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RESEARCH ARTICLE

Effects of Period and Temperature on Quality and Shelf-Life of Cucumber and Garden-Eggs Packaged Using Cassava Starch-Zinc Nanocomposite Film

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ABSTRACT

Nanocomposite film can be used to prolong the shelf-life of fruits and vegetables. This research was undertaken to investigate the effects of packaging period and temperature on the quality and self-lives of cucumber and garden-eggs packaged using cassava starch-zinc nanocomposite film. Hundred grams each of cucumber and garden-eggs were wrapped in a 200× 350 mm size nanocomposite film and low density polyethylene (LDPE) of 2.240± 1.076 × 10^{-10} $gm^{-1}Pa^{-1}s^{-1}$ water vapor and 1.568± 0.084× 10^{-10} $gm\text{-}1Pa^{-1}s^{-1}$ oxygen gas permeability. The products were stored at 10−27°C temperatures and 0−9 day periods, and their quality attributes including β-carotene and ascorbic acid were determined. The results showed a high positive correlation for β-carotene and ascorbic acid contents of the cucumber and the garden eggs packaged in the nanocomposite film and the LDPE ($p< 0.05$). Also, the percentage increase in shelf-life of the packaged products in the cassava starch-zinc nanocomposite films was higher than those packaged in the LDPE materials. This indicates a small quality loss in the products packaged using the nanocomposite film compared with that packaged using the conventional LDPE. Hence, cassava starch-zinc nanocomposite film can be used to extend the shelf-life of the products.

KEY WORDS

Nanocomposite film, Temperature, Quality, Cucumber, Garden-Eggs, Packagin

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INTRODUCTION

Shelf-life can be regarded as the period of time during which food product remains safe and are certain to retain desirable sensory, chemical, physical, microbiological and functional characteristics [1]. Both food safety and quality are important aspects of acceptable shelf life [2]. The initial quality, inherent nature of the product, product formulation, processing method, consumer handling, transportation, storage and packaging are the most important index factors affecting the shelf-life of packaged foods [3]. For perishable food, the initial microbial load will influence the shelf life. Using ingredients that have already started to deteriorate or over-processing can result in loss of texture or nutrients, such as vitamin C. Fresh or perishable foods have an inherently shorter shelf life than shelf-stable foods. The low water activity of some food products, such as rice makes it an inherently shelf-stable food. The addition of preservatives or antioxidants can extend the shelf life of the product [4]. Formulation changes such as replacing the type of acid, removing nitrates from a processed meat, and reducing the amount of added salt can also change the shelf life of the product. Thermal processing will reduce, as in pasteurization, or eliminate, as in sterilization, microbes and extend the shelf life of the product. Other gentle processing techniques such as high pressure processing can also be used to reduce initial microbial levels. After purchase, transfer of food from the store to home can result in higher temperature exposure. Consumer refrigerators can also be at higher-than-optimal storage temperatures [5]. Once the package is opened, the shelf-life date assigned by the food manufacturer is no longer applicable. Exposure of the product to variable temperatures and relative humidity in the supply chain (including the retail environment) can affect the shelf life of foods. For refrigerated products, higher-than-optimal temperature storage can accelerate microbial growth. Oxidation reactions are also accelerated by higher temperature exposure, thus shortening the shelf life of the products. For shelf-stable products, the barrier of the package can affect the shelf life. For example, moisture absorption for a cracker will affect the crispness of the product. If the product has a large fat component, such as potato chips and most horticultural crops, fat oxidation affects the shelf life and an oxygen barrier is required.

Packaging material has been reported to protect food products against moisture, oxygen, odors or microorganisms because of the antimicrobial [6], [7] and oxygen scavenging activities [3] of the nanoparticles embedded in the polymer. However, the use synthetic polymers like the LDPE and HDPE has so far being discouraged probably due to the high amount of heat, which is capable of encouraging microbial deterioration, associated with such packages [8]. Nowadays nano-reinforced materials, such as the nanocomposite films, have replaced the synthetic materials in food packaging application. But, the production of most of the nanoparticles used is quite expensive and sometimes toxic, thus limiting their application. Hence, there is the need for an alternative composite material reinforced with a readily available and less toxic material, like zinc, for food packaging application. Research results of Luo et al. [9], Fadeyibi et al. [3], Jin et al. [10], Tankhiwale and Bajpai [7] and Nafchi et al. [11] have already given credence to the potential application of zinc oxide nanoparticles in food packaging. In fact, the deliberate inclusion of zinc nanoparticles in food packaging material, at a controlled amount, might not likely render the packaged food toxic or unfit for human consumption [7], [10]. This is because the zinc particles have their particles size in the range of 4-9 nm [3] and only 2% has often been used as fillers [12] in the packaging materials. Also, the research results of Fadeyibi et al. [1] recommended a maximum of 2% zinc concentration for food application, and this was not exceeded in the present investigation. Some major breakthroughs

has been recorded in this area of research, like in the application of edible films in packaging and coating of fresh fruits and vegetables [13], [14], and especially in using nanoparticles like montmorilonite and acetylated starch [12]. Although, the performance of cassava starch-zinc nanocomposite film for packaging of tomatoes has been reported [1], there is however no reported research on the nanocomposite film for cucumber and garden-eggs packaging. Also, there are still more to know especially the roles of temperature and storage period on the shelf-life of the produce. Therefore, the objective of this research was to determine the effects of storage period, temperature on the quality attributes and shelf-life of cucumber and garden-eggs packaged using the cassava starch-zinc nanocomposite film.

MATERIALS AND METHODS

Materials

Baskets (2 kg) of day old, cucumber and garden-eggs were bought from the commercial market at Kateregi, Niger State and transported to the Crop Processing and Storage Laboratory of the Federal University of Technology, Minna, Nigeria. Three pieces of the cucumber with average length (50.98 mm), diameter (20.11 mm), weight (100 g) and without bruises were carefully selected from the basket and immediately used for the packaging experiment. Also, five pieces of the garden-eggs with average length (20.44 mm), diameter (14.05 mm), weight (100 g) and without bruises were carefully selected from the basket and immediately used for the packaging experiment.

Packaging

The cassava starch-zinc nanocomposite films, prepared according to the methods reported by Fadeyibi *et al.* [15], were used for the packaging of the cucumber and garden-eggs products. The films were prepared from the blends of 55% glycerol and 0% zinc nanoparticles (T_1), 55% glycerol and 1% zinc nanoparticles (T_2) and 55% glycerol and 2% zinc nanoparticles (T_3). The packaging was done by wrapping 100 g each of the cucumber and garden-eggs in the nanocomposite films and low density polyethylene (LDPE, 10 µm thick). All the nanocomposite films have 200× 350 mm size, 17 µm thick. Also, the oxygen and water vapor permeability were found to be $2.240 \pm 1.076 \times 10^{-10}$ $gm^{-1}Pa^{-1}s^{-1}$ and $1.568 \pm 0.084 \times 10^{-10}$ $gm^{-1}Pa^{-1}s^{-1}$, respectively. The packaged products were stored in the incubator at temperature and period ranges of 10-27°C and 0-9 days, respectively. The total coliform and quality parameters of the cucumber and garden-eggs were evaluated at day 0, and then re-evaluated at an interval of 3 days for a total storage period of 9 days.

Quality Parameter Investigation

In this study, the quality and shelf-life of the cucumber and garden-eggs was determined as a function of their physical, chemical and microbiological properties. The method described by Treena et al. [16] and Gordon [17] were used to determine the total soluble solids, moisture content, vitamin C, β-carotene and titratable acidity of the packaged cucumber and garden-eggs samples.

Statistical Analysis

Karl Pearson's correlation matrix analysis was used to determine the strength of relationship between the packaging materials and the process variables at $p < 0.05$. The packaging materials are the nanocomposite films (T_1, T_2 and T_3), whereas the process variables are the storage period (0−9 days) and temperature (10−27°C). The degree of the relationship among the inter packaging materials and each of the quality parameter (β-carotene, titratable acidity, ascorbic acid, moisture content and total dissolved solid) was investigated for the packaged cucumber and garden-eggs.

RESULTS AND DISCUSSION

Effects of Temperature and Period on the Quality of Cucumber

The effects of temperature and period of packaging on the nutritional qualities of packaged cucumber were shown in Table 1. The total soluble solid of cucumber generally increase with temperature and period of packaging, irrespective of the nature of the packaging material. The increase in the total soluble solid of packaged product may be associated with the increase in the concentration of the dry matter at higher packaging period and temperature. The total soluble solid content of cucumber was higher in T_3 film than in the T_1, T_2 and LDPE films on day 9 at 27^{o}C because of the presence of higher amount of zinc nanoparticles in the polymer matrix constituting the packaging material. Consequently, T_1, T_2 and T_3, which represent the cassava starch nanocomposite films, are better for enhancing the total soluble solid content of cucumber than the 10 µm LDPE film. The moisture content of cucumber decreases with the temperature and period of packaging, as was shown in Table 1. Higher negative correlations were observed, for moisture content, between the period of packaging and all the films used in the packaging of cucumber, except for the films containing 1 and 2% zinc nanoparticles, which show insignificantly lower negative correlations at 10^{o}C ($p< 0.05$), as were shown in Table 2. The LDPE retained moisture better than the cassava starch nanocomposite films probably because of the presence of smaller pore space in its matrix. The observed decrease in the moisture content of cucumber was similar to the finding of Seisuke and Sinha [18] who attributed moisture loss of fruits and vegetables to the post-harvest physiological processes, such as respiration and transpiration, occurring even after harvest.

The ascorbic acid content of the packaged cucumber decreases generally with temperature and period of packaging, as shown in Table 1. Higher negative correlations were observed, for ascorbic acid, between the period of packaging and all the films used in the packaging of cucumber, except the films containing 1% zinc nanoparticles, 2% zinc nanoparticles and 10 µm LDPE film at 10^{o}C, which show significantly lower negative correlations at $p< 0.05$, (Table 2). The cucumber in the LDPE film recorded the least ascorbic acid content at all temperature and period of packaging because of the higher heat of respiration generated in the LDPE film that renders the vitamin thermally unstable. Hosalall [19], Vishal et al. [20] and Debbie et al. [21] reported that ascorbic acid content of packaged biomaterials generally decrease more rapidly at higher storage temperature since it is thermo labile. Therefore, as expected, the ascorbic acid content of cucumber was higher in the cassava starch nanocomposite film on day 3, which progressively decreases with temperature and period of packaging.

The titratable acidity of packaged cucumber increases with temperature and period of packaging, as shown in Table 1. Higher negative correlations were observed, for titratable acidity, between the period of packaging and all the films used in the packaging of cucumber at 10, 15 and 27^{o}C (significant at $p< 0.05$), (Table 3). The knowledge of titratable acidity indicates the pH level of the fruits and vegetables which can help in deciding the best packaging material for cucumber. As much as possible, it is desired to minimize the level of the acid content of the packaged cucumber to a safe limit. Therefore, the packaging of cucumber should be carried out using the cassava starch nanocomposite films instead of the 10 µm LDPE film because of their ability to minimize the titratable acidity under higher temperature and period of packaging.

The β- carotene content of packaged cucumber slightly varies with an increase in the temperature and period of packaging, as shown in Table 1. Higher positive correlations were observed, for β-carotene content, between the period of packaging and all the films used in the packaging of cucumber, except for the films containing 1% zinc nanoparticles, 2% zinc nanoparticles and the 10 µm LDPE, which show insignificantly lower correlations at 15 and 27°C, respectively ($p < 0.05$), (Table 3). The cucumber packaged using T1 has the highest content of β- carotene, which increases from 41.23 to 42.22 IU as the period increases from 3 to 9 days at 10°C. The cucumber packaged using the LDPE has the lowest content of β- carotene, which increases from 36.10 to 36.15 IU as the period increases from 3 to 9 days at 27°C. This implies that the cassava starch nanocomposite films can retain substantial amount of the β- carotene of cucumber at higher temperature and period of packaging.

Table 1: Some Quality attributes of packaged Cucumber at different temperature and packaging period

Packaging Material	Day-0	Packaging at 10 ° C Day-3	Day-6	Day-9	Packaging at 15 ° C Day-3	Day-6	Day-9	Packaging at 27 ° C Day-3	Day-6	Day-9
Total soluble solid [%]										
T1	5.34±0.18	10.55±0.49	6.50±0.06	7.47±0.08	16.24±0.08	15.25±0.05	16.60±0.05	17.31±0.12	20.32±0.78	23.63±0.09
T2	5.34±0.18	8.29±0.12	9.04±0.03	6.56±0.07	17.77±0.05	8.31±0.02	17.23±0.05	18.45±0.06	19.15±0.09	20.82±0.24
T3	5.34±0.18	8.00±0.03	6.34±0.07	7.31±0.02	14.31±0.03	14.40±0.06	17.04±0.03	18.59±0.13	20.11±0.10	20.52±0.16
LDPE (Control)	5.34±0.18	6.47±0.07	6.00±0.09	6.16±0.06	13.73±0.04	13.15±0.03	11.14±0.08	11.38±0.18	10.24±0.08	14.63±0.16
Moisture Content [%, wb]										
T_1	94.66±0.18	89.45±0.49	93.50±0.06	92.53±0.08	83.76±0.08	84.75±0.05	83.40±0.05	82.69±0.12	79.68±0.76	76.37±0.09
T_2	94.66±0.18	91.71±0.12	90.96±0.03	93.44±0.07	82.23±0.05	91.69±0.02	82.77±0.05	81.55±0.06	80.85±0.09	79.18±0.24
T_3	94.66±0.18	92.00±0.03	93.67±0.07	92.69±0.02	85.69±0.03	85.60±0.06	82.96±0.03	81.41±0.13	79.89±0.10	79.48±0.16
LDPE (Control)	94.66±0.18	93.53±0.07	94.00±0.09	93.84±0.06	86.27±0.04	86.85±0.03	88.86±0.08	88.62±0.18	89.76±0.08	85.37±0.16
Ascorbic Acid [mg/100 g]										
T_1	25.44±0.22	19.95±0.12	18.01±0.03	18.05±0.05	15.95±0.08	15.06±0.07	12.12±0.11	12.07±0.08	11.94±0.07	11.96±0.06
T_2	25.44±0.22	18.05±0.06	18.05±0.06	23.92±0.13	14.17±0.16	15.05±0.06	17.96±0.06	13.43±0.09	12.05±0.06	12.05±0.06
T_3	25.44±0.22	24.00±0.04	18.02±0.04	23.92±0.14	16.03±0.07	15.06±0.11	18.03±0.03	12.05±0.10	11.94±0.15	11.92±0.13
LDPE (Control)	25.44±0.22	21.95±0.10	20.51±0.02	23.61±0.02	14.42±0.06	14.29±0.12	15.21±0.04	11.21±0.20	11.21±0.05	9.96±0.04
Titratable Acidity [mg/l]										
T_1	0.40±0.01	0.51±0.02	0.73±0.01	0.58±0.04	0.40±0.01	0.58±0.03	0.79±0.03	0.40±0.00	1.00±0.02	0.97±0.02
T_2	0.40±0.01	0.44±0.01	0.60±0.01	0.51±0.02	0.40±0.03	0.50±0.01	0.79±0.02	0.39±0.01	1.21±0.02	1.11±0.02
T_3	0.40±0.01	0.88±0.04	0.60±0.03	0.59±0.02	0.38±0.03	0.82±0.02	0.79±0.03	0.50±0.00	1.22±0.06	0.91±0.01
LDPE (Control)	0.40±0.01	1.20±0.02	0.90±0.01	0.70±0.02	0.45±0.02	0.89±0.02	1.00±0.02	0.35±0.02	1.29±0.01	0.81±0.01
β-Carotene [IU]										
T_1	36.15±0.34	41.23±0.05	40.25±0.06	42.22±0.05	39.84±0.01	41.25±0.06	39.83±0.06	36.04±0.04	36.08±0.07	46.40±0.36
T_2	36.15±0.34	41.68±0.12	38.40±0.02	40.92±0.63	40.80±0.02	39.86±0.02	37.41±0.06	36.91±0.11	33.59±0.03	33.58±0.04
T_3	36.15±0.34	43.07±0.24	42.23±0.05	42.21±0.09	41.25±0.06	38.88±0.01	38.39±0.03	34.48±0.03	36.02±0.02	33.40±0.37
LDPE (Control)	36.15±0.34	40.95±0.23	38.06±0.15	41.13±0.16	38.40±0.03	36.83±0.10	32.12±0.04	31.09±0.05	35.01±0.03	29.41±0.06

LDPE = low density polyethylene (10µm), T_1 = 50-1-17, T_2 = 55-1-17, T_3 = 55-2-17, (Values presented in the form a± std)

Table 2: Pearson's Inter Packaging Material Correlation of Moisture and Ascorbic acid contents of Cucumber

Quality Parameter		*PP*	*T1 (10)*	*T1(15)*	*T1 (27)*	*T2(10)*	*T2(15)*	*T2(27)*	*T3(10)*	*T3(15)*	*T3(27)*	*C(10)*	*C(15)*	*C(27)*
Moisture content	**PP**	1.00												
	T1 (10)	-0.14	1.00											
	T1(15)	-0.79*	0.67*	1.00										
	T1 (27)	-0.94*	0.42	0.95*	1.00									
	T2(10)	-0.34	0.49	0.72*	0.60*	1.00								
	T2(15)	-0.54*	0.84*	0.79*	0.68*	0.27	1.00							
	T2(27)	-0.85*	0.57*	0.99*	0.98*	0.70*	0.73*	1.00						
	T3(10)	-0.47	0.93*	0.85*	0.69*	0.49	0.96*	0.78*	1.00					
	T3(15)	-0.89*	0.55*	0.98*	0.99*	0.61*	0.77*	0.99*	0.79*	1.00				
	T3(27)	-0.84*	0.55*	0.99*	0.97*	0.75*	0.69*	1.00*	0.76*	0.98*	1.00			
	C(10)	-0.54*	0.89*	0.93*	0.78*	0.69*	0.88*	0.88*	0.97*	0.86*	0.87*	1.00		
	C(15)	-0.57*	0.72*	0.94*	0.82*	0.91*	0.64*	0.91*	0.79*	0.86*	0.92*	0.92*	1.00	
	C(27)	-0.90*	0.54*	0.91*	0.94*	0.39	0.85*	0.92*	0.81*	0.96*	0.90*	0.81*	0.71*	1.00
Ascorbic Acid	**PP**	1.00												
	T1 (10)	-0.89*	1.00											
	T1(15)	-0.91*	0.98*	1.00										
	T1 (27)	-0.78*	0.97*	0.96*	1.00									
	T2(10)	-0.15	0.59*	0.47*	0.70*	1.00								
	T2(15)	-0.54*	0.86*	0.82*	0.95*	0.88*	1.00							
	T2(27)	-0.83*	0.99*	0.97*	1.00*	0.66*	0.92*	1.00						
	T3(10)	-0.41	0.62*	0.44	0.53*	0.67*	0.58*	0.57*	1.00					
	T3(15)	-0.64*	0.92*	0.86*	0.96*	0.85*	0.99*	0.95*	0.67*	1.00				
	T3(27)	-0.78*	0.97*	0.96*	1.00*	0.70*	0.95*	1.00*	0.53*	0.96*	1.00			
	C(10)	-0.42	0.77*	0.64*	0.80*	0.94*	0.91*	0.80*	0.85*	0.93*	0.80*	1.00		
	C(15)	-0.73*	0.96*	0.94*	1.00*	0.75*	0.97*	0.99*	0.56*	0.98*	1.00*	0.84*	1.00	
	C(27)	-0.82*	0.97*	0.98*	1.00*	0.64*	0.92*	1.00*	0.49	0.94*	1.00*	0.76*	0.99*	1.00

*Significant at P< 0.05; C = LDPE Film (Control); 50-1-17=T1; 55-1-17 = T2; 55-2-17 = T3, PP = Packaging Period (days)

Table 3: Pearson's Inter Packaging Material Correlation of β-Carotene content and Titratable acidity of Cucumber

Quality Parameter		*PP*	*T1 (10)*	*T1(15)*	*T1 (27)*	*T2(10)*	*T2(15)*	*T2(27)*	*T3(10)*	*T3(15)*	*T3(27)*	*C(10)*	*C(15)*	*C(27)*
β-Carotene	**PP**	1.00												
	T1 (10)	0.83*	1.00											
	T1(15)	0.74*	0.83*	1.00										
	T1 (27)	0.77*	0.56*	0.16	1.00									
	T2(10)	0.57*	0.91*	0.63*	0.42	1.00								
	T2(15)	0.17	0.57*	0.76*	-0.36	0.61*	1.00							
	T2(27)	-0.82*	-0.40	-0.54*	-0.57*	-0.01	0.12	1.00						
	T3(10)	0.70*	0.95*	0.93*	0.26	0.87*	0.80*	-0.30	1.00					
	T3(15)	0.27	0.74*	0.70*	-0.10	0.85*	0.92*	0.20	0.87*	1.00				
	T3(27)	-0.66*	-0.79*	-0.32	-0.81*	-0.84*	-0.09	0.17	-0.58*	-0.43	1.00			
	C(10)	0.65*	0.93*	0.59*	0.56*	0.99*	0.49	-0.10	0.84*	0.76*	-0.91*	1.00		
	C(15)	-0.66*	-0.28	0.02	-0.94*	-0.09	0.61*	0.66*	0.02	0.42	0.57*	-0.25	1.00	
	C(27)	-0.66*	-0.86*	-0.43	-0.73*	-0.92*	-0.25	0.14	-0.69*	-0.57*	0.99*	-0.97*	0.45	1.00
T. Acidity	**PP**	1.00												
	T1 (10)	-0.77*	1.00											
	T1(15)	-0.77*	1.00	1.00										
	T1 (27)	-0.77*	1.00	1.00	1.00									
	T2(10)	-0.77*	1.00	1.00	1.00	1.00								
	T2(15)	-0.77*	1.00	1.00	1.00	1.00	1.00							
	T2(27)	-0.76*	1.00	1.00	1.00	1.00	1.00	1.00						
	T3(10)	-0.78*	1.00	1.00	1.00	1.00	1.00	1.00	1.00					
	T3(15)	-0.77*	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00				
	T3(27)	-0.77*	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00			
	C(10)	-0.78*	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00		
	C(15)	-0.77*	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	
	C(27)	-0.77*	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00

*Significant at P< 0.05; C = LDPE Film (Control); 50-1-17=T1; 55-1-17 = T2; 55-2-17 = T3, PP = Packaging Period (days)

Effects of Temperature and Period on the Quality of Garden-Eggs

The effects of temperature and period of packaging on the nutritional qualities of packaged garden-eggs were shown in Table 4. The total soluble solid of garden-eggs generally increase with temperature and period of packaging, irrespective of the nature of the packaging material. The increase in the total soluble solid of the product can be associated with the increase in the concentration of the dry matter at higher packaging period and temperature. The total soluble solid content of cucumber was higher in T_3 film than in the T_1, T_2 and LDPE films on day 9 at 27°C probably because of the presence of higher amount of zinc nanoparticles in the polymer matrix constituting the packaging material. Consequently, T_1, T_2 and T_3, which represent the cassava starch nanocomposite films, are better for enhancing the total soluble solid content of garden-eggs than the 10 µm LDPE film. The moisture content of garden-eggs decreases with the temperature and period of packaging, as was shown in Table 4. Higher negative correlations were observed, for moisture content, between the period of packaging and all the packaging materials, except for the film containing 1 and the 10 µm LDPE films, which shows insignificantly lower negative and positive correlations at 10°C, respectively ($p < 0.05$), (Table 5). The LDPE retained moisture better than the cassava starch nanocomposite films probably because of the presence of smaller pore space in its matrix.

The ascorbic acid content of packaged garden-eggs decreases generally with temperature and period of packaging. Higher positive correlations were observed, for ascorbic acid, between the period of packaging and all the films used in the packaging of garden-eggs, except for the films containing 1% nanoparticles, which show insignificantly lower negative correlations at 10 and 27°C ($p< 0.05$); and the film 2% nanoparticles and the 10 µm LDPE, which show insignificantly lower negative correlations at 27°C ($p< 0.05$), (Table 5). The garden-eggs in the LDPE film recorded the least ascorbic acid content at all temperature and period of packaging because of the higher heat of respiration generated in the LDPE film that renders the vitamin thermally unstable. Hosalall [19], Vishal et al. [20] and Debbie et al. [21] reported that ascorbic acid content of packaged biomaterials generally decrease more rapidly at higher storage temperature since it is thermo labile. Therefore, in line with the expectation, the ascorbic acid content of garden-eggs was higher in the cassava starch nanocomposite films than the 10 µm LDPE film at different temperature and period of packaging.

The titratable acidity of packaged garden-eggs increases with temperature and period of packaging, as shown in Table 4. Higher negative correlations were observed, for titratable acidity, between the period of packaging and all the films used in the packaging of garden-eggs at 10, 15 and 27°C (significant at $p< 0.05$), (Table 6). The knowledge of titratable acidity indicates the pH level which can help in deciding the best packaging material to be used for okra. As much as possible, it is desired to minimize the level of the acid content of the packaged biomaterials to a safe limit. Therefore, the packaging of garden-eggs can be carried out using the cassava starch nanocomposite films instead of the LDPE film because of their ability to minimize the titratable acidity under the temperature and period of packaging.

The β- carotene content of packaged garden-eggs slightly varies with the temperature and period of packaging, as shown in Table 4. Higher negative correlations were observed, for β- carotene content, between the period of packaging and all the films used in the packaging of garden-eggs at 10, 15 and 27°C (significant at $p< 0.05$), (Table 6). The garden-eggs packaged using T_1 has the least content of

β- carotene, which decreases from 4.29 to 4.32 IU as the period increases from 3 to 9 days at 10°C. The garden-eggs packaged using the T_2 and LDPE films have the lowest contents of β- carotene, which decreases from 6.24 to 2.55 IU and 4.43 to 2.95 IU as the period increases from 3 to 9 days at 15 and 27°C, respectively. The garden-eggs packaged in both T_2 and T_3 films contain substantial amounts of β- carotene, slightly more than that in T_1 and LDPE films, which decreases with temperature and period of packaging. Thus, it can be concluded that the cassava starch nanocomposite films are able to retain substantial amount of the β- carotene of garden-eggs at higher temperature and period of packaging.

Table 4: Some Quality attributes of packaged Garden-egg at different temperature and packaging period

Packaging Material	Day-0	Packaging at 10 ° C Day-3	Day-6	Day-9	Packaging at 15 ° C Day-3	Day-6	Day-9	Packaging at 27 ° C Day-3	Day-6	Day-9
Total soluble solid [%]										
T_1	10.51±0.17	11.25±0.22	13.31±0.14	18.39±0.24	17.64±0.02	16.73±0.10	17.40±0.06	17.73±0.04	23.80±0.06	25.82±0.10
T_2	10.51±0.17	13.33±0.18	11.82±0.05	19.66±0.18	18.84±0.23	19.00±0.03	18.61±0.12	19.76±0.01	19.77±0.05	19.25±0.05
T_3	10.51±0.17	19.53±0.44	13.51±0.06	15.98±0.15	16.18±0.06	16.71±0.02	19.27±0.08	19.26±0.14	21.37±0.55	17.44±0.03
LDPE (Control)	10.51±0.17	16.33±0.39	10.15±0.18	15.2±0.18	13.67±0.31	12.47±0.08	15.06±0.13	18.22±0.10	19.70±0.06	14.67±0.30
Moisture Content [%, wb]										
T_1	89.49±0.17	88.75±0.22	86.69±0.14	81.61±0.24	82.36±0.02	83.27±0.10	82.60±0.06	82.27±0.04	76.20±0.06	74.18±0.05
T_2	89.49±0.17	86.67±0.18	88.18±0.05	80.34±0.18	81.16±0.23	81.00±0.03	81.39±0.12	80.24±0.01	80.23±0.05	80.75±0.05
T_3	89.49±0.17	80.47±0.44	86.49±0.14	84.03±0.15	83.82±0.06	83.29±0.02	80.73±0.08	80.74±0.14	78.63±0.55	82.56±0.03
LDPE (Control)	89.49±0.17	83.67±0.39	89.85±0.18	84.80±0.18	86.33±0.31	87.53±0.08	84.94±0.13	81.78±0.10	80.30±0.06	85.33±0.30
Ascorbic Acid [mg/100 g]										
T_1	12.00±0.03	12.06±0.06	12.14±0.12	8.05±0.08	9.07±0.09	9.08±0.12	12.03±0.04	10.49±0.04	9.04±0.04	9.06±0.06
T_2	12.00±0.03	24.04±0.03	11.99±0.09	18.16±0.16	9.04±0.06	9.05±0.09	12.10±0.09	6.12±0.11	11.97±0.07	9.07±0.06
T_3	12.00±0.03	23.86±0.23	12.00±0.01	11.96±0.11	6.06±0.07	9.03±0.05	12.08±0.08	10.42±0.07	11.95±0.12	9.07±0.08
LDPE (Control)	12.00±0.03	20.65±0.29	9.44±0.05	9.21±0.10	5.86±0.04	8.05±0.06	10.95±0.06	9.52±0.06	10.14±0.13	8.09±0.09
Titratable Acidity [mg/l]										
T_1	0.25±0.01	0.46±0.02	0.39±0.03	0.58±0.03	0.31±0.01	0.30±0.04	0.27±0.04	0.38±0.03	0.96±0.03	0.58±0.03
T_2	0.25±0.01	0.48±0.10	0.34±0.04	0.22±0.02	0.30±0.03	0.28±0.03	0.76±0.04	0.41±0.01	0.81±0.05	0.40±0.03
T_3	0.25±0.01	0.58±0.02	0.41±0.02	0.50±0.02	0.31±0.02	0.30±0.00	0.60±0.01	0.40±0.01	0.66±0.04	0.42±0.02
LDPE (Control)	0.25±0.01	0.72±0.06	0.65±0.05	0.71±0.02	0.44±0.05	0.53±0.02	0.88±0.03	0.52±0.03	1.12±0.05	0.89±0.01
β-Carotene (IU)										
T_1	10.3±0.02	5.29±0.02	5.29±0.02	4.32±0.01	4.87±0.06	6.71±0.02	3.85±0.02	5.72±0.04	2.87±0.04	2.88±0.01
T_2	10.3±0.02	6.80±0.08	5.26±0.04	4.84±0.06	6.24±0.05	5.30±0.03	2.85±0.06	4.79±0.03	4.32±0.03	3.35±0.05
T_3	10.3±0.02	7.26±0.09	4.86±0.06	5.22±0.05	5.29±0.02	6.25±0.02	3.82±0.08	6.74±0.03	4.85±0.06	3.45±0.10
LDPE (Control)	10.3±0.02	5.12±0.02	4.32±0.08	4.91±0.06	4.43±0.06	5.08±0.09	2.95±0.07	5.37±0.03	4.73±0.04	2.90±0.12

LDPE = low density polyethylene (10μm), T_1 = 50-1-17, T_2 = 55-1-17, T_3 = 55-2-17, (Values presented in the form a± std)

Table 5: Pearson's Inter Packaging Material Correlation of Moisture and Ascorbic Acid content of Garden-Eggs

Quality Parameter		*PP*	*T1 (10)*	*T1(15)*	*T1 (27)*	*T2(10)*	*T2(15)*	*T2(27)*	*T3(10)*	*T3(15)*	*T3(27)*	*C(10)*	*C(15)*	*C(27)*
Moisture content	**PP**	1.00												
	T1 (10)	-0.93*	1.00											
	T1(15)	-0.75*	0.53*	1.00										
	T1 (27)	-0.97*	0.83*	0.83*	1.00									
	T2(10)	-0.83*	0.92*	0.58*	0.70*	1.00								
	T2(15)	-0.76*	0.51*	0.99*	0.86*	0.51*	1.00							
	T2(27)	-0.74*	0.49	0.99*	0.85*	0.50*	1.00*	1.00						
	T3(10)	-0.35	0.20	0.83*	0.41	0.46	0.75*	0.76*	1.00					
	T3(15)	-0.94*	0.80*	0.93*	0.95*	0.80*	0.92*	0.91*	0.65*	1.00				
	T3(27)	-0.63*	0.31	0.91*	0.78*	0.25	0.95*	0.95*	0.62*	0.78*	1.00			
	C(10)	-0.32	0.33	0.63*	0.28	0.65*	0.51*	0.52*	0.90*	0.55*	0.27	1.00		
	C(15)	-0.83*	0.78*	0.87*	0.80*	0.90*	0.81*	0.81*	0.77*	0.94*	0.60*	0.79*	1.00	
	C(27)	-0.44	0.09	0.82*	0.62*	0.04	0.88*	0.88*	0.59*	0.63*	0.97*	0.20	0.44	1.00
Ascorbic Acid	**PP**	1.00												
	T1 (10)	-0.76*	1.00											
	T1(15)	0.01	-0.60*	1.00										
	T1 (27)	-0.94*	0.49	0.31	1.00									
	T2(10)	0.14	-0.19	-0.29	-0.10	1.00								
	T2(15)	0.02	-0.61*	1.00*	0.29	-0.28	1.00							
	T2(27)	-0.14	0.17	0.31	0.10	-1.00*	0.30	1.00						
	T3(10)	-0.26	0.33	-0.58*	0.16	0.86*	-0.58*	-0.87*	1.00					
	T3(15)	0.14	-0.54*	0.91*	0.10	-0.62*	0.91*	0.63*	-0.87*	1.00				
	T3(27)	-0.67*	0.85*	-0.27	0.46	-0.67*	-0.29	0.66*	-0.21	-0.06	1.00			
	C(10)	-0.47	0.44	-0.48	0.39	0.77*	-0.48	-0.78*	0.97*	-0.80*	-0.07	1.00		
	C(15)	-0.04	-0.43	0.93*	0.29	-0.61*	0.93*	0.62*	-0.80*	0.98*	0.02	-0.69*	1.00	
	C(27)	-0.88*	0.75*	0.07	0.80*	-0.58*	0.05	0.58*	-0.17	0.12	0.89*	0.04	0.27	1.00

*Significant at P< 0.05; C = LDPE

Film (Control); 50-1-17=T1; 55-1-17 = T2; 55-2-17 = T3, PP = Packaging Period (days)

Table 6: Pearson's Inter Packaging Material Correlation of β-carotene content and Titratable Acidity of Garden-Eggs

Quality Parameter		*PP*	*T1 (10)*	*T1(15)*	*T1 (27)*	*T2(10)*	*T2(15)*	*T2(27)*	*T3(10)*	*T3(15)*	*T3(27)*	*C(10)*	*C(15)*	*C(27)*
β-carotene	**PP**	1.00												
	T1 (10)	-0.86*	1.00											
	T1(15)	-0.80*	0.95*	1.00										
	T1 (27)	-0.92*	0.94*	0.81*	1.00									
	T2(10)	-0.93*	0.97*	0.86*	1.00*	1.00								
	T2(15)	-0.97*	0.95*	0.92*	0.95*	0.97*	1.00							
	T2(27)	-0.88*	1.00*	0.93*	0.96*	0.98*	0.96*	1.00						
	T3(10)	-0.91*	0.92*	0.77*	1.00*	0.99*	0.92*	0.94*	1.00					
	T3(15)	-0.86*	0.98*	0.99*	0.88*	0.92*	0.96*	0.97*	0.84*	1.00				
	T3(27)	-0.98*	0.94*	0.86*	0.98*	0.99*	0.99*	0.96*	0.97*	0.92*	1.00			
	C(10)	-0.69*	0.96*	0.90*	0.87*	0.89*	0.83*	0.95*	0.85*	0.91*	0.83*	1.00		
	C(15)	-0.86*	0.99*	0.98*	0.91*	0.94*	0.96*	0.99*	0.88*	1.00*	0.93*	0.94*	1.00	
	C(27)	-0.93*	0.98*	0.94*	0.96*	0.98*	0.99*	0.99*	0.94*	0.97*	0.98*	0.90*	0.98*	1.00
Titratable Acidity	**PP**	1.00												
	T1 (10)	-0.77*	1.00											
	T1(15)	-0.78*	1.00	1.00										
	T1 (27)	-0.76*	1.00	1.00	1.00									
	T2(10)	-0.79*	1.00	1.00	1.00	1.00								
	T2(15)	-0.75*	1.00	1.00	1.00	1.00	1.00							
	T2(27)	-0.77*	1.00	1.00	1.00	1.00	1.00	1.00						
	T3(10)	-0.78*	1.00	1.00	1.00	1.00	1.00	1.00	1.00					
	T3(15)	-0.76*	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00				
	T3(27)	-0.77*	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00			
	C(10)	-0.78*	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00		
	C(15)	-0.75*	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	
	C(27)	-0.75*	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00

*Significant at P< 0.05; C = LDPE Film (Control); 50-1-17=T1; 55-1-17 = T2; 55-2-17 = T3, PP = Packaging Period (days

Effect of Packaging Period on Quality Retention of the Products

The quality retention curves of the okra, cucumber, tomatoes and garden-eggs packaged in the cassava starch-zinc nanocomposite and the 10 µm LDPE films were shown in Fig. 1 and Fig. 2. The curves compare the performance of the cassava starch-zinc nanocomposite films and the 10 µm LDPE materials for retaining moisture content, ascorbic acid, β-carotene and titratable acidity for okra, cucumber, tomatoes and garden-eggs at different period of packaging. The performance was higher in the film containing 2% of the zinc nanoparticles than the packaging materials containing 1% zinc nanoparticles and 10 µm LDPE. In a similar research, the application of nanocomposite edible film, made from the blend of cellulose nanofibers with mango purees, for use in the extension of the shelf life of fruits and vegetables, have been reported by Henriette et al. [22] and Henriette et al. [23]. The authors reported that the shelf lives of the fruits and vegetables packaged using the nanofilm were more than those packaged using ordinary cellophane and low density polyethylene films. Based on this, it can be concluded that the cassava starch-zinc nanocomposite films may be suitable for the packaging of fruits and vegetables at a prolonged period and temperature.

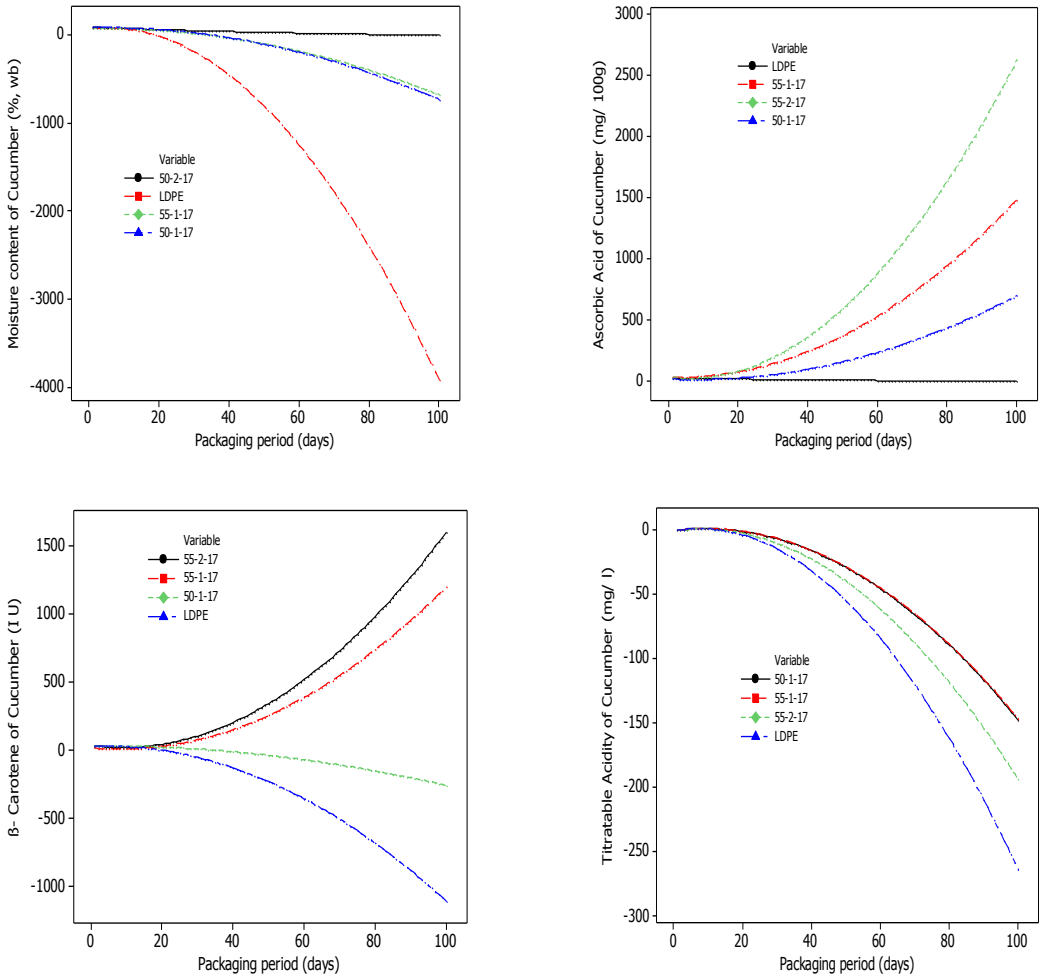


Fig. 1: Quality Retention Curves of packaged cucumber

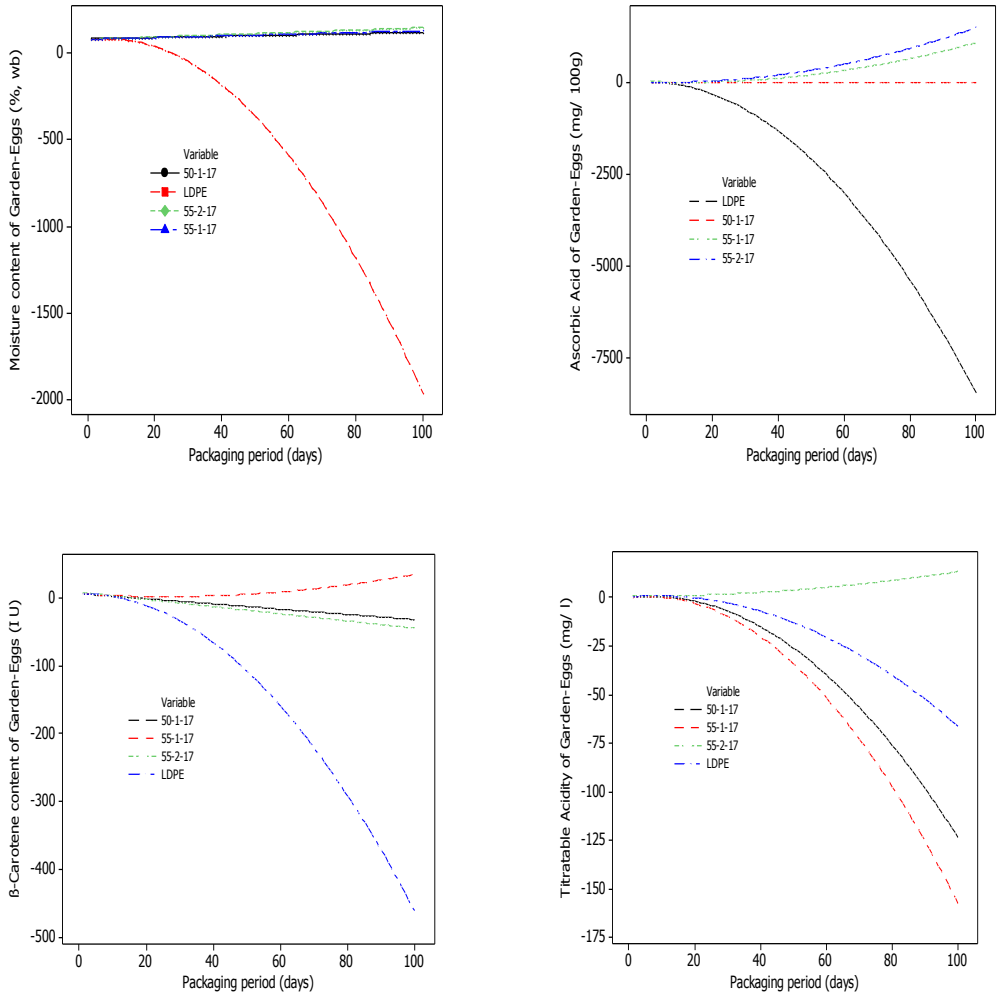


Fig. 2: Quality Retention Curves of Packaged Garden-Eggs

Shelf-life extension of cucumber and garden-eggs

The shelf-life extensions of cucumber and garden-eggs packaged in the cassava starch-zinc nanocomposite films and 10 µm LDPE materials at constant ambient temperature condition and different period of packaging were shown in Fig. 3 and Fig. 4. It can be seen that the cassava starch-zinc nanocomposite films were able to extent the shelf-life of okra than the 10 µm LDPE film. The quality attributes of cucumber and garden-eggs packaged using the 10 µm LDPE film increase with the period of packaging, unlike the cassava starch-zinc nanocomposite films which decreases with packaging period. Thus, a high quality loss is expected the packaged for the cucumber and garden-eggs at ambient temperature (27^{o}C) with extended self-lives shown in Table 7. The percentage increase in shelf-life of the packaged products in the cassava starch-zinc nanocomposite films was higher than those packaged in the LDPE materials. It can also be seen that the more the concentration of the zinc nanoparticles in the films the more the percentage increase in shelf-life.

This agrees with Basharat et al. [24], Liang et al. [25] and Ramos et al. [26], who predicted the shelf-life of packaged cassava-flour-based baked product by using empirical models and activation energy for water vapor permeability of polyethylene films. According to the authors, the empirical models were applicable for rapid and accurate shelf-life prediction. Again, the cassava starch-zinc nanocomposite film containing 2% zinc nanoparticles may be used for fruits and vegetable packaging.

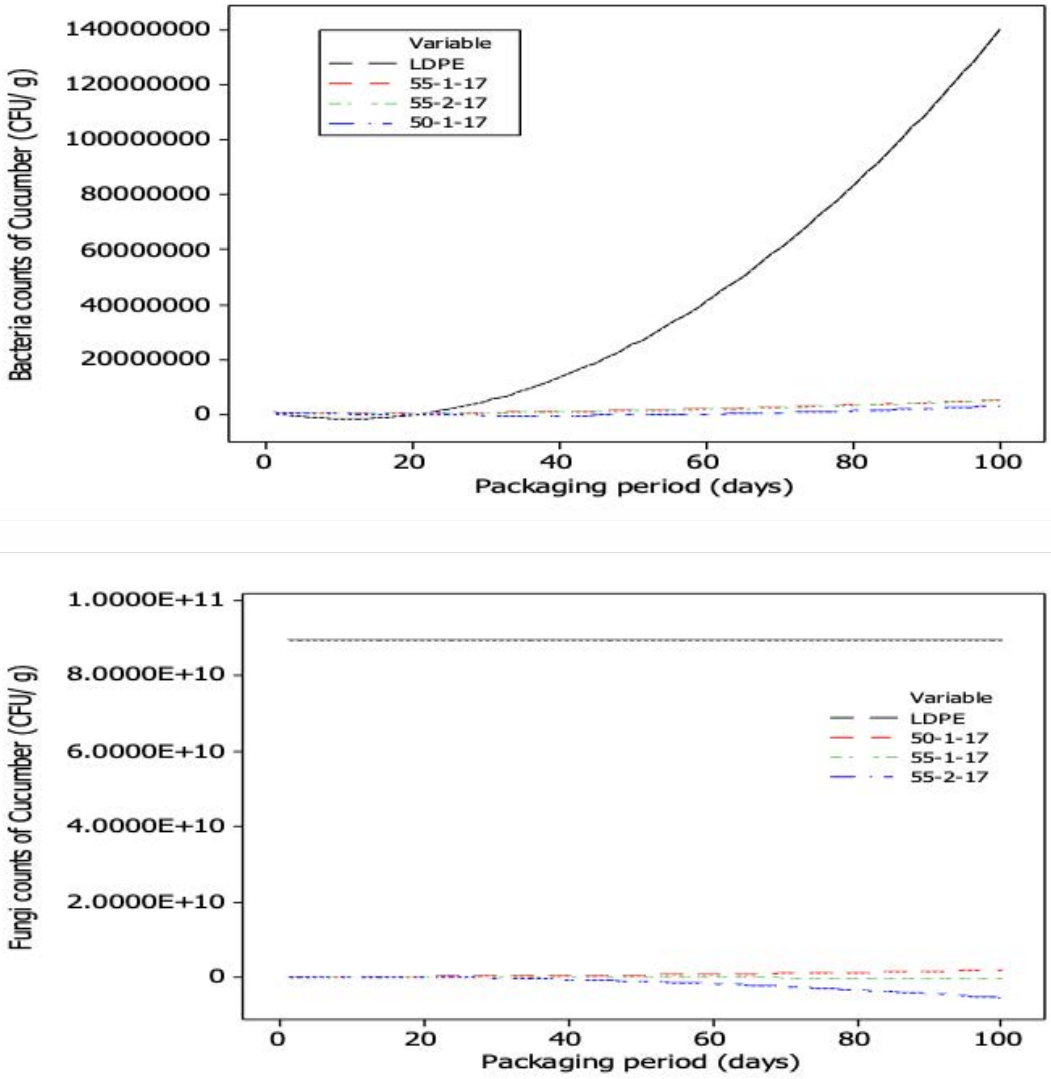


Fig. 3: Microbial growth curves of cucumber packaged using cassava starch nanocomposite films and 10 µm LDPE film

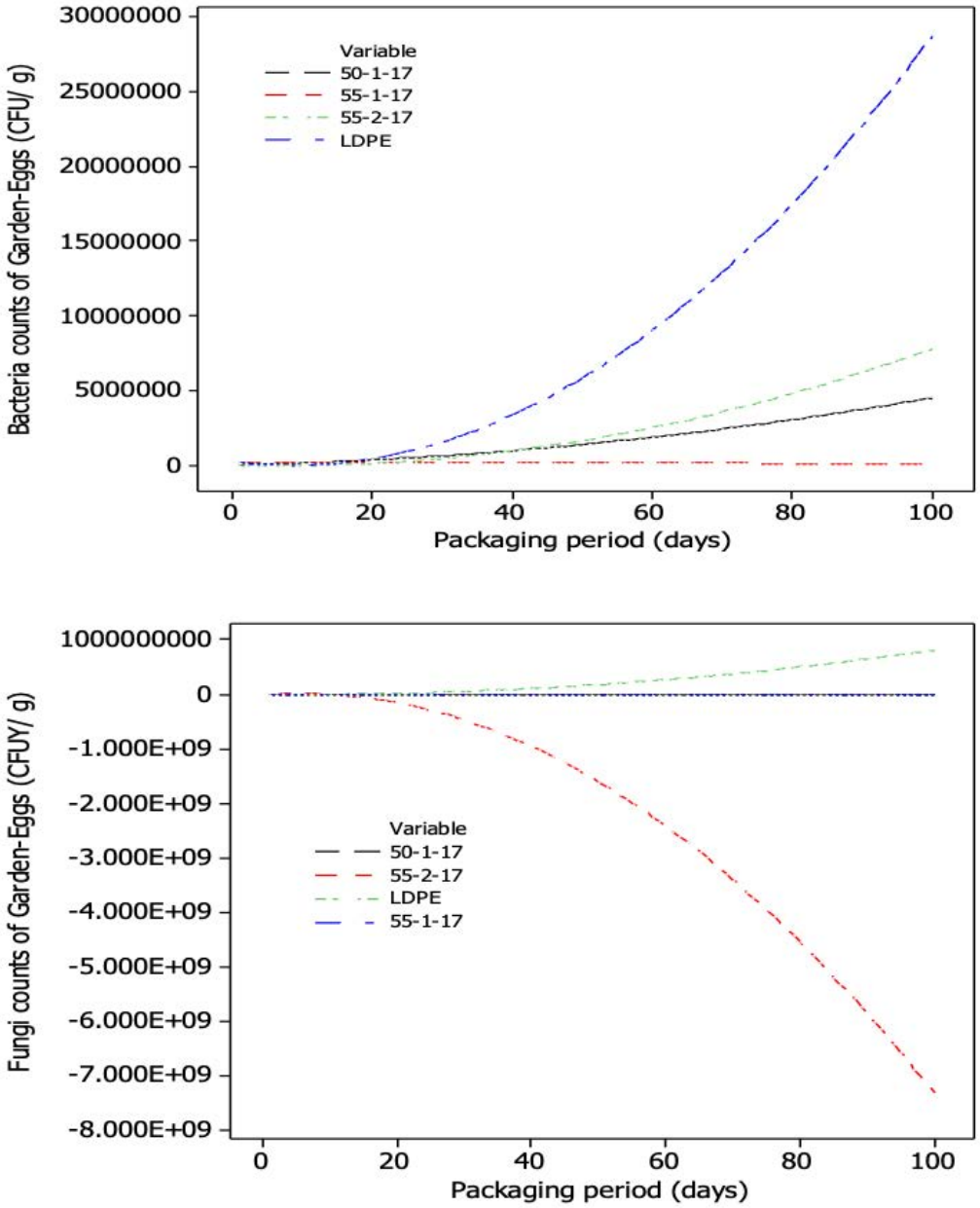


Fig. 4: Microbial growth curves of garden-eggs packaged using cassava starch nanocomposite films and 10 µm LDPE film

Table 7: Shelf-life extension of cucumber and garden-eggs at 27°C

s/n	Product	PM	NSL (days)	EPSL (days)	ΔSL (day)	% SL
1	Cucumber	LDPE	06	07	01	14.29
		T_1	09	10	01	10.00
		T_2	11	14	03	21.43
		T_3	14	21	07	33.33
2	Garden-eggs	LDPE	07	08	01	12.50
		T_1	09	12	03	25.00
		T_2	10	16	06	37.50
		T_3	10	18	08	44.44

NSL – normal shelf-life; PM- packaging material; EPSL- extended shelf-life; ΔSL – change in shelf-life; % SL – percent shelf-life

CONCLUSIONS

Nanotechnology has been applied to extend the shelf-life of agricultural produce. The effects of the packaging period and the temperature on the quality and self-lives of cucumber and garden-eggs packaged using cassava starch-zinc nanocomposite film have been investigated. The results showed a high positive correlation for β-carotene and ascorbic acid contents of the cucumber and the garden eggs packaged in the nanocomposite film and the LDPE ($p < 0.05$). Also, the percentage increase in shelf-life of the packaged products in the cassava starch-zinc nanocomposite films was higher than those packaged in the LDPE materials. This indicates a small quality loss in the products packaged using the nanocomposite film compared with that packaged using the conventional LDPE. Hence, cassava starch-zinc nanocomposite film can be used to extend the shelf-life of the cucumber and garden-eggs.

REFERENCES

[1] A. Fadeyibi, Z. D. Osunde, E. C. Egwim, and P. A. Idah, "Performance evaluation of cassava starch-zinc nanocomposite film for tomatoes packaging," *J. Agric. Eng.*, vol. 48, pp. 137–146, 2017.

[2] A. Fadeyibi, Z. D. Osunde, M. G. Yisa, and A. A. Okunola, "Investigation into properties of starch-based nanocomposite materials for fruits and vegetables packaging- A review," *FUTA J. Eng. Technol*., vol. 11, no. 1, pp. 12–16, 2017.

[3] A. Fadeyibi, and Z. D. Osunde, "Development and Optimisation of Cassava Starch-Zinc-Nanocomposite Film for Potential Application in Food Packaging," *J. Food Process. Technol*., vol. 7, no. 5, 2016.

[4] V. Siracusa, P. Rocculi, S. Romani, and M. D. Rosa, "Biodegradable polymers for food packaging: a review," *Trends Food Sci. Technol*., vol. 19, no. 12, pp. 634–643, 2008.

[5] T. J. Gutiérrez, N. J. Morales, E. Pérez, M. S. Tapia, and L. Famá, "Physico-chemical properties of edible films derived from native and phosphated cush-cush yam and cassava starches," *Food Packag. Shelf Life*, vol. 3, no. 1, pp. 1-8, 2015.

[6] T. A. Nascimento, V. Calado, and C. W. P. Carvalho, "Development and characterization of flexible film based on starch and passion fruit mesocarp flour with nanoparticles," *Food Res. Int*., vol. 49, no. 1, pp. 588-595, 2012.

[7] R. Tankhiwale, and S. K. Bajpai, "Preparation, characterization and antibacterial applications of ZnO-nanoparticles coated polyethylene films for food packaging," *Colloids Surfaces B Biointerfaces*, vol. 90, no. 1, pp. 16-20, 2012.

[8] R. Auras, P. Singh, and J. Singh, "Evaluation of OPLA polymers with existing PET and OPS for fresh food service containers," *Glob. Plast. Environ. Conf. 2005 GPEC 2005 - Creat. Sustain. Environ.*, no. May, pp. 141–156, 2005.

[9] Z. Luo *et al*., "Preparation and properties of enzyme-modified cassava starch-zinc complexes," *J. Agric. Food Chem.*, vol. 61, no. 19, pp.4631-4638, 2013.

[10] H. J. Jin, T., Sun, D., Su, J. Y., Zhang, H., and Sue, "Antimicrobial efficacy of zinc oxide quantum dots against Listeria monocytogenes, Salmonella enteritidis, and Escherichia coli O157:H7," *J. Food Sci*., vol. 74, no. 1, pp. 46–52, 2009.

[11] A. M. Nafchi, R. Nassiri, S. Sheibani, F. Ariffin, and A. A. Karim, "Preparation and characterization of bionanocomposite films filled with nanorod-rich zinc oxide," *Carbohydr. Polym*., 2013.

[12] A. P. Teodoro, S. Mali, N. Romero, and G. M. De Carvalho, "Cassava starch films containing acetylated starch nanoparticles as reinforcement: Physical and mechanical characterization," *Carbohydr. Polym*., vol. 126, no. 1, pp.9-16, 2015.

[13] C. E. Chinma, C. C. Ariahu, and J. O. Abu, "Development and characterization of cassava starch and soy protein concentrate based edible films," *Int. J. Food Sci. Technol*., vol. 47, no. 2, pp.383-389, 2012.

[14] C. E. Chinma, C. C. Ariahu, and J. S. Alakali, "Effect of temperature and relative humidity on the water vapour permeability and mechanical properties of cassava starch and soy protein concentrate based edible films," *J. Food Sci. Technol*., vol. 52, no. 4, pp.2380-2386, 2015.

[15] A. Fadeyibi, Z. D. Osunde, G. Agidi, E. C. Egwim, and P. A. Idah, "Nano-Rheological Behaviour of Cassava Starch-Zinc Nanocomposite Film under Dynamic Loading for High Speed Transportation of Packaged Food," in *Composites from Renewable and Sustainable Materials*, 1st ed., Matheus Poletto, Ed. 241-254: InTech, 2016, pp. 241–253.

[16] T. Delormier, K. L. Frohlich, and L. Potvin, "Food and eating as social practice - Understanding eating patterns as social phenomena and implications for public health," *Sociol. Heal. Illn*., vol. 31, no. 1, pp.215-228, 2009.

[17] G. L. Robertson, "Chapter 4: Optical, Mechanical and Barrier Properties of Thermoplastics Polymers." *Food Packaging-Principles and Practice, 3rd ed.; Taylor & Francis Group: Abingdon, UK* (2013): 91-130.

[18] S. Kimura and N. Sinha, "How to grow tomatoes," *Cold Spring Harb. Protoc.*, 2008.

[19] H. S. Ramaswamy, "Post-harvest technologies of fruits and vegetables," *McGill Univ.*, p.108649, 2014.

[20] V. Singh, M. Hedayetullah, P. Zaman, and J. Meher, "Postharvest Technology of Fruits and Vegetables: An Overview," *J. Post-Harvest Technol.*, vol. 2, no. 2, pp.124-135, 2014.

[21] D. Rees, G. Farrell, and J. Orchard, *Crop Post-Harvest: Science and Technology: Perishables*, vol. 3. John Wiley & Sons, 2012.

[22] H. M. C. Azeredo *et al*., "Nanocellulose reinforced chitosan composite films as affected by nanofiller loading and plasticizer content," *J. Food Sci*., vol. 75, no. 1, pp. 1-7, 2010.

[23] H. M. Henriette, M.C., Azeredo, I. H. C., Mattoso, D.T., Williams, G., Roberto, J. A., & Tara, "Nanocomposite edible films from mango puree reinforced with cellulose nanofibers.," *J. Food Sci*., vol. 74, no. 5, pp. 201–208, 2009.

[24] B. Yousuf, O. S. Qadri, and A. K. Srivastava, "Recent developments in shelf-life extension of fresh-cut fruits and vegetables by application of different edible coatings: A review," *LWT - Food Science and Technology*, vol. 89, no. 1, pp.198-209, 2018.

[25] L. Ma, M. Zhang, B. Bhandari, and Z. Gao, "Recent developments in novel shelf life extension technologies of fresh-cut fruits and vegetables," *Trends in Food Science and Technology*, vol. 64, no. 1, pp.23-38, 2017.

[26] B. Ramos, F. A. Miller, T. R. S. Brandão, P. Teixeira, and C. L. M. Silva, "Fresh fruits and vegetables - An overview on applied methodologies to improve its quality and safety," *Innovative Food Science and Emerging Technologies*, vol. 20, no. 1, pp.1-15, 2013.

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