be attributed to high moisture contents of the films due to moisture adsorption at high relative humidity. The

Fig. 1 Temperature dependence of water vapour permeability of edible films prepared from cassava starch and soy protein concentrate blends. Legend: hexagon = 100 % cassava starch: 0 % soy protein concentrate black circle = 90 % cassava starch: 10 % soy protein concentrate black triangle = 80 % cassava starch: 20 % soy protein concentrate black square = 70 % cassava starch: 30 % soy protein concentrate black diamond = 60 % cassava starch: 40 % soy protein concentrate white square = 50 % cassava starch: 50 % soy protein concentrate

increased moisture content in the films could have resulted in swelling, leading to expansion of biopolymer matrix which enhanced diffusion of water vapour through the edible films as temperature increases. According to Bertuzzi et al. (2007), increase in diffusivity with increasing temperature is due to enhanced motion of the polymer segments and increased energy levels of the permeating molecules; as a result permeability increases with temperature. On the other hand, the composition of the film forming solutions (especially soy protein level) also had a great impact on the properties of films considering the fact that plasticizer level was fixed (20 % glycerol) in this study based on the results of our previous report (Chinma et al. 2012). The result indicated that increasing the level of soy protein concentrates in cassava starch based films reduced the water vapour permeability of the films. This could be attributed to reduction in hydrophilic effect caused by soy protein in retarding water diffusivity through the films and improves its water vapour properties. In addition, the monolayer moisture content of cassava starch–soy protein edible films decreased with increase in temperature and soy protein concentrate level (Chinma et al. 2012). This possibly accounted for the variations in mechanical and water vapour permeability properties of the films at test conditions. The results on the effect of temperature and relative humidity on cassava starch-soy protein films reported in this study is in line with results of Kaya and Maskan (2003). They reported that temperature and relative humidity increased the water vapour permeability of edible films prepared from pestil fruit and starch.

Temperature dependence on water vapour permeability

The activation energy of water vapour permeation defines the energy barrier that needed to be overcome for molecules to permeate through the edible film membrane. The activation energy of permeation of cassava starch-soy protein concentrate edible films ranged from 1.9 to 5.3 kJ/mol (with $r^2 \geq 0.93$) and increased with increase in soy protein concentrate addition in the blend (Table 5). This implies that the water vapour permeability of the films decrease with increase in soy protein concentrate addition in the blends. The increase in activation energy of permeation of cassava starch films with increase in soy protein concentrate addition in the blends could be attributed to reduction in hydrophilic effect caused by cassava starch. Also, the activation energy of edible films prepared from cassava starch-soy protein concentrate blends decreased with increase in temperature and therefore followed Arrhenius relationship (Fig. 1). This could be due to the fact that higher activation energy of cassava films due to soy protein addition resulted to the films being more sensitive to temperature change and therefore selectivity decreased significantly with an increase in temperature. The activation energy of water vapour permeation obtained in this study was lower than

synthetic films such as polyvinylidene chloride (61.9 kJ/mol), polypropylene (42.2–65.3 kJ/mol), polyethylene (33.4–61.7 kJ/mol) but higher than cellophane (1.67 kJ/mol) as reported by Rogers et al. (1982).

Conclusions

The mechanical properties and water vapour permeability of edible films prepared from cassava starch and soy protein concentrate blends were temperature and relative humidity dependent. The temperature dependence of water vapour permeation of cassava starch-soy protein concentrate films followed the Arrhenius relationship. Activation energy of water vapour permeation of cassava starch films increase with increase in soy protein concentrate addition and this indicates low water vapour permeability of the biofilms compared to synthetic films.

Acknowledgments The corresponding author is grateful to Federal University of Technology, Minna, Nigeria for the award of postgraduate fellowship.

References

- Akbari Z, Ghomashchi T, Moghadam S (2007) Improvement in food packaging industry with biobased nanocomposites. *Int J Food Eng* 3(4):3
- Arvanitoyannis I, Biliaderis CG (1998) Physical properties of polyol-plasticized edible films made from sodium caseinate and soluble starch blends. *Food Chem* 62(3):333–342
- Arvanitoyannis I, Psomiadou E, Yamamoto N (1997) Edible films made from sodiumcaseinate, starches, sugars or glycerol, part 1. *Carb Polym* 31:179–192
- Ariahu CC, Kaze SA, Achem CD (2006) Moisture sorption characteristics of tropical fresh water crayfish. *J Food Eng* 75:355–363
- Ashley RJ (1985) Permeability and plastic packaging. In: Comyn J (ed) *Polymer permeability*. Elsevier Applied Science Publishers, London, pp 269–308
- Bertuzzi MA, Armada M, Gottifredi JC (2007) Physicochemical characterization of starch based films. *J Food Eng* 82:17–25
- Bourtoom T, Chinnan MS (2008) Preparation and properties of rice starch-chitosan blend biodegradable film. *LWT - Food Sci Tech* 41:1633–1641
- Chinma CE, Ariahu CC, Abu JO (2012) Development and characterization of edible films based on cassava starch and soy protein concentrate blends. *Int J Food Sci Techn* 47(2):383–389
- Chinma CE, Ariahu CC, Alakali JS (2013) Moisture sorption and thermodynamic properties of cassava starch and soy protein-based edible films. *Int J Food Sci Tech* 48(11):2400–2407
- Cho SY, Rhee C (2002) Sorption characteristics of soy protein films and their relation to mechanical properties. *Lebensm Wiss Technol* 35: 151–157
- Hong S, Krotcha JM (2006) Oxygen barrier performance of whey-protein coated plastic films as affected by temperature, relative humidity, base film and protein type. *J Food Eng* 73(3):484–493
- Ihekonye AL, Ngoddy PO (1985) *Integrated food science and technology for the tropics*. Macmillan publishers, London, pp 252–253

- Kaya S, Maskan A (2003) Water vapor permeability of pestil (a fruit leather) made from boiled grape juice with starch. *J Food Eng* 57: 295–299
- Kokoszka S, Debeaufort F, Hambleton A, Lenart A, Voilley A (2010) Protein and glycerol contents affect physico-chemical properties of soy protein isolate-based edible films. *Innovative Food Sci Emerg Technol*. doi:10.1016/j.ifset.2010.01.006
- Labuza TP (1984). Determination of moisture sorption isotherms. In: *Moisture Sorption: Practical Aspects of Isotherm Measurement and Use*. St. Paul, MN: American Association of Cereal Chemists, pp. 64–73.
- Mali S, Grossmann M, García M, Martino M, Zaritzky N (2008) Antiplasticizing effect of glycerol and sorbitol on the properties of cassava starch films. *Braz J Food Tech* 11:194–200
- Mali S, Grossmann M, García M, Martino M, Zaritzky N (2005) Mechanical and thermal properties of yam starch films. *Food Hydroids* 19:157–164
- Nasri N, El Tinay NA (2007) Functional properties of fenugreek protein concentrate. *Food Chem* 103:582–589
- Osés J, Fabregat-Vázquez M, Pedroza-Islas R, Tomás SA, Cruz-Orea A, Maté JI (2009) Development and characterization of composite edible films based on whey protein isolate and mesquite gum. *J Food Eng* 92:56–62
- Parra DF, Tadini CC, Ponce P, Lugo AB (2004) Mechanical properties and water vapor transmission in some blends of cassava starch edible films. *Carb poly* 58:475–481
- Phan The D, Debeaufort F, Voilley A, Luu D (2009) Biopolymer interactions affect the functional properties of edible films based on agar, cassava starch and arabinoxylan blends. *J Food Eng* 90: 548–558
- Regalado C, Perez-Perez C, Lara-Cortes E, Garcia-Almendarez B (2006) Whey protein based edible food packaging films and coatings. *Advances in Agricultural and Food Biotechnology* Editors: Ramón Gerardo Guevara-González and Irineo Torres-Pacheco. Pp 237–261
- Rhim JW, Wu Y, Weller CL (2000) Physical characteristics of a composite film of soy protein isolate and propylene glycol alginate. *J Food Sci* 64:149–152
- Rogers CE, Fels M, Li NN (1982) Separation by permeation through polymeric membranes. In: Li NN (ed) *Recent developments in separation science*. CRC Press, Florida, pp 107–152
- Ruegg M (1980) Calculation of the activity of water in sulfuric acids solution at various temperatures. *Lebensmittel-wiss and Tech* 13: 22–24
- Steel RDG, Torrie JH (1980) *Principles and procedures of statistics. A Biometrical approach*. 2nd edn. McGraw Hill Co. New York p 623
- Van Soest JJG, Hulleman SHD, de Wit D, Vliegthart JFG (1996) Crystallinity in starch bioplastics. *Ind Crps Prdts* 5(1):11–22
- Were L, Hettiarachchy NS, Coleman MC (1999) Properties of cysteine-added soy protein-wheat gluten films. *J Food Sci* 64: 514–518