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Comparative Effects of Silver Nanoparticles, Sucrose and Sodium Chloride as Osmotic Solutions for Tomato Slices: Antioxidant Activity, Microbial Quality and Modelling with Polynomial Regression Model

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ABSTRACT

This study has reported comparative effects of silver nanoparticles (AgNPs), sucrose and sodium chloride as osmotic solutions on antioxidant activity and microbial quality of 10 mm tomato slices. 40 g of tomato slices were dehydrated osmotically (OD) at different temperatures (60, 70 and 80 °C) and time (30, 60, 90, 120 150 and 180 min). Water loss, solid impregnation, water and solid diffusivities of tomato slices were found to increase with increase in solution temperatures and concentrations with AgNPs having the greatest influence. Antioxidant activities using 2,2-diphenyl-1-picrylhydrazyl increased with increase in solution concentrations but decreased with increase in temperature. Three-way ANOVA ($R^2 = 0.998$) revealed additive statistically significant effects of osmotic agents, concentrations and temperatures on antioxidant activity; $F_{(8,54)} = 67.854$, $P = 0.00$. Polynomial regression analysis with response surface methodology validated experiments such that for each unit increase in concentration and temperature, antioxidant activity increased with good coefficients of determination; sucrose ($R^2 = 0.87$), NaCl, ($R^2 = 0.89$) and AgNPs ($R^2 = 0.91$). Potato dextrose and nutrient agars were used for isolating and identifying microorganisms in OD tomato slices. Tomato slices dehydrated with AgNPs had the highest microbial inhibition of fungi with growth occurring after 7 days, unlike in treatments with sucrose and NaCl where fungal growth appeared after 2 and 5 days, respectively. *Aspergillus niger* was the most prevalent fungus. It can be concluded that AgNPs may serve as a viable means to dehydrate and preserve tomatoes without loss of antioxidant activity.

KEYWORDS

Osmotic dehydration, polynomial regression, response surface, antioxidant activity, three-way ANOVA, silver nanoparticles.

1. Introduction

Tomatoes (*Lycopersicon esculentum*) are essentially beneficial vegetables containing polyphenols, carotenoids, vitamins and minerals that can be either eaten raw or processed.[1–5] Studies have established that consumption of tomatoes with inverse correlation with risk of degenerative diseases. This stems from the antioxidant, anti-inflammatory and anti-cancer properties of bioactive compounds contained in tomatoes.[4,6] Quality of tomatoes is affected by microbial degradation because of high moisture content which aids rottenness and allows potent mycotoxin producers such as *Aspergillus*, *Trichoderma*, *Fusarium*, *Curvularia* and *Penicillium* species to thrive, thus making rotten tomatoes hazardous for consumption.[7–10]

Different dehydration processes have been reported for preserving tomatoes; however, some of these methods, especially those involving thermal treatment, degrade bioactive components in tomatoes.[11,12] Thus, the need to use osmotic dehydration (OD) which retains antioxidant activity of foods better than thermal processes.

Osmotic dehydration (OD) is a method of preservation that involves partial moisture loss from food materials to improve their shelf-lives. It saves energy and prevents oxidative browning.[13–16] It is done by immersing food materials either in whole or units into hypertonic solution which allows diffusion of moisture from the food material into the solution concurrently with solid impregnation into the food material.[10,17–22] This transfer could also be accompanied by leaching of organic acids, sugars, salts, fragrances, colourants and minerals from the food materials into the solution.[16,23] Sugar and salt solutions are usually employed with sucrose and sodium chloride as the mostly used.[16,17,24–27]

Salt and sucrose solutions preserve food materials and equally impede the growth of microorganisms which cause rottenness by weakening the structure of microbial enzymes involved in deterioration. Use of mixtures of these solutions like sucrose-sodium chloride has also been reported by some authors with advantages.[17,24–27] However, none of these osmotic solutions have been reported to improve antioxidant activities of food materials. Furthermore, several studies have reported use of nanoparticles, especially silver nanoparticles, for food processing and preservation.[51–53] Silver nanoparticles (AgNPs) offer food

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industries range of approaches to improve quality, shelf-life and nutritional composition of food. Biogenic AgNPs have been reported with activity to inhibit growth of bacteria, moulds and yeasts as well as having ability to boost antioxidant activity due to its high antioxidant activity. AgNPs is used as antibacterial agent in food and food packaging due to their low volatility including stability at high temperature. Though there is dearth of information on the toxicity of AgNPs from food consumption but concerns about the potential toxicity likely due to release of silver ion (Ag^+) exist.[28–36,54,55] However, results of Yekeen *et al.*[56] show that AgNPs has minimal effects on the inhibition of *Allium cepa* cells. Consequently, a comparative study with biogenic silver nanoparticles (AgNPs) synthesized from extracts of cocoa beans (CBE) as an alternative to constantly used osmotic solutions was undertaken in this study.

Mass transfer kinetic parameters play major roles in determining the extent of preservation, water loss, solid impregnation as well as antioxidant activity status of food materials during OD as functions of immersion time, solution concentrations and temperatures. Many researchers have studied effects of different osmotic parameters but none has predicted their effects on improvement of antioxidant activity of food materials.

Polynomial regression model is a statistical modelling tool for investigating the relationships between variables to provide estimates of values of the dependent variable by using the prediction equation. It is highly useful when relationship between dependent and independent variables is curvilinear. It consists of successive power terms. It is an effective and flexible curve fitting technique.[37,38]

In this study, effects of concentrations of osmotic solution and operating temperature were fitted to quadratic equations generated from modelled antioxidant activities of osmotic agents to provide estimates of antioxidant activity at the optimum conditions.

2. Materials and Methods

2.1. Reagents

Analar grade chemicals, 2,2-diphenyl-1-picrylhydrazyl (DPPH), CH_3OH, NaCl and sucrose, were purchased from Sigma-Aldrich, Germany.

2.2. Osmotic Solutions, Biosynthesis and Characterization of Silver Nanoparticles (AgNPs)

AgNPs used in this study were biologically synthesized using the extract of cocoa beans as reported by Azeez *et al.*[28] The scheme for biosynthesis is illustrated in Fig. 1. The biosynthesized AgNPs were characterized by UV–Vis spectroscopy, Fourier transform infrared spectroscopy (FTIR) and transmission electron microscopy (TEM) following standard procedures. Different concentrations of 25, 50, and 75 ppm of AgNPs, sucrose and NaCl solutions were prepared.

2.2.1. *Osmotic Treatment*

Raw tomatoes (Hausa tomatoes varieties) were purchased from Sasa local market Osogbo, Osun State, Nigeria. They were rinsed, blotted and cut into spherical slices of 3 cm × 10 mm (diameter × thickness). Then, 40 g of tomato slices were immersed into 100 mL of 25, 50, 75 ppm of AgNPs, sucrose and NaCl in a 2 L stainless steel container placed in a water bath. The bath was maintained at 60, 70 and 80 °C for 30, 60, 90, 120, 150 and 180 min. Tomato slices were removed 30 min interval, blotted and weighed. Moisture content was determined at 80 °C for 24 h in an oven (Uniscope SM9053 Surgifield Medicals England). The control samples were oven-dried at 60, 70, and 80 °C.

2.3. Mass Transfer Kinetics During Osmotic Dehydration

2.3.1. *Water Loss and Solid Gain*

Water loss (WL) and solid gain (SG) during osmotic dehydration of tomato slices are calculated using Equations 1 and 2.

$$WL = \frac{(M_o - m_o)(M - m)}{m_o} \quad (1)$$

$$SG = \frac{(m - m_o)}{m_o} \quad (2)$$

where WL is the water loss, SG is solid gain, M_o is the initial mass of fresh tomato slices (g), M is the mass of tomato slices after time (t) of osmotic dehydration (g), m is the dry mass of tomato slices (g) after time (t) of osmotic dehydration, and m_o is the initial dry mass of tomato slices (g).

2.3.2. *Effective Diffusivities and Activation Energy*

Fick's model is usually employed to describe the mass transfer involved in dehydration and impregnation during osmotic dehydration.[23,39] Equations 3–6 were used to calculate moisture ratio, solid ratio, effective diffusivities and activation energy.

$$MR = \frac{8}{\pi^2}\sum_{n=0}^{\infty}\frac{1}{2n-1}e^{\left(\frac{-(2n-1)^2\pi^2 D_{ew}t}{4L^2}\right)} \quad (3)$$

$$SR = \frac{8}{\pi^2}\sum_{n=0}^{\infty}\frac{1}{2n-1}e^{\left(\frac{-(2n-1)^2\pi^2 D_{es}t}{4L^2}\right)} \quad (4)$$

$$D_{ew} = D_{es} = \frac{-\text{slope}4L^2}{\pi^2} \quad (5)$$

D_{ew} and D_{es} are fitted to Arrhenius Equation (13) to calculate activation energy

$$D_{ew} = D_{es} = D_0 e^{\frac{E_a}{RT}} \quad (6)$$

where MR is moisture ratio, SR is solid ratio, D_{ew} is the effective diffusivity of water loss ($m^2\ s^{-1}$), D_{es} is the effective diffusivity of solid ($m^2\ s^{-1}$), t is the time (s), L is the slice half thickness (m), D_0 is the Arrhenius constant ($m^2\ s^{-1}$), E_a is the activation energy (kJ mol^{-1}), R is the universal gas constant (8.314 J $mol^{-1}\ K^{-1}$), and T is the absolute temperature (K). The slope of ln(D_{ew} or D_{es}) against $\frac{1}{T}$ is the activation energy.

2.4. Extraction and Determination of Antioxidant Activities in Tomato Slices

Dried osmotically dehydrated and oven-dried tomatoes were blended with Crown star electric blender to powder. Then, 1 g of the powdered tomato samples was extracted with 100 mL of 70 % aqueous methanol for 2 h 30 min, filtered and dried in a water bath. Different methanolic concentrations of the extract were prepared for the determination of antioxidant activities using the stable radical DPPH method as previously reported by Azeez *et al.*[29] and calculated using Equation 7.

$$\text{Inhibition}\ (\%) = \frac{(A_{control} - A_{sample})}{A_{control}} \times 100 \quad (7)$$

where $A_{control}$ and A_{sample} are absorbance values of the control and extract, respectively.

2.5. Polynomial Regression Modelling of Optimum Conditions for Antioxidant Activity

Polynomial is a form of linear regression that predicts a single dependent variable (y) by expressing the independent variables (x) in i^{th} order polynomial. Different powers of the x variables are sequentially added to polynomial equation to significantly increase R^2. The basic polynomial regression model of a depend-

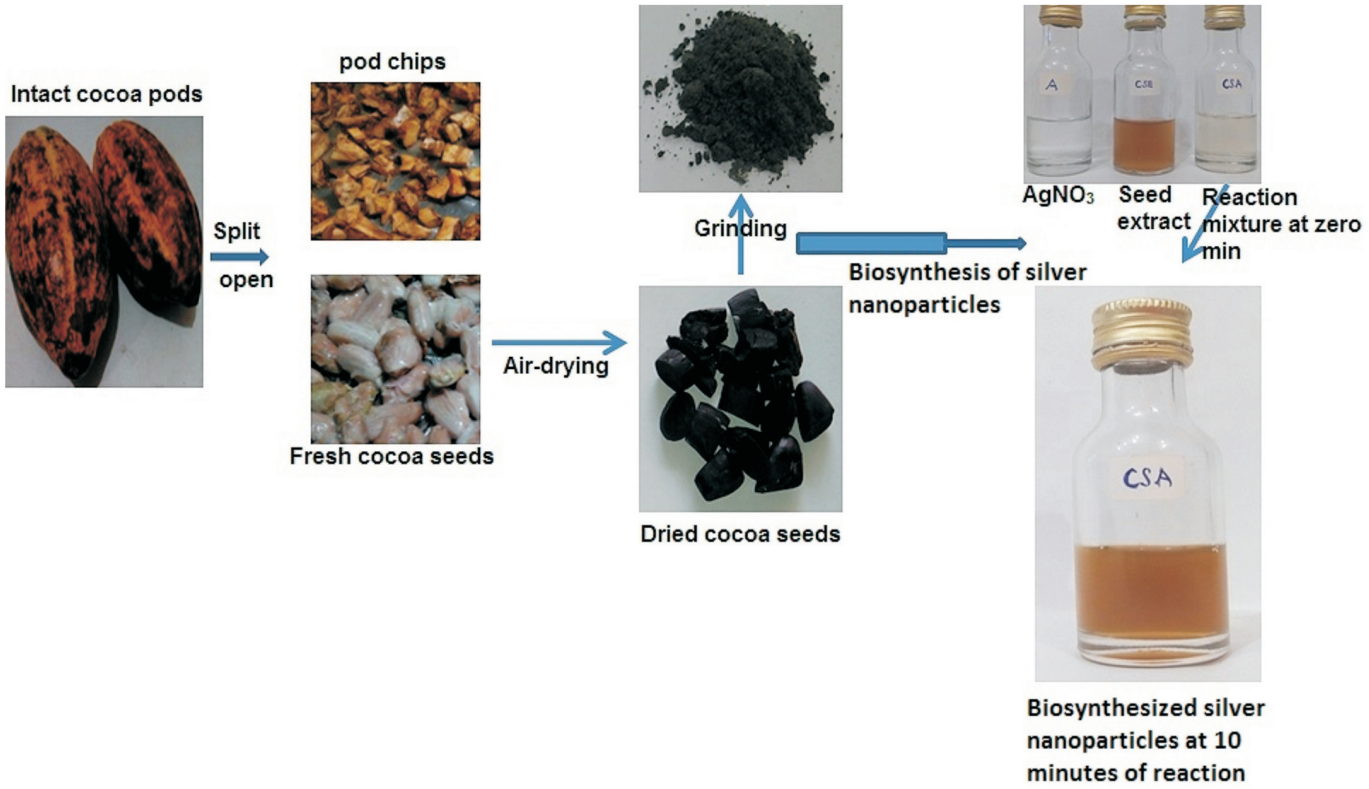

Figure 1 Scheme for the biogenic synthesis of AgNPs using the pod extract of cocoa.

ent variable y on a set of x independent variables can be expressed as

$$y = \beta_0 + \beta_1 x + \beta_2 x^2$$

where β_0, β_1, β_2 are the intercept of the regression surface, linear effects and quadratic effect parameters, respectively.

When two or more independent variables are fitted, second-order polynomial regression model is used, therefore the methodology of response surface methodology is used to fit such models and helps in estimating values of the dependent.[37,38]

2.6. Microbial Quality of Osmotically Dehydrated Tomato Slices

2.6.1. *Isolation and Identification of Microorganisms*

Potato dextrose agar (PDA) and nutrient agar were the growth media prepared for microbial isolation. Solutions of tomato samples osmotically dehydrated with sucrose, sodium chloride and AgNPs were prepared by aseptically introducing 1 g of dried tomato samples into 10 mL of distilled water and was then serially diluted to 10^{-3}, 10^{-5} and 10^{-7}. Then, 1 mL each from the selected tube was introduced to the prepared media (PDA and nutrient agar), which were incubated at 25 and 37 °C for seven days for the growth of fungi and bacteria. Isolates obtained were purified to obtain pure cultures, identified and characterized based on their colonial and morphological characteristics. The microscopic features of fungi were compared with fungal compendium.[40]

2.7. Model Fitting and Analysis of Statistical Significance

Data of antioxidant activity are presented as mean ± standard deviation of three replicates. A three-way ANOVA was conducted to reveal the effects of osmotic dehydration conditions on antioxidant activity at 95 % confidence level using SPSS software (IBM SPSS Statistics 20, Chicago, USA).

Matlab R2014a was used for data analysis, polynomial model building, and experimental design. Analysis of variance and response surface analysis were employed to determine the regression coefficients and statistical significance of the model terms and to fit the polynomial models.

Similarities between predicted polynomial regression and experimental antioxidant activities were determined by correlation coefficient (R^2)

3. Results and Discussion

3.1. Biogenic Synthesis of AgNPs

As previously reported by Azeez *et al.*[28], extract of cocoa beans facilitated the bioformation of AgNPs within 10 min of reaction under benign conditions leading to development of brown colloidal solution which had maximum absorption at 438.5 nm (Fig. 2). The nearly spherical AgNPs were polydispersed with size distribution of 8.96–54.22 nm (Fig. 2). The AgNPs displayed antimicrobial activities against drug-resistant bacteria by inhibiting their growth to the tune of 10–14 mm. It also improved antibacterial activities of some antibiotics by 42.9–100 % through synergy, and inhibited bacterial and fungal growth when used as additive in paint. Furthermore, the AgNPs demonstrated larvicidal activities against larvae of *Anopheles gambiae*, and also prevented coagulation of blood.[28,30–32]

3.2. Effects of Different Osmotic Agents, Concentrations, Temperatures and Immersion Time on Water Loss and Solid Gain of Tomato Slices

The effects of time of immersion, solution concentrations and temperatures during OD on water loss (WL) of tomato slices in different osmotic agents are presented in Fig. 3 while their effects on solid gain (SG) are presented in Fig. 4. Generally, WL and SG increased with increased immersion time, concentrations and temperatures of osmotic solution with the trend of

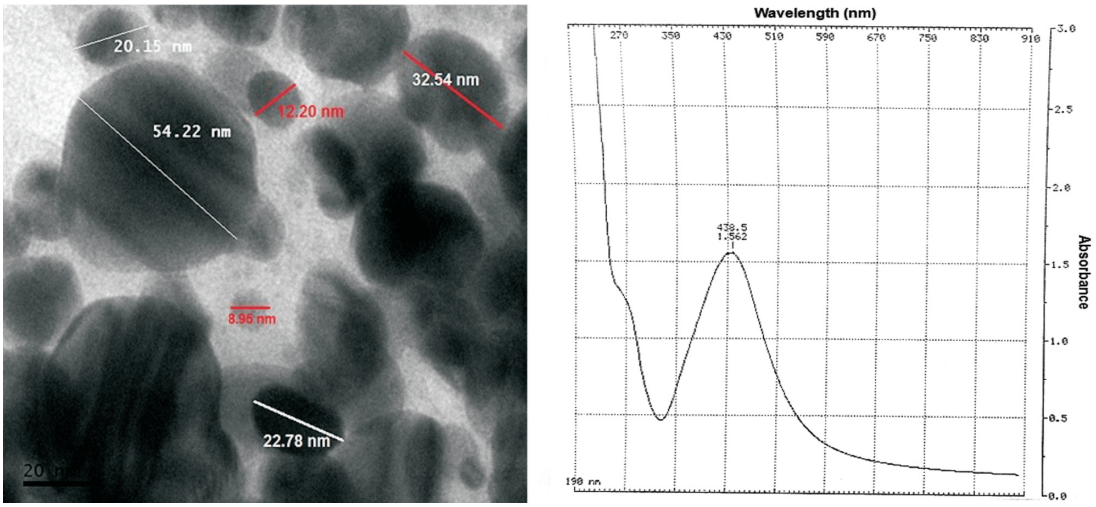

Figure 2 TEM micrograph and UV-Vis spectrum of biosynthesized AgNPs.

increase as function of osmotic agents ranging from AgNPs > NaCl > sucrose for WL and AgNPs > sucrose > NaCl for SG. This agrees with the acceleration of diffusion process owing to the ability of temperature and immersion time to lower viscosity of osmotic solution while increase in osmotic solution concentration increase the driving potential.[13,16,23,27,41,42] Greatest influence of AgNPs on WL and SG could be due to its nanostructure which enhanced diffusion leading to higher water loss and better solid impregnation.[43]

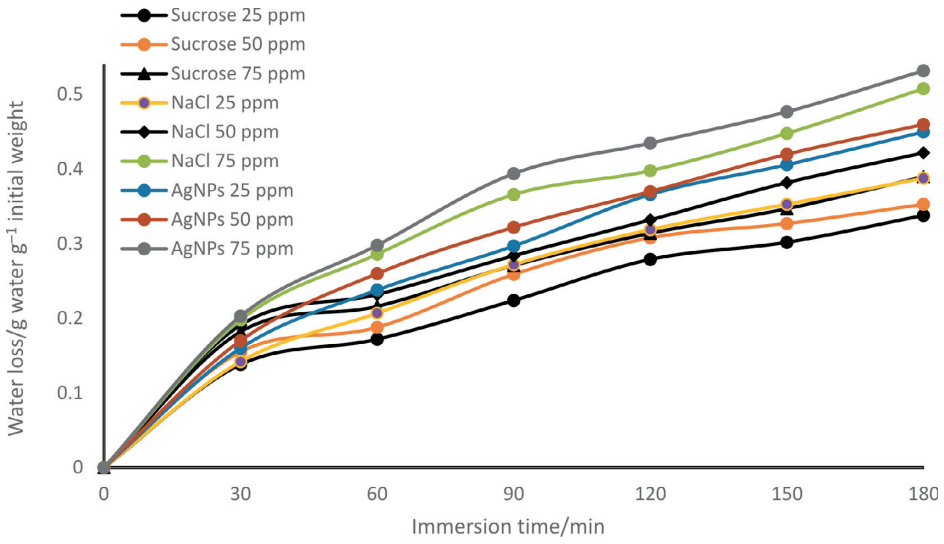

Figure 3 Effects of osmotic solutions, solution concentrations and immersion time on water loss from 10 mm tomato slices at 80 °C.

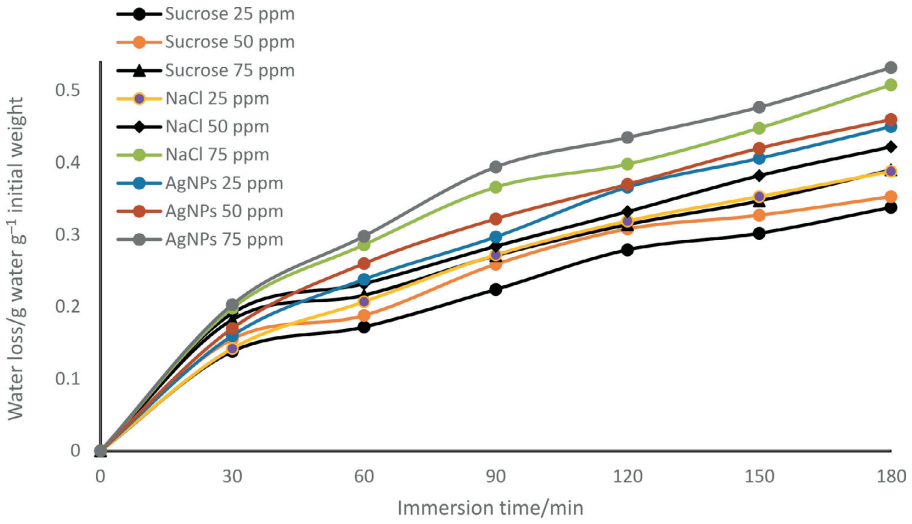

Figure 4 Effects of osmotic solutions, solution concentrations and immersion time on solid gain on 10 mm tomato slices at 60 °C.

3.2.1. *Effects of Different Osmotic Agents, Concentrations and Temperatures on Water and Solid Diffusivities*

WL and SG data were fitted to Fick's diffusion model to evaluate effective diffusion coefficients (D_{eff}) and activation energy for10 mm tomato slices osmotically dehydrated with 25–75 ppm AgNPs, sucrose and NaCl from 60–80 °C. Tables 1 and 2 show the values of effective diffusion coefficients calculated using Equations 11–13 for 10 mm tomato slices in different osmotic solutions. Water diffusivities (WD_{eff}) ranged from 5.76×10^{-8} to 6.74×10^{-8} for AgNPs, 5.10×10^{-8} to 6.16×10^{-8} for sucrose and 4.83×10^{-8} to 6.55×10^{-8} for NaCl. Solid diffusivities (SD_{eff}) ranged from 9.70×10^{-8} to 1.25×10^{-7} for AgNPs, 8.20×10^{-8} to 1.59×10^{-7} for sucrose and 8.33×10^{-8} to 2.18×10^{-7} for NaCl. It was observed that WD_{eff} and SD_{eff} increased with increase in temperatures and concentrations of osmotic agents. The increase in D_{eff} with increase in osmotic medium temperature might be connected to the vapour pressure inside tomato slices which resulted from increased diffusion process and higher porousity as functions of temperature and concentrations.[23,44] Comparatively, the trend in WD_{eff} followed AgNPs > NaCl > sucrose while the trend in SD_{eff} follows NaCl > Sucrose > AgNPs. The values of diffusion coefficients in this study are similar to results in references 23, 27, 41 and 42.

3.2.2. *Effects of Different Osmotic Agents, Concentrations and Temperatures on Activation Energy*

Activation energies for water and solid diffusivities calculated using Fick's model are presented in Table 3. Activation energy reduced with increase in concentration of osmotic solution. The trend of activation energy with respect to osmotic solution follows AgNPs < sucrose < NaCl. Lower activation energy of AgNPs compared to other solutions shows that in osmotic dehydration using AgNPs required lower energy to initiate diffusion process[16,44,45] and this could be better alternative

3.3. Effects of Osmotic Agents, Concentrations and Temperatures on Antioxidant Activity of Tomatoe Slices

The results of antioxidant activity of 10 mm tomato slices subjected to different osmotic dehydrations conditions are presented in Table 4. Antioxidant activities increased with increase in concentration of osmotic solution but reduced with increase in temperature. The trend of effects of osmotic agents on antioxidant activity in decreasing order followed AgNPs > sucrose > NaCl. This is in consonance with water loss and solid impregnation abilities of the agents. This shows that AgNPs had higher ability to improve antioxidant activity. Comparing antioxidant activities of osmotically dehydrated with vacuum oven-dried (control) tomato slices, OD treated tomato samples with AgNPs and sucrose had higher antioxidant activities than the control at 60 °C, lower at other temperatures except for AgNPs at 70 °C. Osmotic dehydration using AgNPs preserved and improved antioxidant activity of tomato slices better than other solution. Three-way ANOVA ($R^2 = 0.998$) conducted on the results revealed additive statistically significant effects of osmotic agents, concentrations and temperatures on antioxidant activity, $F_{(8,54)} = 67.854$, $P = 0.00$. Additive statistically significance

Table 1 Water diffusivities for tomato slices osmotically dehydrated at different temperatures and osmotic concentrations for different osmotic agents.

Solution:	AgNPs			Sucrose			NaCl		
	Concentration/ppm			Concentration/ppm			Concentration/ppm		
	75	50	25	75	50	25	75	50	25
Temperature									
60 °C	6.34E-08	6.20E-08	5.76E-08	5.10E-08	5.12E-08	5.15E-08	5.64E-08	4.83E-08	5.87E-08
70 °C	6.09E-08	6.06E-08	5.97E-08	5.86E-08	5.54E-08	5.36E-08	5.89E-08	6.18E-08	5.97E-08
80 °C	6.74E-08	6.33E-08	6.11E-08	6.16E-08	5.74E-08	5.19E-08	6.55E-08	5.42E-08	5.93E-08

Table 2 Solid diffusivities for tomato slices osmotically dehydrated at different temperatures and osmotic concentrations for different osmotic agents.

Solution:	AgNPs			Sucrose			NaCl		
	Concentration/ppm			Concentration/ppm			Concentration/ppm		
	75	50	25	75	50	25	75	50	25
Temperature									
60 °C	1.20E-07	9.71E-08	9.70E-08	1.59E-07	8.20E-08	1.05E-07	1.31E-07	8.19E-08	8.10E-08
70 °C	1.25E-07	1.22E-07	1.03E-07	1.23E-07	1.17E-07	1.05E-07	1.52E-07	1.13E-07	8.33E-08
80 °C	1.23E-07	1.06E-07	1.05E-07	1.15E-07	1.11E-07	1.06E-07	2.18E-07	1.32E-07	1.13E-07

Table 3 Activation energy/kJ mol^{-1} for tomato slices osmotically dehydrated at different temperatures and osmotic concentrations.

Solution:	AgNPs		Sucrose		NaCl	
Concentration (ppm)	Water diffusivity	Solid diffusivity	Water diffusivity	Solid diffusivity	Water diffusivity	Solid diffusivity
25	2.975	4.506	9.259	15.101	7.279	25.610
50	2.957	3.950	5.606	2.716	5.756	24.945
75	0.965	1.478	0.396	0.751	0.445	16.148

Table 4 Antioxidant activity of tomato slices osmotically dehydrated at different temperatures and osmotic concentrations for different osmotic agents.

Solution:	AgNPs			Sucrose			NaCl			
	Concentration/ppm			Concentration/ppm			Concentration/ppm			
Temp.	25	50	75	25	50	75	25	50	75	Control
60 °C	46.67 ± 0.24	80.42 ± 2.14	88.31 ± 2.32	60.72 ± 1.07	66.99 ± 1.67	71.17 ± 0.34	41.22 ± 0.48	41.62 ± 1.56	42.28 ± 2.95	67.31 ± 0.77
70 °C	30.33 ±0.58	75.52 ±1.96	84.68 ± 0.36	58.50 ± 0.35	67.69 ± 0.16	68.01 ± 1.84	28.06 ± 0.09	34.98 ± 1.15	42.39 ± 0.41	82.74 ± 0.02
80 °C	27.04 ± 0.04	46.71 ± 0.39	80.01 ± 0.01	30.93 ± 0.22	50.48 ± 0.56	57.71 ± 0.87	27.04 ± 1.08	35.84 ± 0.12	41.20 ± 0.06	83.61 ± 0.13

Data are presented as mean ± standard deviation of three replicates.

of binary effects of osmotic agents and concentration gave $F_{(4,54)} = 790.449$, $P = 0.00$, osmotic agents and temperatures gave $F_{(4,54)} = 169.551$, $P = 0.00$, while solution concentrations and temperatures gave $F_{(4,54)} = 101.485$, $P = 0.00$.

3.3.1. *Polynomial Regression Modelling and Prediction of Antioxidant Activity*

The predictions and validation for all experimental data of each osmotic agent are summarized in the Table 5. The predicted values were determined by the polynomial model of $y = p_1x^2 + p_2x + p_3$ with 95 % confidence interval, where p_3 is the constant that fixes the response at a given concentration and temperature of the experiment, p_2 and p_1 are the regression coefficients for the polynomial interaction effect terms and x is the relationship between the independent variables (sucrose, NaCl and AgNPs). The coefficients for the linear quadratic terms of antioxidant activities for AgNPs are presented in Fig. 5a,b. The modelling effect of concentrations on the antioxidant activities in terms of the temperatures at which the antioxidant improved was found to improve by increasing amounts for each unit increase in temperature and concentration through a quadratic model of the form: $\text{fitpoly4}(x) = p_1x^2 + p_2x + p_3$.

The predicted quadratic models for antioxidant activities are shown in Equations 8, 9 and 10 for sucrose, NaCl and AgNPs, respectively.

In the analysis of the predicted models, good coefficients of determination were obtained for each of antioxidant activity (sucrose $R^2 = 0.87$; NaCl $R^2 = 0.89$; AgNPs $R^2 = 0.91$) where the model explained most of the observed variations (Table 6). This shows that antioxidant activity forecasting for AgNPs is excellent while for NaCl and sucrose is very good.[38] Significant ($P < 0.05$) quadratic effects of different concentrations at different temperatures were observed. The model *P*-values of antioxidant activities of the three solutions were less than 0.05 which implies that the model is significant.

$$-1.158e-06x^2 + 0.01481x + 19.69 \quad (8)$$

$$-4.746e-08x^2 + 0.002405x + 26.47 \quad (9)$$

$$-1.28e-06x^2 + 0.02289x + 15.64 \quad (10)$$

3.3.2. *Response Surface Analysis of Antioxidant Predictions*

Antioxidant activity was significantly affected by the concentrations and temperatures of osmotic solutions with $P < 0.05$ for linear, quadratic and interactive effects. There are marginal increases in predicted values (Table 6), which are close to the experimental values. The effects of the variables and their interaction on antioxidant activities are shown in Fig. 6a–c. Concentrations of sucrose, NaCl and AgNPs increased in positive proportion, hence it had a significant influence on the antioxidant properties of OD tomato slices

3.4. Effects of Osmotic Agents and Solution Temperatures on the Fungal Growth of Osmotically Dehydrated Tomato Slices

The result of OD temperatures on fungal growth is presented in Fig. 7. The number of fungal isolates reduced with increase in temperature implying that the fungal isolates were temperature sensitive. No growth was observed on nutrient agar for all OD tomato slices with sucrose, sodium chloride and silver nanoparticles after incubation at 37 °C for 24 h. For PDA plates, fungal growth was observed two days after incubation for slices dehydrated with sucrose solution and control. The growth appeared on the fifth and seventh day after incubation for sodium chloride and silver nanoparticles, respectively. Plates showing fungal isolates are shown in Fig. 8. OD samples with sucrose were found to be least effective because growth was found just two days after inoculation followed by sodium chloride in which growth was observed five days after inoculation. This is in line with the findings of Manafi *et al.*[43] that using salt solutions as osmotic media have advantages over sucrose because it has low viscosity and their ions diffuse better due to smaller sizes which

Table 5 The experimental and predicted values of concentration and temperature for the three antioxidants.

Conc.	Temp.	Sucrose		NaCl		AgNPs	
		Experimental value	Predicted value	Experimental value	Predicted value	Experimental value	Predicted value
75	60	71.17	72.25	42.28	42.99	88.31	89.00
75	70	68.01	69.06	42.39	43.07	84.68	85.43
75	80	57.17	57.98	41.20	42.62	80.01	80.89
50	60	66.99	67.02	41.62	41.88	80.42	81.31
50	70	67.69	68.21	34.98	35.05	75.52	76.29
50	80	50.48	51.22	35.84	36.32	46.71	47.65
25	60	60.72	60.86	41.22	42.94	46.67	47.77
25	70	58.50	59.02	28.06	28.88	30.33	32.03
25	80	30.93	31.11	27.65	28.23	27.04	28.67

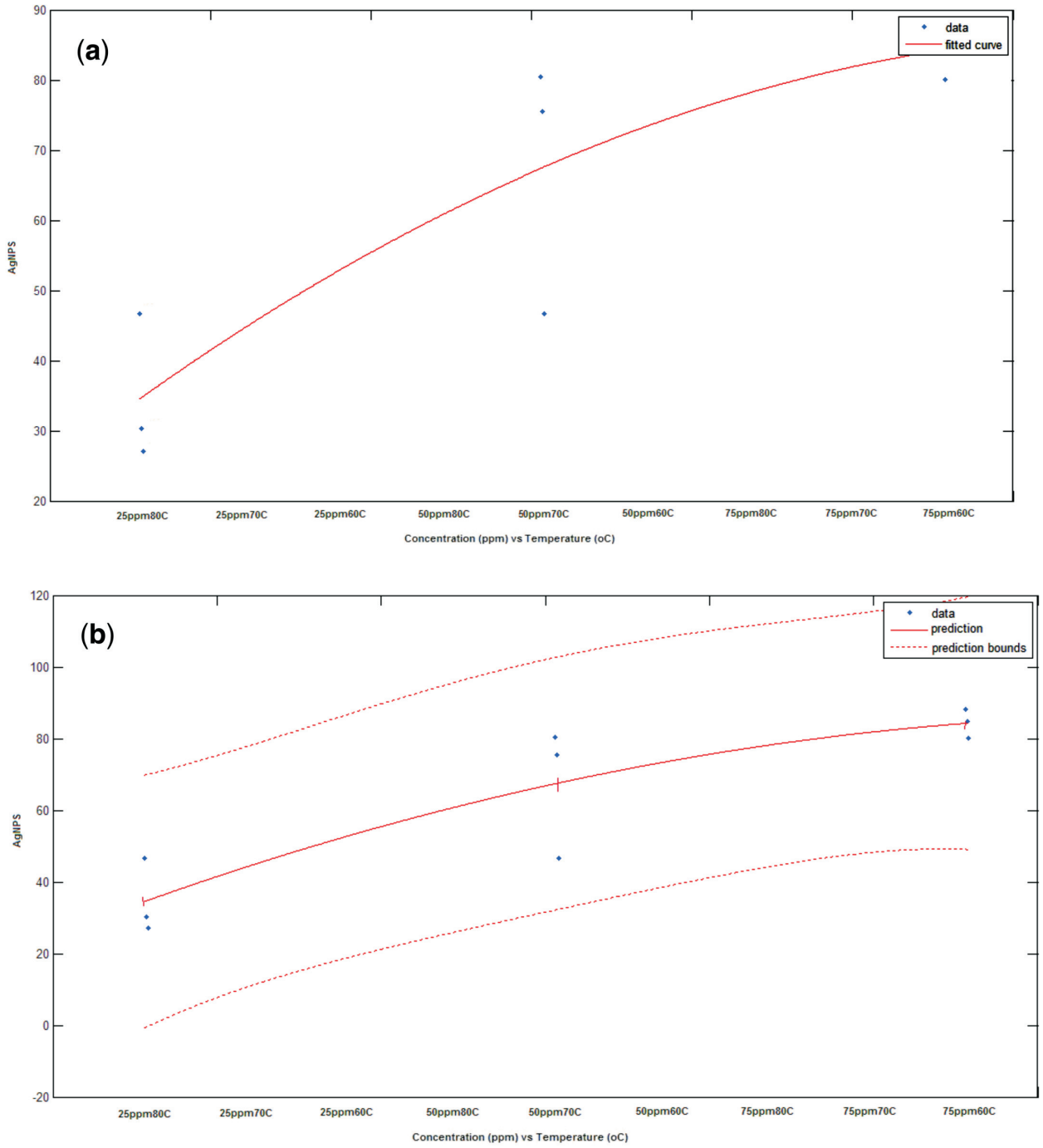

Figure 5 (**a**) Polynomial regression modelling of antioxidant activity in OD using AgNPs. (**b**) Polynomial regression fitted line plot of antioxidant activity in OD using AgNPs.

also account for more water loss than sucrose. OD samples with AgNPs were found to be most effective, having the highest inhibitory effect because growth was found on the seventh day of inoculation. This is an indication that OD tomato slices with AgNPs can extend shelf life of tomato samples longer than sucrose and NaCl which are known osmotic dehydration solutions. This is similar to the findings of Kabir *et al.*[46] which reported that 50 and 100 ppm AgNPs had significant inhibitory effect against powdery mildew (a disease caused by fungi) in tomatoes.

3.4.1. *Microbial Community in Treated Tomato Slices*

The number of fungal isolates as determined in the osmotically dehydrated tomato slices using sucrose, sodium chloride and silver-nanoparticles is presented in Fig. 9. A total of 20 fungal isolates were obtained from all the samples. Seven isolates were obtained from samples osmotically dehydrated with sucrose and the isolates covered four genera, namely *Aspergillus* spp., *Trichoderma* spp., *Penicillium* spp. and *Rhizopus* spp. with *Trichoderma* spp. occurring most. Six isolates were obtained from samples osmotically dehydrated with sodium chloride and the isolates covered two genera namely *Curvularia* spp. and *Aspergillus* spp. with *Aspergillus niger* occurring most. Four isolates were obtained from samples osmotically dehydrated with AgNPs and the isolates covered two genera, namely *Aspergillus* spp. and *Penicillium* spp. with *Aspergillus niger* also occurring most and three isolates were found in the control sample and the isolates covered two genera, namely *Aspergillus*

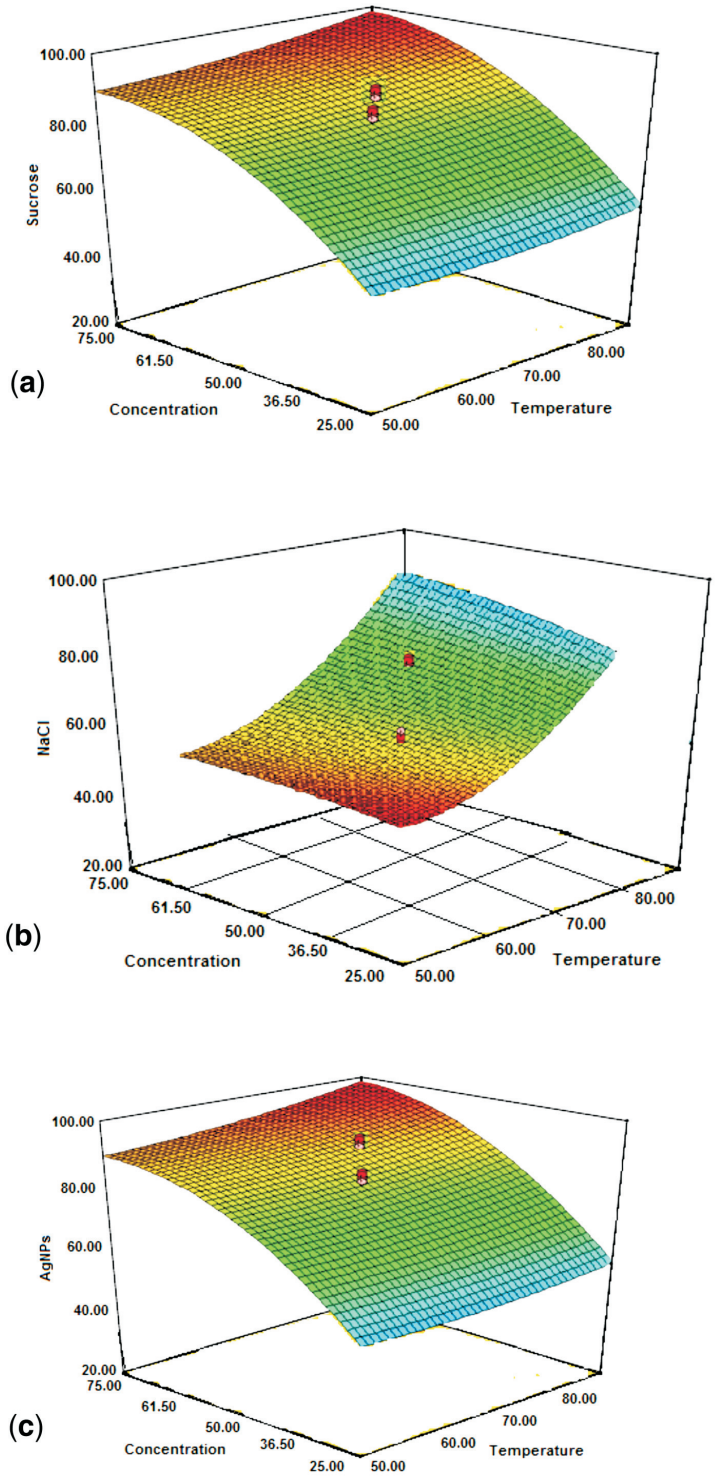

Figure 6 (**a**) Response surface for antioxidant activity of OD tomatoes using sucrose. (**b**) Response surface for antioxidant activity of OD tomatoes using NaCl. (**c**) Response surface for antioxidant activity of OD tomatoes using AgNPs.

niger and *Rhizopus* spp. However, no growth was obtained on the nutrient agar plates. This implies that there was no bacterial growth on the tomato osmotically dehydrated with the three dehydrating agents used in this study. In all, five fungal genera were isolated from osmotically dehydrated tomato slices, namely: *Aspergillus* spp., *Trichoderma* spp., *Rhizopus* spp., *Curvularia* spp. and *Penicillium* spp. This is in consonance with the results of Ibrahim *et al.*[7], Baker [47], Akinmusire[48], Wogu and Ofuase[49] and Abdel-Mallek *et al.*[50] that reported *Aspergillus niger*, *Rhizopus* spp. and *Penicillum* spp. as the major fungi responsible for rottenness of tomatoes and the production of volatile compounds in rotten tomatoes. Most of the fungi isolated in this study could be sources of potent mycotoxins which are detrimental to health. This is agreement with the reports of Ibrahim *et al.*[7] that *Aspergillus niger* is a source of ochratoxin which is considered to be a potent carcinogen. As observed in this study, *Aspergillus niger* had the highest occurrence while *Penicillium* spp. and *Curvularia* spp. occurred least, which is in consonance with report of Onuorah and Orji[9] that reported the dominance of *Aspergillus niger* in the fungal spoilage of

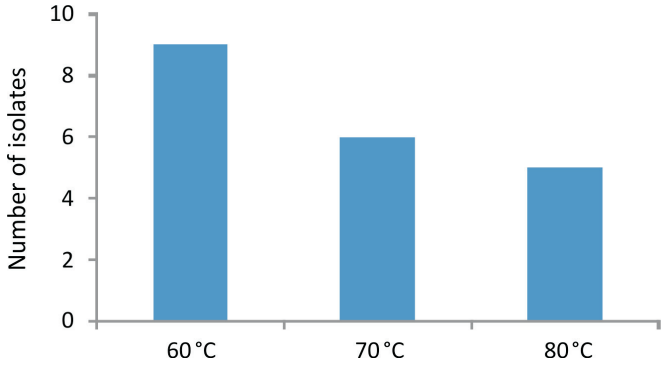

Figure 7 Fungal growth pattern of osmotically dehydrated tomato slices using sucrose, sodium chloride and silver nanoparticles against their temperatures.

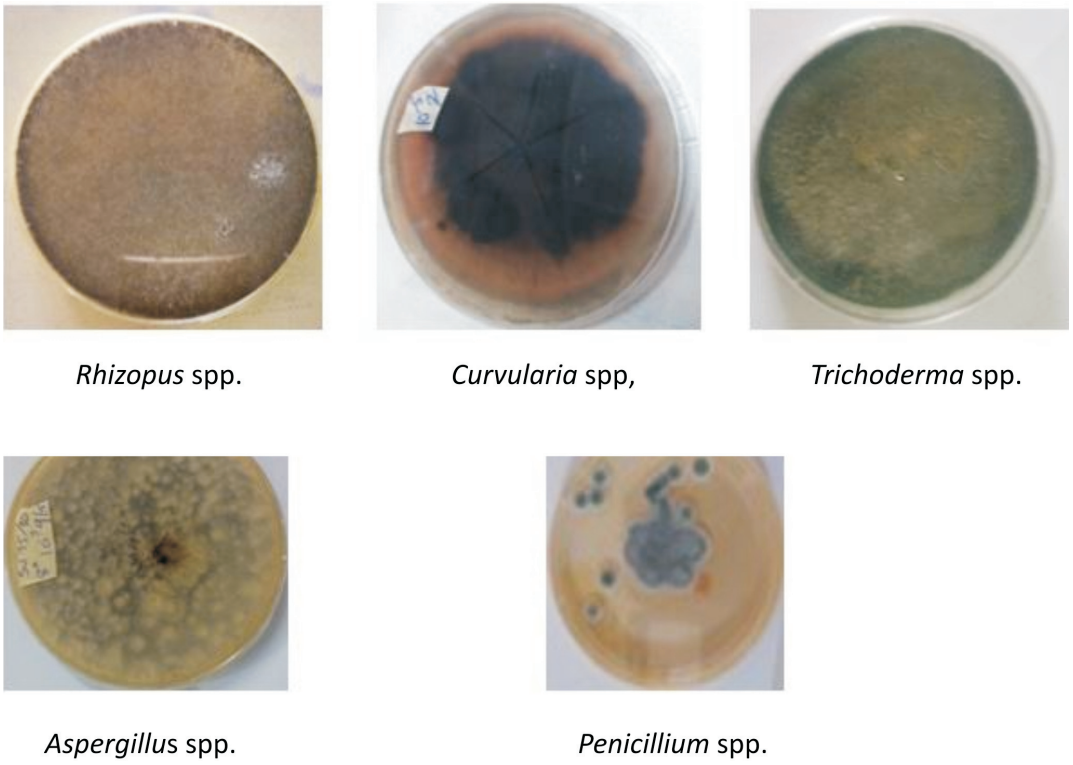

Figure 8 Fungal isolates in tomato slices osmotically dehydrated.

post-harvest tomato fruits sold in major markets in Awka, Nigeria.

4. Conclusion

This study has comparatively investigated the use of AgNPs, sucrose and NaCl as osmotic solutions for the preservation of tomato slices at different temperatures with different concentrations. AgNPs had the greatest influence in suppressing microbial growth, improved antioxidant activity, water loss, solid gain, water and solid diffusivities. Polynomial regression model and three-way ANOVA were successfully applied to model and determine statistical significance of osmotic conditions on anti-

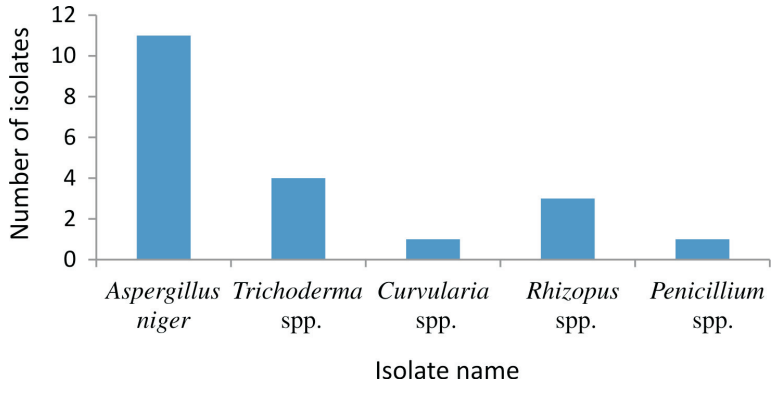

Figure 9 Number of fungal isolates in osmotically dehydrated tomato slices.

oxidant activity, which showed that the effects were statistically significant.

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