Storage stability of banana chips in polypropylene based nanocomposite packaging films

M. R. Manikantan · Rajiv Sharma · R. Kasturi ·
N. Varadharaju

Revised: 14 August 2012 / Accepted: 28 August 2012 / Published online: 6 September 2012
© Association of Food Scientists & Technologists (India) 2012

Abstract In this study, polypropylene (PP) based nanocomposite films of 15 different compositions of nanoclay, compatibilizer and thickness were developed and used for packaging and storage of banana chips. The effect of nanocomposite films on the quality characteristics viz. moisture content (MC), water activity (WA), total color difference (TCD), breaking force (BF), free fatty acid (FFA), peroxide value(PV), total plate count (TPC) and overall acceptability score of banana chips under ambient condition at every 15 days interval were studied for 120 days. All quality parameters of stored banana chips increased whereas overall acceptability scores decreased during storage. The elevation in FFA, BF and TCD of stored banana chips increased with elapse of storage period as well as with increased proportion of both nanoclay and compatibilizer but decreased by reducing the thickness of film. Among all the packaging materials, the WA of banana chips remained lower than 0.60 i.e. critical limit for microbial growth up to 90 days of storage. The PV of banana chips packaged also remained within the safe limit of 25 meq oxygen kg⁻¹ throughout the storage period. Among all the nanocomposite films, packaging material having 5 % compatibilizer, 2 % nanoclay & 100 µm thickness (treatment E) and 10 % compatibilizer, 4 % nanoclay & 120 µm thickness (treatment N) showed better stability of measured quality characteristics of banana chips than any other treatment.

Keywords Banana chips · Storage · Nanocomposite · Packaging · Quality

Introduction

Banana chips are very popular value added snack foods which are generally consumed in southern parts of India. They are generally packaged in different polymer films, aluminium foil, glass and tin containers. The main causes of spoilage in banana chips are moisture absorption, rancidity, breakage and environmental factors such as oxygen, temperature, light and relative humidity during handling. Shelf-life tests of chips must be related to critical deterioration factors (chemical, physical & sensory) and in this respect, the problem of moisture absorption is more serious than that of oxygen exposure (Ammawath et al. 2002). Due to short shelf-life of processed products, one of the most important means of reducing losses is the introduction of improved packaging material along with improved packaging techniques. To ensure profitable sales, the deep-fat-fried banana chips have to be shelf-stable and crisp when they are consumed (Sacharow and Griffin 1980). In the processing and storage of banana chips, proper packaging is important to preserve the quality during storage and marketing (Callegarin et al. 1997; Juin et al. 1982).

Commercially available polymer based food packaging materials exhibit both oxygen & water vapor permeability and food processing industry demands a packaging material with less permeability and more bearing strength which will be an alternative to the expensive multi layer films. Nanocomposite technology is one of the approaches to achieve the above requirement. Polymer nanocomposites consist of resins (either thermoset or thermoplastics) and nano fillers enhances the barrier performance to ultraviolet rays, strength, stiffness, dimensional stability, optical properties and heat resistance (Sinha Ray and Okamoto 2003).

M. R. Manikantan · R. Sharma (✉)
Central Institute of Post Harvest Engineering and Technology,
PAU Campus,
Ludhiana 141004, India
e-mail: sharmapau@yahoo.co.in

R. Kasturi · N. Varadharaju
Post Harvest Technology Centre,
Tamil Nadu Agricultural University,
Coimbatore 641003, India

Polypropylene (PP) has the lowest density and highest melting point of all the high volume usage thermoplastics and has a relatively low cost. This versatile plastic can be processed in many ways and has many food packaging applications in both flexible film and rigid form. PP is chemically inert and resistant to most commonly found chemicals, both organic and inorganic. It is a barrier to water vapour and has oil and fat resistance. PP is not subject to environmental stress cracking (Kirwan and Strawbridge 2003).

Manikantan and Varadharaju (2011) studied the effect of compatibilizer, nanoclay and thickness of film on oxygen transmission rate (OTR), water vapor transmission rate (WVTR), tensile strength and percent elongation of PP based nanocomposite films and found 21.4 % and 28.1 % reduction in OTR and WVTR respectively, whereas 71.7 % increase in the tensile strength of PP based nanocomposite films over the control. OTR and WVTR decreased with decrease of both nanoclay & compatibilizer and increase of film thickness whereas, opposite trend was observed in case of tensile strength and percent elongation. Ammawath et al. (2002) stored deep-fat fried banana chips for 8 weeks at ambient temperature (27 °C) using four types of packaging material viz. laminated aluminium foil (LAF), oriented polypropylene (OPP), polypropylene (PP) and low-density polyethylene (LDPE). The moisture content, water activity and breaking force values of all samples increased during storage. The hunter color values (L = lightness, a = redness/greenness & b = yellowness/blueness) showed higher L and lower a & b values during storage. The most notable sensory change that occurred during storage was decrease in crispness. Samples packed in LAF exhibited higher scores, whilst LDPE gave the lowest scores for crispness and odour than any other sample during storage. Sandhu and Bawa (1993) found that the potato chips packed in aluminum foil of 0.02 mm thickness had very good acceptability even after 90 days of storage under ambient conditions (14–34 °C and 45–77 % RH), while the chips stored in polyethylene (100 µm) remained acceptable up to 60 days under similar conditions of storage. Sabikhi and Tiwari (1999) stated that chips are sensitive to water vapor (loss of crispiness), light (rancidity of fat) and mechanical damage. Therefore, packaging material for chips must be light proof and impermeable to water vapor and gases. The authors recommended packaging materials such as polypropylene, aluminium foil and laminates with water vapor permeability less than 10 g m⁻² day⁻¹. Bal et al. (2002) reported that aluminium foil exhibited better moisture barrier than polyethylene and laminated paper. Aluminium foil gave a shelf-life of 90 days to the potato chips fried in sunflower oil under ambient conditions. Silva et al. (2004) evaluated the lipid oxidation in potato chips and reported that the most effective conditions in order to avoid/delay lipid oxidation at room temperature

were storage with an oxygen scavenger. Krishnankutty et al. (1981) studied the packaging and storage studies of deep fat fried banana chips in inert gas packaging at ambient conditions for 6 months.

The effects of nanomaterials and compatibilizer based packaging material on the shelf life of banana chips have not been studied so far. Hence, the present study was undertaken to study the storage stability of banana chips in developed polypropylene (PP) based nanocomposite food packaging films at ambient room temperature.

Materials and methods

Experimental design Polypropylene based nanocomposite films of 15 different compositions of nanoclay and compatibilizer were developed based on the procedure followed by Manikantan and Varadharaju (2011) and evaluated for storage stability of banana chips. The details for the development of PP based nanocomposite films of different composition of nanoclay, compatibilizer & thickness and their barrier characteristics (OTR & WVTR) are given in Table 1.

Materials for film fabrication Repol H100EY grade PP granules from M/s Reliance Industries Limited, India were selected for this study. The melt flow index and density of PP granules as per the manufacturer is 11.0 g/10 min and 0.9 g/cm³ respectively. The compatibilizer used for the fabrication of nanocomposite films was Exxelor PO 1020 grade maleic anhydride grafted polypropylene procured from M/s ExxonMobile Chemical Company, Houston, Texas, USA. The maleic anhydride level in the compatibilizer was ranged from 0.5 wt.% to 1.0 wt.%. The melt flow index and density of the compatibilizer as per the manufacturer is 12.5 g/10 min and 0.9 g/cm³ respectively. The nanomaterial of montmorillonite clay was used in this study. The montmorillonite clay was surface modified with 15–35 wt.% of octadecyl amine and 0.5–5 wt.% of aminopropyltriethoxysilane. The nanoclay, Nanomer[®] was procured from M/s. Nanocor, USA. The nanoclay used in the study was having particle size within a range 16–20 µm, density of 1.9 gcm⁻³ and interlayer distance of 2.2 nm.

Experimental procedure for film fabrication The PP granules, compatibilizer and nanoclay were taken according to the composition prescribed in the experimental design (Table 1). The nanoclay was dried at 60 °C in the hot air oven prior to the mixing. The raw materials were thoroughly mixed for about 15 min. The mixture was fed into the high-performance co-rotating twin screw extruder (ZE-25 model, Berstorff Maschinenbau GmbH D-3000, Hannover, Germany) at a feed rate of 2.5 kg/h to get compounded

Table 1 Composition and barrier characteristics of developed nanocomposite films used for packaging of banana chips

Treatment	Composition of packaging film				Barrier characteristics	
	Polypropylene, %	Compatibilizer, %	Nanoclay, %	Thickness, μm	OTR, $\text{cc m}^{-2} \text{ day}^{-1} \text{ atm}^{-1}$	WVTR, $\text{g m}^{-2} \text{ day}^{-1}$
A	93	5	2	50	1,398	3.1
B	83	15	2	50	1,524	4.1
C	89	5	6	50	1,477	3.6
D	79	15	6	50	1,541	5.0
E	93	5	2	100	924	1.7
F	83	15	2	100	1,072	1.9
G	89	5	6	100	950	1.7
H	79	15	6	100	1,094	2.0
I	86	10	4	75	1,498	3.7
J	94.4	1.6	4	75	1,289	1.9
K	77.6	18.4	4	75	1,446	2.2
L	89.4	10	0.6	75	1,139	2.4
M	86	10	4	35	2,035	5.7
N	86	10	4	120	919	2.0
Control	100	0	0	100	1,169	3.3

OTR oxygen transmission rate; WVTR water vapor transmission rate

materials of nanocomposites. The screw speed was set at 200 rpm. The temperature of nine zones of extruder was set between 150 °C and 222 °C. Pale-yellow or pale-brown strands of the compounds according to the nanoclay content were obtained through the die. The strands coming out of the die were cooled in a water bath, pelletized with a Dynaspede Granulator (CC-40S Model, M/s Dynaspede Integrated Systems Private Limited, Hosur, India) at 700–750 rpm and dried in a hot air oven at 60 °C. The dried granulated compounds were then fed into Dr Collin multilayer blown film plant (Dr Collin GmbH, Ebersberg, Germany) for fabricating nanocomposite films. The capacity of the plant is 10 kg/h with a screw speed of 50 rpm. A total of 15 types (treatments) of nanocomposite films and control were fabricated. The prepared nanocomposite films were stored at ambient condition (28 °C mean temperature and 60 % mean relative humidity) for further testing (Manikantan and Varadharaju 2011).

Sample preparation The fresh banana chips ($2 \text{ mm} \pm 0.5$) of cv. *Nendran* were procured from the local market. For the preparation of banana chips, fully matured unripe banana fruits were manually peeled, steeped in 2 % sodium chloride salt solution for 15 min, wiped with cloth and 1.75 to 2 mm thick uniform slices were chipped using hand slicer and directly put into the coconut oil frying medium at 160 °C, keeping fat and material ratio 4:1. The banana chips were fried in batches of 500 g each. At the end of frying, the salt was sprinkled at the rate of 0.6 % of the fresh material. The fried chips were drained in a perforated stainless aluminium tray and then sun-dried for 10 min.

The pouches ($15 \times 10 \text{ cm}$) of developed nanocomposite material were prepared using a sealing machine (Sevana, India). Banana chips (50 g) were packaged in the prepared pouches and sealed. Three pouches of each packaging material as replicates were used for quality evaluation of banana chips for every storage interval. The fresh chips were subjected to initial quality evaluation before packaging.

The chips packaged in prepared nanocomposite based pouches were considered as treated and the chips packed in plain polypropylene pouches were considered as untreated (control) samples (Table 1). The sealed packages were then stored at ambient condition (Temperature and relative humidity were 20.2–32.5 °C and 50.8–71.3 % respectively). The quality evaluation was undertaken after every 15 days during storage for 120 days.

Storage studies Moisture content of banana chips was determined by digital moisture meter (MA150, Sartorius, Germany) using standard procedure (AOAC 2000). The hunter color values (L = lightness, a = redness/greenness & b = yellowness/blueness) of banana chips were measured using Hunter's colorimeter (Mini Scan XE Plus Hunter Associates Lab inc., Reston, Virginia, USA) and the total color difference was calculated (Fernande et al. 2011). For color determination, 10–12 banana chips samples were filled in the circular (6.25 cm diameter) glass cell provided with the instrument. An automated water activity meter (M/s. Aqua lab, USA) was used to determine the water activity of banana chips. Texture Analyzer (TA-HDi, Stable Micro System, UK) was used to determine the crispiness of banana

chips in terms of the breaking force. The biochemical parameters of banana chips such as peroxide value (PV) and free fatty acids (FFA) were analyzed as per AOCS (1989). For total plate count, aseptically drawn sample (1 g) was homogenized in 9 ml sterile distilled water for 30 s. The test tubes containing various dilutions were vortexed to suspend the microbes homogeneously. Inoculum (0.1 ml) from different tubes containing micro-flora from Banana chips were plated on nutrient agar (Himedia India) plates. After spreading, plates were incubated at $37\text{ }^{\circ}\text{C}\pm 1$ for bacterial growth. After incubation, viable plate count was taken to record the microbial growth as logarithmic colony forming unit per gram (Akubor and Adejo 2000). The sensory attributes for overall acceptability were scored using 9 point hedonic scale (Liked extremely = 9, Liked very much = 8, Liked moderately = 7, Liked slightly = 6, Neither liked nor disliked = 5, Disliked slightly = 4, Disliked moderately = 3, Disliked very much = 2, Disliked extremely = 1). A group of semi-trained panelist consisting of 15 faculty members (10 males and 5 females, age 23 to 55) were selected voluntarily from the Department of Food and Agricultural Process Engineering, Agricultural Engineering College and Research Institute, Tamil Nadu Agricultural University, Coimbatore. Before the actual sensory evaluation, the panel was trained and instructed for the sensory attributes to be evaluated so as to get familiar with the sensory procedure.

Statistical analysis Duncan's multiple range test (DMRT) was used to separate significant differences in mean values

of the measured parameters (Ananthan et al. 2012). The analysis of variance test (ANOVA) was carried out using SPSS 7.5 software and statistical procedures described by Gomez and Gomez (1984) to examine the effect of storage period and storage temperature on the measured quality parameters of stored banana chips.

Results and discussion

Moisture content The moisture content of banana chips increased during storage (Table 2). The increase in moisture content was less for 60 days of storage and then it was more for the remaining period. The initial moisture content of banana chips was determined as 2.6 % dry basis (d.b) and after 120 days of storage it ranged between 5.3 % and 9.3 % (d.b.). Banana chips packaged in the treatment N exhibited minimum increase of moisture content (103.8 %) and the maximum increase was observed in treatment M (257.7 %). The moisture increase may be due to the water vapor transmission characteristics of the packaging film (Purohit and Rajyalakshmi 2011; Jagdeesh et al. 2007). The WVTR of treatment N & M were 2.1 and $5.7\text{ gm}^{-2}\text{ day}^{-1}$ respectively (Table 1) and was responsible for the difference in moisture content of the chips. Higher moisture content was observed in the packaging film having higher clay and compatibilizer level and lower film thickness. At higher film thicknesses, due to the insertion of nanoclay in the polymer medium, there will be blockage and more length of pathway for the

Table 2 Effect of treatments on moisture content (% dry basis) of banana chips during storage

Treatment	Storage period, days							
	15	30	45	60	75	90	105	120
A	2.7±0.15 ^{aA}	3.0±0.16 ^{bAB}	3.1±0.25 ^{cAB}	3.2±0.37 ^{dA}	4.2±0.21 ^{eB}	5.6±0.35 ^{fD}	6.6±1.05 ^{gH}	8.0±0.56 ^{hGH}
B	3.4±0.22 ^{aD}	3.8±0.42 ^{bEF}	4.0±1.05 ^{cD}	4.4±1.25 ^{dDE}	4.8±1.14 ^{eDE}	5.4±0.85 ^{fD}	5.8±1.08 ^{gEF}	6.4±0.78 ^{hDE}
C	2.7±0.63 ^{aA}	3.7±1.07 ^{bDE}	4.3±1.11 ^{cE}	5.1±0.58 ^{dE}	5.7±0.63 ^{eG}	6.6±1.06 ^{fF}	7.3±0.85 ^{gJ}	8.1±0.45 ^{hH}
D	3.7±1.14 ^{aE}	4.9±1.21 ^{bH}	4.9±1.32 ^{cHI}	5.1±0.71 ^{dE}	5.7±0.23 ^{eG}	6.6±0.65 ^{fF}	7.2±1.41 ^{gIJ}	8.0±0.21 ^{hGH}
E	2.9±0.41 ^{aAB}	3.2±0.56 ^{bBC}	3.2±1.13 ^{cB}	3.4±1.21 ^{dA}	3.9±0.52 ^{eA}	4.6±1.03 ^{fAB}	5.1±0.25 ^{gB}	5.9±0.29 ^{hB}
F	2.7±1.11 ^{aA}	2.8±0.85 ^{bA}	3.0±0.23 ^{cA}	3.3±1.14 ^{dA}	3.9±1.31 ^{eA}	4.8±0.52 ^{fB}	5.4±0.33 ^{gC}	6.2±0.25 ^{hCD}
G	3.2±1.02 ^{aC}	4.3±0.91 ^{bG}	4.6±0.82 ^{cF}	5.0±1.05 ^{dF}	5.2±1.11 ^{eF}	5.5±0.28 ^{fD}	5.7±1.02 ^{gDE}	5.9±1.13 ^{hB}
H	2.7±0.85 ^{aA}	3.2±0.55 ^{bC}	3.6±1.21 ^{cC}	4.1±1.04 ^{dC}	4.5±0.85 ^{eC}	5.1±0.63 ^{fC}	5.5±1.05 ^{gCD}	6.1±0.08 ^{hBC}
I	3.7±0.19 ^{aE}	4.0±0.82 ^{bF}	4.1±0.52 ^{cDE}	4.2±0.39 ^{dCD}	4.8±0.85 ^{eD}	5.5±0.71 ^{fD}	6.0±0.29 ^{gG}	6.7±0.36 ^{hF}
J	2.7±0.52 ^{aA}	3.1±0.26 ^{bBC}	3.7±1.02 ^{cC}	4.6±1.16 ^{dE}	5.0±1.22 ^{eEF}	5.6±0.85 ^{fD}	5.9±0.66 ^{gFG}	6.6±1.04 ^{hE}
K	4.1±0.44 ^{aF}	4.5±1.05 ^{bG}	4.7±1.08 ^{cFG}	5.1±1.21 ^{dE}	5.7±0.28 ^{eG}	6.5±0.16 ^{fF}	7.0±1.06 ^{gI}	7.8±0.42 ^{hG}
L	3.9±0.08 ^{aF}	4.4±1.06 ^{bG}	4.8±0.82 ^{cGH}	5.4±0.29 ^{dF}	6.1±0.08 ^{eH}	7.1±1.05 ^{fG}	7.7±0.05 ^{gK}	8.7±0.84 ^{hI}
M	3.1±0.05 ^{aBC}	4.7±0.32 ^{bH}	5.1±1.04 ^{cI}	5.6±0.76 ^{dG}	6.4±0.43 ^{eI}	7.5±1.05 ^{fG}	8.2±0.25 ^{gL}	9.3±0.69 ^{hI}
N	2.9±1.02 ^{aAB}	3.0±0.23 ^{bAB}	3.3±0.54 ^{cB}	3.7±1.08 ^{dB}	4.0±0.25 ^{eAB}	4.5±1.13 ^{fA}	4.8±0.54 ^{gA}	5.3±0.23 ^{hA}
Control	3.4±0.23 ^{aD}	3.5±0.54 ^{bD}	3.7±0.25 ^{cC}	3.8±0.45 ^{dB}	4.7±1.05 ^{eCD}	5.9±1.08 ^{fE}	6.8±1.14 ^{gH}	8.0±0.51 ^{hGH}

*Means in same row with same small letters and in same column with same capital letters do not differ significantly at $p\leq 0.01$ ($n=3$)

A–N and Control: Refer to Table 1

Table 3 Effect of treatments on water activity of banana chips during storage

Treatment	Storage period, days									
	15	30	45	60	75	90	105	120		
A	0.23±0.063 ^{aB}	0.42±0.074 ^{bEF}	0.47±0.056 ^{cG}	0.54±0.052 ^{deH}	0.55±0.026 ^{eFG}	0.57±0.025 ^{fG}	0.58±0.032 ^{fH}	0.59±0.025 ^{fD}		
B	0.30±0.023 ^{aEF}	0.44±0.023 ^{bFGH}	0.45±0.047 ^{bEFG}	0.48±0.021 ^{cG}	0.51±0.024 ^{dG}	0.55±0.013 ^{eFG}	0.57±0.064 ^{eFG}	0.62±0.041 ^{fE}		
C	0.23±0.052 ^{aB}	0.45±0.041 ^{bGH}	0.45±0.025 ^{bEFG}	0.46±0.062 ^{bEFG}	0.51±0.012 ^{cG}	0.57±0.056 ^{dG}	0.62±0.045 ^{el}	0.69±0.012 ^{fG}		
D	0.26±0.045 ^{aCD}	0.44±0.033 ^{bFGH}	0.44±0.014 ^{bDEF}	0.45±0.062 ^{bDEF}	0.50±0.026 ^{cG}	0.57±0.045 ^{dG}	0.62±0.041 ^{el}	0.70±0.052 ^{fG}		
E	0.19±0.012 ^{aA}	0.42±0.044 ^{bEF}	0.42±0.071 ^{bbCD}	0.43±0.021 ^{bd}	0.45±0.071 ^{cCDE}	0.48±0.074 ^{dBCD}	0.50±0.012 ^{eAB}	0.53±0.025 ^{eA}		
F	0.23±0.047 ^{aB}	0.39±0.023 ^{bCD}	0.40±0.041 ^{bb}	0.40±0.033 ^{bb}	0.43±0.048 ^{bc}	0.47±0.029 ^{dABC}	0.50±0.031 ^{eAB}	0.54±0.033 ^{fAB}		
G	0.30±0.071 ^{aEF}	0.36±0.071 ^{bb}	0.37±0.045 ^{ba}	0.37±0.015 ^{ba}	0.40±0.041 ^{cA}	0.46±0.019 ^{dAB}	0.49±0.023 ^{eA}	0.54±0.061 ^{fAB}		
H	0.28±0.065 ^{aDE}	0.33±0.047 ^{bcA}	0.35±0.017 ^{ca}	0.37±0.025 ^{da}	0.41±0.012 ^{dAB}	0.47±0.021 ^{eABC}	0.51±0.045 ^{fABC}	0.56±0.023 ^{gBC}		
I	0.19±0.085 ^{aA}	0.41±0.074 ^{bDE}	0.41±0.025 ^{bbc}	0.42±0.085 ^{ebC}	0.44±0.023 ^{cCD}	0.49±0.033 ^{cCD}	0.51±0.041 ^{dABC}	0.56±0.052 ^{eBC}		
J	0.26±0.025 ^{aCD}	0.42±0.056 ^{bEF}	0.42±0.023 ^{bbCD}	0.44±0.024 ^{cDE}	0.46±0.025 ^{cDE}	0.50±0.036 ^{dd}	0.52±0.085 ^{dCD}	0.56±0.039 ^{eC}		
K	0.24±0.043 ^{aBC}	0.42±0.029 ^{bCEF}	0.43±0.031 ^{bcDE}	0.45±0.011 ^{dDEF}	0.47±0.052 ^{dEF}	0.51±0.045 ^{eE}	0.54±0.041 ^{fDE}	0.58±0.081 ^{gCD}		
L	0.32±0.023 ^{aF}	0.41±0.052 ^{bDE}	0.42±0.025 ^{bbc}	0.43±0.021 ^{cd}	0.46±0.045 ^{cDE}	0.50±0.021 ^{dd}	0.53±0.045 ^{cCDE}	0.57±0.074 ^{fCD}		
M	0.32±0.045 ^{aF}	0.46±0.036 ^{bH}	0.46±0.041 ^{bFG}	0.47±0.069 ^{efG}	0.49±0.025 ^{cFG}	0.53±0.085 ^{def}	0.55±0.046 ^{eFG}	0.59±0.063 ^{eD}		
N	0.29±0.019 ^{aE}	0.37±0.023 ^{bBC}	0.37±0.019 ^{ba}	0.37±0.063 ^{ca}	0.40±0.085 ^{ca}	0.45±0.074 ^{da}	0.46±0.029 ^{deA}	0.48±0.025 ^{eA}		
Control	0.37±0.074 ^{aF}	0.43±0.012 ^{bEFG}	0.44±0.071 ^{bDF}	0.45±0.036 ^{dDEF}	0.50±0.045 ^{cG}	0.56±0.065 ^{dG}	0.60±0.071 ^{eHI}	0.67±0.052 ^{fF}		

*Means in same row with same small letters and in same column with same capital letters do not differ significantly at $p \leq 0.01$ ($n=3$)

A–N and Control: Refer to Table 1

water vapor molecule to travel inside the film. This may be the reason for lower WVTR and moisture content of banana chips in treatment E and N (Manikantan and Varadharaju 2011). Krishnankutty et al. (1981) also observed increase in moisture content of banana chips packaged in HDPE and LDPE films.

Water activity The initial water activity of the fresh banana chips was 0.16 and it is evident that water activity of the banana chips increased with the storage period (Table 3). An increase in water activity showed that the water vapor was able to permeate from outside. The level of nanoclay, compatibilizer and film thickness influenced the water vapor permeability. At lower level of nanoclay (2 %) & compatibilizer (5 %) and higher level of film thickness (100–120 μm), due to uniform scattering of nanoclay in the polymer matrix, more tortuous path is created for water vapor molecule to travel in the film (Manikantan and Varadharaju 2011). The water activity ranged between 0.48 and 0.70 during storage. The maximum increase in water activity (337.5 %) was observed in the D package and minimum (200 %) in N and E packaging treatment. As foods with water activity lower than 0.60 are essentially free from microbial growth (Irawandi et al. 1998). In this study, the water activity of all the treated samples remained less than 0.60 after 90 days of storage. However, at the end of 120 days of storage, the samples of the treatment B, C, D and control were having the water activity higher than 0.60. The water vapor transmission rate of the treatments B (4.1 g

$\text{m}^{-2}\text{day}^{-1}$), C (3.6 $\text{g m}^{-2}\text{day}^{-1}$), D (5.0 $\text{g m}^{-2}\text{day}^{-1}$) and control (3.3 $\text{g m}^{-2}\text{day}^{-1}$) were comparatively more than the other treatments (Table 1) and hence increased water activity was observed. The results were in good agreement with Ammawath et al. (2002) who found an increase in water activity of banana chips stored in PP films.

Color difference value The initial value of total color difference was observed as 1.1 and then it increased gradually with storage period (Table 4). This clearly indicates the discoloration in the banana chips during storage. The maximum color difference (18.6) was observed at the end of 120 days in the control samples and minimum (6.7) in the treatment G. This variation might be due to the differences in the transmittance of light of the developed nanocomposite packages used in the experiment. Generally, PP films are clear and more transparent than other polymer films. Hence, light is able to enter into the package and influence the color of the packaged material (Kirwan and Strawbridge 2003). But, on addition of nanoclay and compatibilizer, the light transmission inside the polymer matrix due to the dispersion of nanoclay is reduced and hence the color difference of stored banana chips in the developed nanocomposite films with higher clay and compatibilizer content (Treatment G and H) was significantly less than the control. This may be partly due to the opaque appearance caused by the interaction between polymer matrix and nanoclay. The opaque appearance of the nanocomposite films hinders light transmission through the films resulting in the reduced film transparency.

Table 4 Effect of treatments on hunter colour difference value of banana chips during storage

Treatment	Storage period, days							
	15	30	45	60	75	90	105	120
A	5.2 $\pm$ 0.21 ^{aG}	6.1 $\pm$ 0.52 ^{bE}	6.6 $\pm$ 0.23 ^{cE}	7.4 $\pm$ 0.28 ^{dF}	8.5 $\pm$ 0.41 ^{eEF}	10.2 $\pm$ 0.67 ^{fH}	13.1 $\pm$ 0.16 ^{gL}	16.3 $\pm$ 0.27 ^{hK}
B	4.0 $\pm$ 0.32 ^{aE}	5.6 $\pm$ 0.36 ^{bD}	6.2 $\pm$ 0.36 ^{cD}	7.2 $\pm$ 0.25 ^{dE}	8.0 $\pm$ 0.52 ^{eC}	9.4 $\pm$ 0.36 ^{fF}	11.9 $\pm$ 0.22 ^{gJ}	14.6 $\pm$ 0.36 ^{hJ}
C	4.1 $\pm$ 0.41 ^{aE}	6.3 $\pm$ 0.42 ^{bF}	7.4 $\pm$ 0.29 ^{cG}	9.2 $\pm$ 0.62 ^{dI}	9.8 $\pm$ 0.33 ^{eH}	10.6 $\pm$ 0.21 ^{fI}	12.1 $\pm$ 0.55 ^{gJ}	13.7 $\pm$ 0.41 ^{hH}
D	3.3 $\pm$ 0.52 ^{aCD}	4.2 $\pm$ 0.74 ^{bB}	5.5 $\pm$ 0.74 ^{cB}	7.5 $\pm$ 0.22 ^{dF}	8.1 $\pm$ 0.28 ^{eC}	9.0 $\pm$ 0.17 ^{fE}	10.6 $\pm$ 0.19 ^{gG}	12.3 $\pm$ 0.21 ^{hF}
E	3.1 $\pm$ 0.32 ^{aC}	4.0 $\pm$ 0.57 ^{bB}	5.5 $\pm$ 0.58 ^{cB}	8.3 $\pm$ 0.24 ^{dH}	8.6 $\pm$ 0.63 ^{eF}	9.2 $\pm$ 0.54 ^{fE}	10.1 $\pm$ 0.25 ^{gF}	11.1 $\pm$ 0.36 ^{hE}
F	3.3 $\pm$ 0.41 ^{aC}	4.9 $\pm$ 0.38 ^{bC}	5.4 $\pm$ 0.69 ^{cB}	6.0 $\pm$ 0.31 ^{dB}	6.6 $\pm$ 0.19 ^{eB}	7.4 $\pm$ 0.35 ^{fC}	8.7 $\pm$ 0.62 ^{gD}	10.2 $\pm$ 0.29 ^{hC}
G	4.0 $\pm$ 0.74 ^{aE}	5.5 $\pm$ 0.29 ^{bD}	5.9 $\pm$ 0.45 ^{cC}	6.5 $\pm$ 0.72 ^{dC}	6.5 $\pm$ 0.63 ^{eB}	6.6 $\pm$ 0.19 ^{fA}	6.6 $\pm$ 0.41 ^{gA}	6.7 $\pm$ 0.36 ^{hA}
H	3.5 $\pm$ 0.69 ^{aD}	5.0 $\pm$ 0.34 ^{bC}	5.4 $\pm$ 0.19 ^{cB}	6.0 $\pm$ 0.82 ^{dB}	6.7 $\pm$ 0.52 ^{eB}	7.0 $\pm$ 0.21 ^{fB}	7.7 $\pm$ 0.74 ^{gB}	7.8 $\pm$ 0.52 ^{hB}
I	5.2 $\pm$ 0.65 ^{aG}	7.0 $\pm$ 0.52 ^{bH}	7.3 $\pm$ 0.78 ^{cFG}	7.8 $\pm$ 0.45 ^{dG}	8.5 $\pm$ 0.36 ^{eEF}	9.7 $\pm$ 0.65 ^{fG}	11.6 $\pm$ 0.25 ^{gI}	13.8 $\pm$ 0.59 ^{hH}
J	4.3 $\pm$ 0.42 ^{aF}	6.3 $\pm$ 0.36 ^{bEF}	6.8 $\pm$ 0.96 ^{cE}	7.8 $\pm$ 0.32 ^{dG}	8.2 $\pm$ 0.25 ^{eCD}	8.8 $\pm$ 0.32 ^{fD}	9.8 $\pm$ 0.41 ^{gE}	10.9 $\pm$ 0.84 ^{hD}
K	2.9 $\pm$ 0.31 ^{aB}	6.7 $\pm$ 0.42 ^{bG}	7.1 $\pm$ 0.38 ^{cF}	7.8 $\pm$ 0.15 ^{dG}	8.5 $\pm$ 0.19 ^{eEF}	9.5 $\pm$ 0.36 ^{fFG}	11.2 $\pm$ 0.36 ^{gH}	13.1 $\pm$ 0.52 ^{hG}
L	3.3 $\pm$ 0.43 ^{aC}	6.7 $\pm$ 0.75 ^{bG}	7.4 $\pm$ 0.42 ^{cG}	8.3 $\pm$ 0.62 ^{dH}	9.1 $\pm$ 0.28 ^{eG}	10.2 $\pm$ 0.31 ^{fH}	12.0 $\pm$ 0.28 ^{gJ}	14.2 $\pm$ 0.26 ^{hI}
M	7.1 $\pm$ 0.25 ^{aH}	7.8 $\pm$ 0.29 ^{bI}	8.6 $\pm$ 0.35 ^{cH}	9.8 $\pm$ 0.41 ^{dJ}	10.3 $\pm$ 0.37 ^{eI}	11.2 $\pm$ 0.42 ^{fJ}	12.7 $\pm$ 0.42 ^{gK}	14.3 $\pm$ 0.41 ^{hI}
N	1.4 $\pm$ 0.39 ^{aA}	3.0 $\pm$ 0.62 ^{bA}	3.6 $\pm$ 0.15 ^{cA}	4.5 $\pm$ 0.52 ^{dA}	5.2 $\pm$ 0.45 ^{eA}	6.4 $\pm$ 0.54 ^{fA}	8.4 $\pm$ 0.26 ^{gC}	10.8 $\pm$ 0.28 ^{hD}
Control	3.5 $\pm$ 0.42 ^{aD}	5.5 $\pm$ 0.29 ^{bD}	6.1 $\pm$ 0.27 ^{cCD}	6.9 $\pm$ 0.63 ^{dD}	8.3 $\pm$ 0.51 ^{eDE}	10.5 $\pm$ 0.21 ^{fI}	14.4 $\pm$ 0.18 ^{gM}	18.6 $\pm$ 0.65 ^{hL}

*Means in same row with same small letters and in same column with same capital letters do not differ significantly at $p \leq 0.01$ ($n=3$)

A–N and Control: Refer to Table 1

Table 5 Effect of treatments on breaking force (N) of banana chips during storage

Treatment	Storage period, days									
	15	30	45	60	75	90	105	120		
A	6.4±0.36 ^{aEF}	7.2±0.63 ^{bFG}	7.3±0.25 ^{dD}	7.4±0.36 ^{dD}	7.6±0.32 ^{eB}	7.8±0.23 ^{fC}	8.1±0.36 ^{gBC}	8.5±0.58 ^{hBC}		
B	6.6±0.23 ^{aFG}	8.6±0.26 ^{bK}	9.4±0.41 ^{cH}	10.6±0.25 ^{dH}	10.7±0.25 ^{eG}	10.9±0.15 ^f	11.2±0.45 ^{gK}	11.7±0.62 ^{hG}		
C	6.3±0.52 ^{aE}	7.9±0.52 ^{bl}	7.9±0.26 ^{bF}	7.9±0.4 ^{beE}	8.1±0.36 ^{dD}	8.4±0.36 ^{eE}	8.9±0.52 ^{fF}	9.5±0.41 ^{gD}		
D	6.9±0.69 ^{aH}	7.5±0.85 ^{bH}	7.9±0.18 ^{cF}	8.5±0.19 ^{dF}	8.6±0.19 ^{eE}	8.8±0.41 ^{fF}	9.0±0.41 ^{gF}	9.4±0.85 ^{hD}		
E	5.8±0.54 ^{aAB}	6.4±0.34 ^{bB}	6.6±0.27 ^{cB}	6.9±0.77 ^{dA}	6.9±0.45 ^{eA}	7.2±0.52 ^{fA}	7.4±0.36 ^{gA}	7.5±0.41 ^{hA}		
F	6.5±0.69 ^{aEF}	6.9±0.25 ^{bDE}	7.5±0.52 ^{cE}	8.5±0.81 ^{dF}	8.5±0.25 ^{dE}	8.5±0.36 ^{deE}	8.5±0.28 ^{eE}	8.5±0.74 ^{fBC}		
G	6.0±0.45 ^{aCD}	7.3±0.41 ^{bGH}	7.3±0.41 ^{beDE}	7.4±0.74 ^{cCD}	7.5±0.52 ^{dB}	7.8±0.41 ^{cC}	8.2±0.63 ^{fCD}	8.7±0.85 ^{gC}		
H	5.9±0.85 ^{aBC}	6.6±0.16 ^{bC}	6.8±0.72 ^{cC}	7.2±0.55 ^{dBC}	7.4±0.41 ^{eB}	7.7±0.74 ^{fC}	8.2±0.85 ^{gBC}	8.7±0.17 ^{hC}		
I	6.8±0.74 ^{aH}	8.4±0.25 ^{bJ}	8.7±0.28 ^{cG}	9.3±0.63 ^{dG}	9.5±0.36 ^{eF}	9.8±0.25 ^{fH}	10.2±0.69 ^{gI}	10.7±0.26 ^{hF}		
J	6.9±0.36 ^{aH}	7.2±0.29 ^{bFG}	7.2±0.36 ^{dD}	7.4±0.52 ^{dD}	7.5±0.27 ^{eB}	7.7±0.39 ^{fC}	8.0±0.25 ^{gBC}	8.4±0.41 ^{hB}		
K	6.1±0.49 ^{aCD}	6.7±0.31 ^{bCD}	7.0±0.41 ^{cC}	7.4±0.69 ^{dD}	7.8±0.69 ^{eC}	8.5±0.85 ^{fE}	9.5±0.85 ^{gG}	10.7±0.25 ^{hEF}		
L	6.7±0.15 ^{aGH}	7.0±0.47 ^{bEF}	7.4±0.29 ^{dDE}	8.0±0.32 ^{dE}	8.1±0.32 ^{eD}	8.2±0.29 ^{fD}	8.4±0.41 ^{gDE}	8.6±0.13 ^{hC}		
M	6.4±0.25 ^{aEF}	6.9±0.81 ^{bDE}	6.9±0.71 ^{cC}	6.9±0.41 ^{dAB}	7.8±0.48 ^{eC}	9.0±0.41 ^{fG}	11.1±0.74 ^{gJ}	13.2±0.41 ^{hH}		
N	5.6±0.42 ^{aA}	5.8±0.85 ^{bA}	6.2±0.15 ^{cA}	6.8±0.74 ^{dA}	7.0±0.98 ^{eA}	7.1±0.96 ^{fB}	7.1±0.25 ^{gB}	7.3±0.32 ^{hBC}		
Control	6.8±0.25 ^{aGH}	7.3±0.71 ^{bG}	7.8±0.42 ^{cF}	8.5±0.52 ^{dF}	9.4±0.25 ^{eF}	9.0±0.28 ^{fG}	9.7±0.69 ^{gH}	10.5±0.42 ^{hE}		

*Means in same row with same small letters and in same column with same capital letters do not differ significantly at $p \leq 0.01$ ($n=3$)

A–N and Control: Refer to Table 1

Table 6 Effect of different treatments on free fatty acids (%) of banana chips during storage

Treatment	Storage period, days									
	15	30	45	60	75	90	105	120		
A	0.65±0.042 ^{aA}	0.80±0.056 ^{bA}	0.99±0.012 ^{cA}	1.28±0.025 ^{dABC}	1.39±0.075 ^{eBC}	1.55±0.031 ^{fDE}	1.81±0.052 ^{gDE}	2.40±0.062 ^{hCDE}		
B	0.69±0.025 ^{aA}	0.86±0.044 ^{bA}	1.02±0.024 ^{cA}	1.25±0.036 ^{dABC}	1.33±0.049 ^{eABC}	1.44±0.027 ^{fABCDE}	1.63±0.063 ^{gABCD}	2.04±0.025 ^{hAB}		
C	0.55±0.063 ^{aA}	0.80±0.052 ^{bA}	0.98±0.062 ^{cA}	1.26±0.031 ^{dABC}	1.36±0.024 ^{eABC}	1.51±0.019 ^{fBCDE}	1.76±0.058 ^{gCDE}	2.31±0.028 ^{hC}		
D	0.65±0.044 ^{aA}	0.86±0.085 ^{bA}	1.06±0.054 ^{cA}	1.35±0.052 ^{dC}	1.44±0.021 ^{eC}	1.57±0.014 ^{fE}	1.79±0.025 ^{gDE}	2.32±0.063 ^{hC}		
E	0.56±0.011 ^{aA}	0.66±0.041 ^{bA}	0.84±0.058 ^{cA}	0.91±0.041 ^{dAB}	0.96±0.015 ^{eAB}	1.02±0.062 ^{fAB}	1.08±0.063 ^{gAB}	1.12±0.024 ^{hAB}		
F	0.66±0.074 ^{aA}	0.93±0.065 ^{bA}	0.99±0.041 ^{cA}	1.09±0.015 ^{dAB}	1.18±0.026 ^{eAB}	1.32±0.0036 ^{fABCD}	1.54±0.052 ^{gABC}	2.01±0.027 ^{hAB}		
G	0.62±0.015 ^{aA}	0.88±0.085 ^{bA}	0.96±0.085 ^{cA}	1.09±0.023 ^{dAB}	1.18±0.031 ^{eAB}	1.31±0.054 ^{fABC}	1.52±0.041 ^{gAB}	1.99±0.046 ^{hAB}		
H	0.73±0.019 ^{aA}	0.92±0.025 ^{bA}	0.99±0.025 ^{cA}	1.10±0.042 ^{dAB}	1.19±0.014 ^{eAB}	1.32±0.025 ^{fABCD}	1.53±0.028 ^{gABC}	2.00±0.019 ^{hAB}		
I	0.68±0.023 ^{aA}	0.97±0.036 ^{bA}	1.09±0.012 ^{cA}	1.28±0.036 ^{dABC}	1.38±0.026 ^{eBC}	1.53±0.018 ^{fCDE}	1.78±0.065 ^{gDE}	2.34±0.024 ^{hCD}		
J	0.66±0.074 ^{aA}	0.96±0.041 ^{bA}	1.05±0.026 ^{cA}	1.18±0.052 ^{dABC}	1.31±0.085 ^{eABC}	1.52±0.026 ^{fBCDE}	1.85±0.025 ^{gDE}	2.59±0.052 ^{hE}		
K	0.67±0.054 ^{aA}	0.93±0.085 ^{bA}	1.03±0.039 ^{cA}	1.17±0.065 ^{dAB}	1.27±0.025 ^{eABC}	1.42±0.063 ^{fABCDE}	1.66±0.036 ^{gABCDE}	2.20±0.012 ^{hBC}		
L	0.62±0.025 ^{aA}	0.88±0.066 ^{bA}	1.05±0.029 ^{cA}	1.30±0.052 ^{dBC}	1.39±0.036 ^{eBC}	1.52±0.25 ^{fBCDE}	1.73±0.024 ^{gBCDE}	2.19±0.023 ^{hBC}		
M	0.65±0.069 ^{aA}	0.88±0.041 ^{bA}	1.03±0.027 ^{cA}	1.26±0.085 ^{dA}	1.38±0.015 ^{eBC}	1.57±0.041 ^{fE}	1.87±0.062 ^{gE}	2.55±0.021 ^{hDE}		
N	0.52±0.015 ^{aA}	0.61±0.027 ^{bA}	0.75±0.021 ^{cA}	0.85±0.063 ^{dABC}	0.91±0.063 ^{eA}	0.93±0.047 ^{fA}	0.95±0.025 ^{gA}	1.03±0.063 ^{hA}		
Control	0.63±0.029 ^a	0.88±0.052 ^b	1.00±0.039 ^c	1.17±0.054 ^d	1.28±0.085 ^{eABC}	1.45±0.026 ^{fABCDE}	1.73±0.028 ^{gBCDE}	2.32±0.024 ^{hC}		

*Means in same row with same small letters and in same column with same capital letters do not differ significantly at $p \leq 0.01$ ($n=3$)

A–N and Control: Refer to Table 1

Table 7 Effect of different treatments on peroxide value (meq oxygen kg⁻¹) of banana chips during storage

Treatment	Storage period, days							
	15	30	45	60	75	90	105	120
A	3.2±0.63 ^{aA}	5.7±0.21 ^{bC}	7.7±0.24 ^{cD}	10.7±0.16 ^{dF}	11.2±0.52 ^{eHI}	12.1±0.52 ^{fK}	13.5±0.23 ^{gI}	17.7±0.52 ^{hF}
B	4.4±0.52 ^{aFGH}	6.1±0.14 ^{bD}	8.1±0.85 ^{eF}	11.1±.34 ^{dG}	11.4±0.19 ^{eIJ}	11.8±0.15 ^{fHI}	12.5±0.19 ^{gG}	14.5±0.24 ^{hD}
C	4.2±0.29 ^{aDEF}	5.4±0.27 ^{bAB}	7.0±0.52 ^{cC}	9.5±0.21 ^{dD}	9.9±0.36 ^{eD}	10.4±0.2 ^{fE}	11.4±0.33 ^{gD}	14.2±0.1 ^{hC}
D	4.2±0.36 ^{aDEF}	7.7±0.34 ^{bG}	8.8±0.41 ^{cG}	10.5±0.14 ^{dF}	11.1±0.15 ^{eH}	12.0±0.52 ^{fK}	13.6±0.21 ^{gIJ}	18.4±0.52 ^{hH}
E	4.5±0.82 ^{aH}	7.1±0.25 ^{bF}	7.5±0.65 ^{cD}	8.2±0.26 ^{dB}	8.7±0.2 ^{EB}	9.4±0.46 ^{FB}	10.5±0.41 ^{GB}	13.9±0.63 ^{hAB}
F	4.3±0.27 ^{aEFG}	6.9±0.41 ^{bF}	7.6±0.22 ^{cD}	8.7±0.41 ^{dC}	9.1±0.28 ^{eC}	9.7±0.29 ^{fC}	10.7±0.26 ^{gC}	13.7±0.15 ^{hA}
G	3.4±0.62 ^{aB}	5.7±0.26 ^{bC}	6.9±0.24 ^{cC}	8.7±0.26 ^{dC}	9.1±0.63 ^{eC}	9.7±0.27 ^{fC}	10.7±0.28 ^{gC}	13.7±0.41 ^{hA}
H	4.0±0.12 ^{aD}	5.2±0.14 ^{bA}	6.5±0.36 ^{CB}	8.5±0.18 ^{dC}	9.1±0.85 ^{eC}	10.0±0.85 ^{fD}	11.5±0.26 ^{gD}	14.0±0.29 ^{hBC}
I	4.1±0.24 ^{aDE}	7.9±0.72 ^{bG}	9.9±0.21 ^{cH}	12.9±0.41 ^{dH}	13.1±0.4 ^{eK}	13.4±0.41 ^{fK}	13.8±0.12 ^{gJ}	15.1±0.74 ^{hE}
J	4.6±0.81 ^{aH}	7.8±0.21 ^{bG}	8.8±0.32 ^{cG}	10.5±0.62 ^{dF}	10.8±0.22 ^{eG}	11.4±0.36 ^{fG}	12.3±0.33 ^{gF}	15.0±0.52 ^{hE}
K	3.4±0.26 ^{aB}	5.5±0.62 ^{bBC}	7.6±0.25 ^{cD}	10.7±0.52 ^{dF}	11.1±0.41 ^{eH}	11.7±0.52 ^{fH}	12.8±0.26 ^{gH}	15.0±0.63 ^{hE}
L	4.1±0.54 ^{aDE}	6.3±0.29 ^{bD}	7.7±0.63 ^{cD}	9.9±0.82 ^{dE}	10.3±0.36 ^{eF}	10.8±0.4 ^{fF}	11.8±0.21 ^{gE}	14.6±0.52 ^{hD}
M	4.5±0.26 ^{aGH}	6.9±0.34 ^{bF}	8.7±0.41 ^{cG}	11.2±0.41 ^{dG}	11.5±0.52 ^{eI}	12.0±0.26 ^{fJK}	12.8±0.28 ^{gH}	15.1±0.41 ^{hE}
N	3.7±0.81 ^{aC}	5.7±0.21 ^{bC}	6.3±0.23 ^{cA}	7.2±0.72 ^{dA}	7.8±0.82 ^{eA}	8.6±0.32 ^{fA}	9.9±0.62 ^{gA}	14.0±0.85 ^{hBC}
Control	4.5±0.63 ^{aGH}	6.6±0.28 ^{bE}	7.8±0.18 ^{cD}	9.6±0.52 ^{dD}	10.1±0.26 ^{eE}	10.7±0.75 ^{fF}	11.9±0.21 ^{gE}	15.3±0.74 ^{hG}

*Means in same row with same small letters and in same column with same capital letters do not differ significantly at $p \leq 0.01$ ($n=3$)

A–N and Control: Refer to Table 1

However, the main reason that the films lost transparency when adding the clay at higher proportions might be due to the aggregation of nano-particles which, in turn, obstruct the transmission of light (Sothornvit et al. 2010). Hong and Rhim (2012) also observed that the

transparency of the LLDPE/clay nanocomposite films decreased significantly compared to the neat LLDPE films. Ammawath et al. (2002) also observed significant variation in hunter color values of the deep fat fried banana chips packaged in laminated aluminum foil,

Table 8 Effect of different treatments on total plate count (log cfu/g) of banana chips during storage

Treatment	Storage period, days							
	15	30	45	60	75	90	105	120
A	1.9±0.03 ^{aF}	2.1±0.08 ^{bI}	2.2±0.03 ^{cN}	2.2±0.09 ^{dM}	2.3±0.03 ^{eN}	2.3±0.03 ^{fL}	2.3±0.05 ^{gL}	2.3±0.07 ^{hJ}
B	2.0±0.04 ^{aL}	2.1±0.06 ^{bG}	2.2±0.01 ^{eL}	2.2±0.01 ^{dL}	2.20.02± ^{eI}	2.2±0.05 ^{fG}	2.3±0.08 ^{gD}	2.3±0.05 ^{hL}
C	1.9±0.06 ^{aG}	2.1±0.07 ^{bH}	2.2±0.01 ^{cM}	2.1±0.06 ^{dJ}	2.2±0.04 ^{eJ}	2.3±0.09 ^{fK}	2.3±0.04 ^{gJ}	2.4±0.04 ^{hK}
D	1.9±0.03 ^{aJ}	2.1±0.01 ^{bL}	2.1±0.02 ^{cG}	2.1±0.08 ^{dH}	2.2±0.01 ^{eG}	2.2±0.05 ^{fJ}	2.3±0.05 ^{gK}	2.3±0.09 ^{hN}
E	1.8±0.01 ^{aA}	1.9±0.05 ^{bB}	2.1±0.07 ^{cC}	2.1±0.03 ^{dC}	2.2±0.04 ^{eK}	2.3±0.08 ^{fI}	2.3±0.01 ^{gI}	2.3±0.01 ^{hF}
F	1.9±0.02 ^{aE}	2.0±0.04 ^{bE}	2.1±0.01 ^{cE}	2.1±0.07 ^{dF}	2.2±0.02 ^{eH}	2.2±0.05 ^{fF}	2.3±0.08 ^{gE}	2.3±0.02 ^{hC}
G	2.0±0.04 ^{aK}	2.1±0.01 ^{bK}	2.1±0.05 ^{cH}	2.1±0.08 ^{dG}	2.2±0.03 ^{eJ}	2.3±0.08 ^{fH}	2.3±0.01 ^{gI}	2.3±0.04 ^{hH}
H	1.9±0.01 ^{aI}	2.0±0.02 ^{bF}	2.0±0.01 ^{cD}	2.1±0.03 ^{dC}	2.1±0.09 ^{eD}	2.2±0.05 ^{fE}	2.3±0.09 ^{gF}	2.3±0.04 ^{hG}
I	1.9±0.01 ^{aC}	1.9±0.01 ^{bD}	2.0±0.02 ^{cA}	2.0±0.05 ^{dA}	2.1±0.01 ^{eA}	2.1±0.03 ^{fA}	2.2±0.03 ^{gA}	2.3±0.02 ^{hB}
J	1.9±0.02 ^{aH}	2.1±0.01 ^{bJ}	2.1±0.05 ^{cF}	2.1±0.04 ^{dD}	2.1±0.05 ^{eB}	2.2±0.02 ^{fB}	2.3±0.06 ^{gB}	2.3±0.05 ^{hE}
K	1.9±0.01 ^{aD}	2.1±0.02 ^{bM}	2.1±0.01 ^{cI}	2.1±0.09 ^{dI}	2.2±0.02 ^{eF}	2.2±0.04 ^{fD}	2.3±0.08 ^{gD}	2.3±0.02 ^{hI}
L	2.0±0.05 ^{aK}	2.0±0.05 ^{bA}	2.1±0.09 ^{cF}	2.2±0.06 ^{dE}	2.1±0.09 ^{eE}	2.2±0.03 ^{fC}	2.3±0.06 ^{gC}	2.3±0.02 ^{hD}
M	1.9±0.02 ^{aI}	2.1±0.05 ^{bN}	2.2±0.05 ^{cJ}	2.2±0.01 ^{dK}	2.2±0.04 ^{eL}	2.2±0.05 ^{fG}	2.3±0.09 ^{gH}	2.4±0.07 ^{hK}
N	1.9±0.01 ^{aB}	1.9±0.08 ^{bC}	2.0±0.02 ^{cB}	2.1±0.01 ^{dB}	2.2±0.06 ^{eC}	2.2±0.04 ^{fD}	2.3±0.04 ^{gG}	2.2±0.08 ^{hA}
Control	2.0±0.07 ^{aM}	2.1±0.01 ^{bJ}	2.2±0.01 ^{cK}	2.2±0.02 ^{dK}	2.3±0.03 ^{eM}	2.3±0.03 ^{fL}	2.3±0.08 ^{gM}	2.5±0.08 ^{hM}

*Means in same row with same small letters and in same column with same capital letters do not differ significantly at $p \leq 0.01$ ($n=3$)

A–N and Control: Refer to Table 1

oriented polypropylene, polypropylene and low density polyethylene films during storage.

Breaking force The breaking force of banana chips at 0th day was 5.6 N. Minimum breaking force (7.3 N) was observed for the treatment N and maximum (13.2 N) for the treatment M (Table 5). The moisture content and water activity in the treatment N was less than the treatment M (Tables 2 and 3) and hence minimum breaking force was observed in the treatment E. The increase in breaking force at the end of storage period was 30.4 and 135.7 % in the treatments E and M respectively. The increase in moisture content and water activity during the storage period might have influenced the breaking force. Hence, the breaking force is directly influenced by water vapor transmission characteristics of film. The film having lower clay & compatibilizer level and higher film thickness exhibited lower WVTR (Table 1) which might be resulted in higher breaking force (Manikantan and Varadharaju 2011). Ammawath et al. (2002) also observed the increase in breaking force of banana chips stored in PP films during storage.

Free fatty acids The initial FFA of banana chips was 0.44 % and it ranged from 1.03 % to 2.59 % at the end of the storage period (Table 6). The variation in FFA content might be due to the hydrolysis and oxidation of oil component in the banana chips (Che Man et al. 2003). The increase in FFA content was minimum in the treatment N (134.1 %) and maximum in treatment J (488.6 %). The increased FFA in

treatment J might be due to higher moisture content (6.6 %) and water activity (0.56) of banana chips. The treatments E & N exhibited uniform scattering of nanoclay in the polymer matrix and reduction of OTR and WVTR which might have resulted in lower FFA of stored banana chips. Films made by other levels of nanoclay and compatibilizer exhibited tactoids structures of nanoclay which resulted in more OTR and WVTR and higher FFA of banana chips during storage (Manikantan and Varadharaju 2011).

Peroxide values The initial peroxide value of banana chips was 1.65 meq oxygen kg^{-1} and it increased to the maximum of 18.4 meq oxygen kg^{-1} in the treatment D after 120 days (Table 7). The increase in peroxide value of chips during storage might be due to the reaction of lipid oxidation in the presence of light and oxygen (Che Man et al. 2003). The films having lower light and oxygen permeability resulted in banana chips with lower PV. The partly exfoliated and intercalated structure of nanoclay at lower level of nanoclay & compatibilizer and higher level of film thickness resulted in lower OTR (Manikantan and Varadharaju 2011). It was also observed that the banana chips stored in the films with more OTR recorded increased PV. The banana chips stored in treatment D having OTR of $1,541 \text{ cm}^3 \text{ m}^{-2} \text{ day}^{-1} \text{ atm}^{-1}$ (Table 1) had a peroxide value of 18.4 meq oxygen kg^{-1} whereas the film of treatment G with less OTR of $950 \text{ cm}^3 \text{ m}^{-2} \text{ day}^{-1} \text{ atm}^{-1}$ (Table 1) recorded only 13.7 meq oxygen kg^{-1} . The increase in peroxide value was minimum (732.1 %) in treatments F & G and maximum (1014.5 %) in treatment D. The peroxide value less

Table 9 Effect of different treatments on overall acceptability scores of banana chips during storage

Treatment	Storage period, days							
	15	30	45	60	75	90	105	120
A	7.4±0.71 ^{aBC}	7.2±0.34 ^{bCD}	7.2±0.66 ^{bCD}	6.8±0.47 ^{eBC}	6.8±0.74 ^{eBC}	6.6±0.74 ^{dBC}	6.2±0.25 ^{eBC}	5.8±0.56 ^{fBC}
B	7.4±0.42 ^{aBC}	7.0±0.54 ^{bBC}	7.0±0.41 ^{bBC}	6.8±0.26 ^{eBC}	6.8±0.81 ^{eBC}	6.6±0.26 ^{dBC}	6.2±0.62 ^{eBC}	5.8±0.45 ^{fBC}
C	7.4±0.52 ^{aBC}	6.8±0.52 ^{bAB}	6.8±0.65 ^{bAB}	6.4±0.14 ^{eA}	6.4±0.21 ^{eA}	6.2±0.41 ^{dA}	6.0±0.74 ^{eAB}	5.6±0.21 ^{fAB}
D	7.4±0.26 ^{aBC}	7.2±0.41 ^{bCD}	7.0±0.41 ^{bBC}	6.6±0.3 ^{eAB}	6.4±0.15 ^{dA}	6.2±0.52 ^{eA}	6.0±0.65 ^{fAB}	5.8±0.36 ^{gBC}
E	7.8±0.52 ^{aDE}	7.6±0.85 ^{bE}	7.6±0.22 ^{bE}	7.2±0.85 ^{eDE}	7.2±0.63 ^{eDE}	7.0±0.43 ^{dDE}	6.8±0.29 ^{eEF}	6.6±0.25 ^{fE}
F	7.6±0.41 ^{aCD}	7.4±0.74 ^{bD}	7.4±0.51 ^{bDE}	7.2±0.77 ^{eDE}	7.2±0.45 ^{eDE}	7.0±0.85 ^{dDE}	6.6±0.74 ^{eDE}	6.2±0.75 ^{fDE}
G	8.0±0.85 ^{aE}	7.6±0.63 ^{bE}	7.4±0.36 ^{eDE}	7.0±0.65 ^{dCD}	7.0±0.25 ^{dCD}	6.8±0.71 ^{eCD}	6.8±0.84 ^{eEF}	6.4±0.62 ^{fEF}
H	7.8±0.74 ^{aDE}	7.6±0.29 ^{bE}	7.6±0.74 ^{bE}	7.2±0.52 ^{eDE}	7.2±0.26 ^{eDE}	7.0±0.62 ^{dDE}	6.8±0.52 ^{eEF}	6.4±0.36 ^{fEF}
I	7.6±0.74 ^{aCD}	7.2±0.31 ^{bCD}	7.2±0.12 ^{bCD}	7.0±0.41 ^{eCD}	6.8±0.41 ^{dBC}	6.6±0.26 ^{dBC}	6.2±0.41 ^{fBC}	5.8±0.18 ^{gBC}
J	7.4±0.51 ^{aBC}	7.0±0.32 ^{bBC}	7.0±0.27 ^{bBC}	6.8±0.85 ^{eBC}	6.8±0.74 ^{eDC}	6.8±0.41 ^{eCD}	6.6±0.39 ^{dDE}	6.0±0.85 ^{eCD}
K	7.2±0.38 ^{aAB}	6.6±0.38 ^{bA}	6.6±0.36 ^{bA}	6.6±0.65 ^{bAB}	6.6±0.26 ^{bAB}	6.4±0.36 ^{eAB}	6.4±0.75 ^{dCD}	6.0±0.29 ^{dCD}
L	7.4±0.74 ^{aBC}	7.4±0.21 ^{aDE}	7.2±0.28 ^{bCD}	6.8±0.22 ^{eBC}	6.8±0.25 ^{eBC}	6.6±0.41 ^{dBC}	6.6±0.85 ^{dDE}	6.2±0.42 ^{eBE}
M	7.0±0.65 ^{aA}	6.6±0.29 ^{bA}	6.6±0.95 ^{bA}	6.6±0.26 ^{bAB}	6.4±0.74 ^{eA}	6.2±0.74 ^{dA}	6.0±0.63 ^{eAB}	5.6±0.55 ^{fAB}
N	8.0±0.85 ^{aE}	7.6±0.22 ^{bE}	7.6±0.53 ^{bE}	7.4±0.31 ^{eE}	7.4±0.26 ^{eE}	7.2±0.23 ^{dE}	7.0±0.75 ^{eF}	6.6±0.62 ^{eF}
Control	7.8±0.74 ^{aD}	7.4±0.31 ^{bDE}	7.4±0.19 ^{bDE}	7.0±0.43 ^{eCD}	6.8±0.41 ^{dBC}	6.4±0.74 ^{eAD}	5.8±0.23 ^{fA}	5.4±0.71 ^{gA}

*Means in same row with same small letters and in same column with same capital letters do not differ significantly at $p \leq 0.01$ ($n=3$)

A–N and Control: Refer to Table 1

than 25 meq oxygen kg^{-1} is the safe limit for storage of chips (Ikpeme et al. 2007) and it is evident that PV of all the samples remained within the safe limit.

Total plate count The initial plate count was recorded as 1.9 log cfu/g which increased steadily with storage period (Table 8). The moisture content & water activity of banana chips and OTR & WVTR of the packaging films influenced the microbial growth. The films of treatment E and N exhibited lower OTR and WVTR due to the characteristic scattering of nanoclay inside the polymer matrix which resulted in lower moisture content and water activity of banana chips. Hence, the microbial growth was lower in the films of treatment E and N. The plate count was observed maximum for the control sample however, lowest microbial growth was recorded for treatment N. Similar results were observed by Akubor and Adejo (2000) for plantain chips in polyethylene packages during storage.

Sensory evaluation The overall acceptability score reduced gradually with storage period (Table 9). The initial overall acceptability score of banana chips was 8.0 and it ranged between 5.4 and 6.6 during storage. This indicated that the

overall acceptability scores falls between ‘Neither like nor dislike’ and ‘like moderately’. The chips with higher levels of moisture content, water activity, color difference, FFA and PV resulted in reduction of organoleptic quality (crispness, taste and flavor) which might have resulted in the lower overall acceptability score. Hence, the films with lower OTR and WVTR resulted in higher overall acceptability score. The maximum OA scores were recorded for the banana chips stored in films of treatments E & N and minimum for the control samples at the end of storage period.

Statistical analysis The statistical results pertaining to analysis of variance (ANOVA) of the measured quality parameters of stored banana chips is given in Table 10. The influence of storage period and temperature independently or in combination (interactions) was found significant ($p \leq 0.01$) for all the measured quality parameters.

Conclusion

The quality parameters viz., moisture content, water activity, total color difference, breaking force, free fatty acid, peroxide value, total plate count of banana chips in nanocomposite films increased whereas overall acceptability scores decreased during storage. The water activity of banana chips in PP based nanocomposite films remained lower than the critical limit of 0.60 (favorable for microbial growth) upto 90 days of storage. The peroxide value of banana chips in all packages also remained within the safe limit of 25 meq oxygen kg^{-1} throughout. On the basis of the stability of measured parameters and overall acceptability scores, packaging material having 5 % compatibilizer, 2 % nanoclay and 100 μm thickness (treatment E) and 10 % compatibilizer, 4 % nanoclay and 120 μm thickness (treatment N) of all nanocomposite films showed better stability of measured quality characteristics of banana chips than any other treatment. PP based films already have wide range of applications such as biscuits, crisps (chips), snack foods, chocolate, sugar confectionery, ice cream, frozen food, tea and coffee. Due to the enhancement of strength and barrier characteristics, this study will definitely find place for PP based nanocomposite food packaging films’ applicability in other high value food products also.

References

- Akubor PI, Adejo EE (2000) Physicochemical, microbiological and sensory changes in stored plantain chips. *Plant Foods Hum Nutr* 55:139–146
- Ammawath W, Che Man YB, Yusof S, Rahman RA (2002) Effects of type of packaging material on physicochemical and sensory characteristics of deep-fat-fried banana chips. *J Sci Food Agric* 82:1621–1627

Table 10 Statistical analysis and significance ($p \leq 0.01$) of measured quality parameters

Parameter	Variable	F Calculated
Moisture content	Storage period (SP)	1552.14*
	Temperature (T)	173.43*
	SP $\times$ T	10.14 *
Water activity	Storage period (SP)	1452.83*
	Temperature (T)	46.50*
	SP $\times$ T	4.33*
Total color difference	Storage period (SP)	2791.32*
	Temperature (T)	162.04*
	SP $\times$ T	14.64*
Free fatty acids	Storage period (SP)	4598.01*
	Temperature (T)	49.03*
	SP $\times$ T	7.33*
Peroxide value	Storage period (SP)	2391.57*
	Temperature (T)	52.09*
	SP $\times$ T	5.51*
Breaking force	Storage period (SP)	282.22*
	Temperature (T)	56.12*
	SP $\times$ T	4.48*
Total plate count	Storage period (SP)	41.54*
	Temperature (T)	5.89*
	SP $\times$ T	2.69*
Overall acceptability scores	Storage period (SP)	37.27*
	Temperature (T)	4.37*
	SP $\times$ T	0.23*

*Significant at $p \leq 0.01$

- Ananthan P, Sharma GK, Srihari KA, Bawa AS (2012) Development of shelf stable protein rich composite cereal bar. *J Food Sci Technol* 49:335–341
- AOAC (2000) Official methods of analysis. Association of Official Analytical Chemists International, Maryland
- AOCS (1989) Official methods and recommended practices of American Oil Chemists Society, 5th edn. A.O.C.S, Champaign
- Bal A, Sandhu KS, Ahluwalia P (2002) Studies on suitability of cultivars, frying medium and packaging for potato chips. *J Food Sci Technol* 39:394–402
- Callegarin F, Quezada Gallo JA, Debeaufort F, Voilley A (1997) Review: lipids and bio packaging. *J Am Oil Chem Soc* 74:1183–1192
- Che Man YB, Ammawath W, Rahman RA, Yusof S (2003) Quality characteristics of refined, bleached and deodorized palm olein and banana chips after deep-fat frying. *J Sci Food Agric* 83:395–401
- Fernande GH, Kerstein H, Noel A, Ousmane C, Pascal F, Joseph H (2011) Effect of storage conditions on microbiological quality of shea butter. *J Food Sci Technol* 48:274–279
- Gomez AK, Gomez AA (1984) Statistical procedures for agricultural research, 2nd edn. Wiley, Singapore
- Hong SI, Rhim JW (2012) Preparation and properties of melt-intercalated linear low density polyethylene/clay nanocomposite films prepared by blow extrusion. *LWT—Food Sci Technol* 48:43–51
- Ikpeme CAE, Eneji CA, Essiet U (2007) Storage stability and sensory evaluation of taro chips fried in palm oil, palmolein oil, groundnut oil, soybean oil and their blends. *Pakistan J Nutr* 6:570–575
- Irawandi J, Che Man YB, Yusof S, Jinap S, Sugisawa H (1998) Effects of type of packaging materials on physicochemical, microbiological and sensory characteristics of durian fruit leather during storage. *J Sci Food Agric* 76:426–434
- Jagdeesh SL, Hegde L, Kotimani S, Gorbal K, Reddy BS, Swamy GSK, Basavaraj N, Raghvan GSV (2007) Influence of packaging on storage behavior of jackfruit papad. *J Food Sci Technol* 34:15–19
- Juin ML, Nair J, Siddappa M, Girdhari H (1982) Studies to improve the keeping quality of fried plantain chips. *J Food Sci* 11:335–341
- Kirwan JM, Strawbridge JW (2003) Plastics in food packaging. In: Richard C, Derek M, Kirwan JM (eds) *Food packaging technology*. Blackwell, CRC press, USA, pp 174–240
- Krishnankutty S, Varkey GA, Bhat AV, Dhanaraj S, Shanthi N (1981) Packaging and storage studies of deep fat fried *Nendran* banana chips. *J Food Sci Technol* 18:104–108
- Manikantan MR, Varadharaju N (2011) Preparation and properties of polypropylene based nanocomposite films for food packaging. *Packag Technol Sci* 24:191–209
- Purohit C, Rajyalakshmi P (2011) Quality of products containing defatted groundnut cake flour. *J Food Sci Technol* 48:26–35
- Sabikhi L, Tiwari BD (1999) Factors in food frying. *Indian Food Ind* 18:100–104
- Sacharow S, Griffin RC (1980) Snack foods. In: *Principles of food packaging*. AVI, Westport, pp 441–455
- Sandhu KS, Bawa AS (1993) Requirements for quality potato chips—an overview. *Indian Food Ind* 12:47–50
- Silva AS, Hernandez JL, Losada PP (2004) Modified atmosphere packaging and temperature effect on potato crisps oxidation during storage. *Anal Chem Acta* 524:185–189
- Sinha Ray S, Okamoto M (2003) Polymer/layered silicate nanocomposites: a review from preparation to processing. *Progress Polymer Sci* 28:1539–1641
- Sothornvit R, Hong SI, An DJ, Rhim JW (2010) Effect of clay content on the physical and antimicrobial properties of whey protein isolate/organo-clay composite films. *LWT—Food Sci Technol* 43:279–284