American Journal of

Food Technology

ISSN 1557-4571

Academic Journals Inc.

www.academicjournals.com

OPEN ACCESS American Journal of Food Technology

ISSN 1557-4571
DOI: 10.3923/ajft.2017.124.131

Research Article
Effect of Edible Coating on Extending the Shelf Life and Quality of Fresh Cut Taro

Sanaa S.H. Aly, Entsar N. Mohamed and Entsar S. Abdou

Department of Food Engineering and Packaging Research, Food Technology Research Institute, Agriculture Research Center, Egypt

Abstract
Background: Fresh cut fruits and vegetables go through preparation steps such as peeling, cutting or slicing so they exposed to wounding stress, spoilage and microbial growth. Edible coatings with antimicrobial agents can extend the shelf-life of fresh-cut fruit and vegetables. **Methodology:** Preparation of chitosan/starch coating solutions with different ratios and studying their rheological properties then using them in coating of taro (*Colocasia esculenta* L. Schott) pieces, coated taro pieces were packed in foam trays and wrapped using stretch poly ethylene film then kept at 4°C. Changes in weight loss, firmness, pH, total soluble solids (TSS), moisture content, sensory evaluation and microbial growth were measured during 20 days. **Results:** Coating solutions showed shear-thinning (pseudo plastic) behavior the flow behavior (Shear stress against shear rate) of the solutions was well described using the power law model. Coating solutions containing chitosan enhance chemical and microbial properties of coated taro, enhancement increases as chitosan percent increases reach to maximum with 100% chitosan solution. Weight loss of coated samples decreases compared to uncoated samples, moisture content of uncoated samples dropped to 34.41% from its original moisture content at the end of storage period while the moisture content of coated samples ranged from 59.20-66.28%. The pH, TSS and firmness changed slightly along the storage period. Hundred percent chitosan coating treatment extend the shelf life of fresh cut taro for 20 days also improved quality and acceptability of fresh cut taro. The presence of chitosan in the coatings inhibited the growth of total count bacteria and yeast and mold throughout the storage period and improved the sensory evaluation. **Conclusion:** Chitosan/starch coating solutions behaves as pseudoplastic, chitosan/starch coating solutions increase the shelf life of and enhance different properties of fresh cut taro.

Key words: Taro, edible coating, antimicrobial, shelf life, rheology, fresh cut

Received: August 24, 2016 Accepted: November 11, 2016 Published: February 15, 2017

Citation: Sanaa S.H. Aly, Entsar N. Mohamed and Entsar S. Abdou, 2017. Effect of edible coating on extending the shelf life and quality of fresh cut taro. Am. J. Food Technol., 12: 124-131.

Corresponding Author: Entsar S. Abdou, Department of Food Engineering and Packaging Research, Food Technology Research Institute, Agriculture Research Center, Egypt

Competing Interest: The authors have declared that no competing interest exists.

Data Availability: All relevant data are within the paper and its supporting information files.

INTRODUCTION

Taro (*Colocasia esculenta* L. Schott) is a starch-rich corms it has been reported that taro has 70-80/100 g starch[1] and is rich in gums (mucilage) (up to 9.1%)[2]. Taro also contains 0.6-0.8/100 g fibre, 2-6/100 g protein, vitamins, phosphorous and calcium[3].

Although, using fresh cut vegetables easier and preferred by consumers it leads to increase in the respiratory rates, biochemical reactions, microbiological spoilage and quality deterioration[4,5].

Recently edible coating become one of the most important methods of fresh cut vegetables packaging to delay physical, chemical and microbiological decomposition extending shelf life of fresh cut vegetables[6-8]. Chitosan is a linear copolymer composed of β (1→4)-linked 2-acetamido-2-deoxy-β-d-glucopyranose and 2-amino-2-deoxy-β-d-glucopyranose units. It is a biocompatible and biodegradable Chitosan has been reported to have a number of functional properties these include its antimicrobial activity and its ability to form protective films[9,10], its texturizing[11], binding action[12] and its antioxidant activity[13,14].

Chitosan and its blends with starch and other natural polymers are wildly used as edible coting to improve quality and extend shelf life of fresh cut vegetables[15,16].

Rheological properties of starch/chitosan blends, which are concentration (C) dependent are important for the use of these blends in edible coatings[17]. The knowledge of rheological properties of blends is necessary for a successful product formulation and engineering scale up[18].

The aim of this research (1) Studying rheological properties of chitosan/starch blends and (2) Studying the effect of chitosan/starch coating solutions as edible coating on quality of fresh cut taro and extend the shelf life.

MATERIALS AND METHODS

Materials: Taro corms were purchased from local market peeled and chopped into circular pieces uniform in size, chitosan with molecular weight 200000 Da was purchased from Acros Organics company, glycerol was obtained from Adwik company, Egypt, starch was a free gift from Mefad company.

Preparation of the coating solutions: Starch solution with concentration 4% (w/v) was gelatinized first in microwave oven at full power WP800 for 4 min then blended with 1.5% (w/v) chitosan solution by different ratios (v/v) of starch and chitosan using 1% glycerol as plasticizer. Table 1 shows the different formulas of the coating solutions.

Rheological properties of coating solutions: Rheological properties of coating solutions were studied using Brookfield Digital Rheometer, model HA DVIII Ultra (Brookfield Engineering Laboratories INC.), the coating solutions were placed in a small sample adapter, SC4-21 spindle was selected for the sample measurement[19].

Taro coating: Taro pieces dipped into coating solutions for 1 min and left 2 h to dry at room temperature to form coating film on taro pieces surface then taro pieces packed in foam trays and wrapped using stretch poly- ethylene film then kept at 4°C.

Weight loss: Weight loss of coated and uncoated taro pieces was determined by weighing them, in a semi-analytical balance (RADWAG) with 0.001 g readability. The analysis was performed on the processing day and every 4 days thereafter. Weight Loss (WL) percentage was determined by following the formula: $(A-B)/A \times 100$, where A was taro sample weight just before storage and B was taro sample weight after the storage period.

pH measurement: The pH value was recorded using a pH meter (Lovibond, Model Sensodirect 150) at 25°C as described by AOAC[20].

Firmness measurement (N): Osmotic dehydration sample texture was determined by universal testing machine (Cometech, B type, Taiwan). Flat head stainless cylindrical probe of 2 mm diameter was used for penetration test. The start of penetration test was the contact of the probe and sample surface, finish when the probe penetrated the tissue to 50% of sample height. The probe[21] speed was 1 mm sec^{-1}.

Total soluble solids (TSS%) measurement: The TSS was determined according to AOAC[20].

Moisture content (%): Moisture content were determined according to AOAC[22].

Table 1: Different ratios of starch/chitosan coating solutions formulation

No. of samples	Starch (%)	Chitosan (%)
1	60	40
2	70	30
3	80	20
4	100	0
5	0	100

Microbiological analysis: Aerobic Plate (AP) count was determined using serial dilutions on Plate Count Agar (PCA) with pour plate method.

The duplicate plates were incubated at 30°C for 48 h. the enumeration of total yeasts and moulds (YM) count with the same dilutions was also carried out on potato dexterous agar (PDA) at 25°C for 5 days using the pour plate method. Results were expressed as "CFU g^{-1}" according to AOAC[23].

Sensory evaluation: The samples of taro were sensory evaluated by visual inspection of colour, odor texture and overall quality during storage period according to the method described by Lawless and Heymann[24].

Statistical analysis: The collected data of taro were statistically analyzed and carried out with the SPSS 20.0 software (IBM, Inc.) by the Least Significant Differences (LSD) at the 5% level of probability according to Snedecor and Cochran[25] procedure.

RESULTS AND DISCUSSION

Rheological properties of coating solutions: The flow property of coating solutions is useful technologically to identify the most appropriate coating system design as well as optimize operating conditions.

The flow curves (shear rate versus shear stress) in Fig. 1 shows the flow behaviour of coating solutions, all coating solutions behaves as non-newtonian pseudoplastic fluid as previously reported for chitosan/starch blends[26]. Constitutive equations are also important for providing the material parameters required by process control, the shear stress-shear rate properties of coating solutions obeys the following power law relationship.

$$\tau = k\gamma^n$$

where, τ is the shear stress (Pa), k is the consistency index, γ is the shear rate (sec^{-1}) and n is the flow behaviour index.

Shear rate/viscosity relation: Figure 2 shows the relation between shear rate and viscosity. Values of viscosity for all prepared coating solutions decrease, as shear rate increases.

The relation between viscosity and shear rate was fitted to the following equation these results agree with the study of Lin *et al.*[27].

$$\mu = K\gamma^{n-1}$$

where, μ apparent viscosity (Pa sec), shear rate (sec^{-1}), k is the consistency index and n is the flow behaviour index.

Weight loss (%): Table 2 results showed lower weight loss for coated samples, dependent on coating type, compared to the control.

Increasing chitosan percent in coating solutions leads to decreasing in weight loss percent this can be attributed to that addition of chitosan to starch in coating solutions

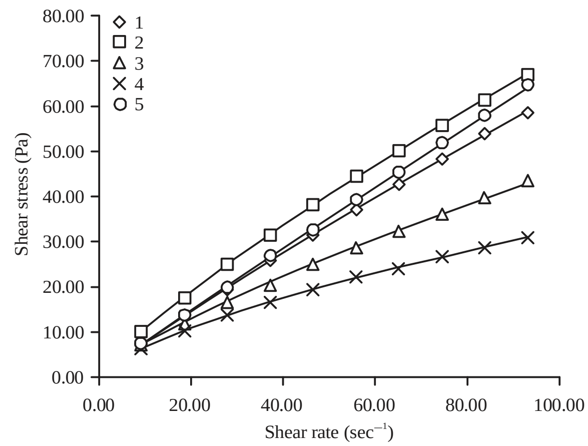

Fig. 1: Flow behavior of coating solutions

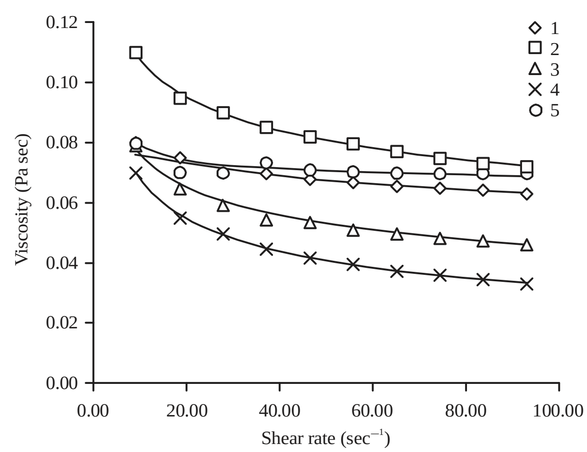

Fig. 2: Shear rate/viscosity relation of coating solutions

Table 2: Effect of edible coating on weight loss (%) of fresh cut taro stored for 20 days at 4°C

	Storage period (days)					
Treatments	0	4	8	12	16	20
Control	-	1.496	3.682	5.911	8.132	10.527
1	-	3.208	4.423	4.955	5.499	6.023
2	-	3.372	4.606	5.213	5.342	6.971
3	-	3.626	5.117	6.544	7.881	8.969
4	-	4.950	6.419	7.632	8.577	9.407
5	-	1.198	2.118	2.937	3.527	4.366

increase the barrier properties of coating film formed on taro pieces surface this effect increases with increasing chitosan percent[28], this almost happened over the all storage period.

After 20 days of storage the uncoated samples had lost approximately 10.5% of their initial mass, there are little differences between uncoated samples and starch coated samples.

pH measurement: The pH was maintained between 6.48 and 6.72 and approximately unchanged between treatments throughout the storage period this can be seen in Table 3. Similar behavior was observed by Sanchez-Gonzalez *et al.*[29], who observed that the pH values of uncoated samples were not significantly changed during storage.

Firmness measurement (N): Table 4 shows that firmness of all coated and uncoated samples increases slightly along the storage period this effect decreases with increasing chitosan percent in coating solutions reached to the lowest value with 100% chitosan and the largest value with control and 100% starch coated samples, this can be attributed to that the loss of moisture content in uncoated and 100% starch coated samples was greater than the loss of moisture content in coating solutions containing chitosan where, coating solutions containing chitosan increase the barrier properties of coating film formed on taro pieces surface[28] and also, taro corms contain mucilage characterized by high viscosity and water soluble gum formed other coating on taro surface, which harden the samples and increase their firmness[30].

Total Soluble Solids (TSS%): Results in Table 5 showed that fresh cut taro at zero time had 15% TSS value, storage of fresh cut taro for 20 days at 4°C recorded slight decrease in TSS compared to zero time, Rivas *et al.*[31] reported that the change in total soluble solids is due to the presence of the microorganisms that cause deterioration as a result of sugar fermentation.

Moisture content measurement: Moisture content measurements illustrated in Table 6 show that uncoated sample dropped to 34.41% from its original moisture content at the end of storage period while the moisture content of coated samples at the end of storage period ranged from 59.20-66.28% this means that coating solutions make barrier film on the samples surface prevent moisture loss especially in solutions containing chitosan[28]. As chitosan percentage increases moisture loss decreases the lower value was with 100% chitosan.

Microbiological analysis: Table 7 indicated that there is a continuous increase in all tested microorganisms (total bacterial count (TBC) and yeast and mold count (Y and M), especially in control treatment where increased from 1.60 and 1.30 log CFU g^{-1} in TBC, Y and M, respectively at zero time to 3.86 and 2.93 log CFU g^{-1} after 8 days from storage. This may be due to the increasing of relative humidity in cold chamber and the suitability of refrigerator temperature for yeast and mold growth[32].

Table 3: Effect of edible coating on pH measurement of fresh cut taro stored for 20 days at 4°C

	Storage period (days)					
Treatments	0	4	8	12	16	20
Control	6.48	6.39	6.37	6.28	6.28	6.26
1	6.48	6.41	6.41	6.39	6.38	6.38
2	6.48	6.43	6.42	6.41	6.40	6.38
3	6.48	6.44	6.43	6.43	6.43	6.41
4	6.48	6.50	6.54	6.65	6.69	6.72
5	6.48	6.34	6.32	6.25	6.14	6.11

Table 4: Effect of edible coating on firmness measurement of fresh cut taro stored for 20 days at 4°C

	Storage period (days)					
Treatments	0	4	8	12	16	20
Control	18.88	19.61	20.45	21.32	22.03	22.95
1	18.88	19.01	20.16	20.77	21.85	22.24
2	18.88	19.24	20.25	20.85	21.96	22.34
3	18.88	19.47	20.28	20.97	22.31	22.59
4	18.88	19.56	20.33	21.29	22.00	22.66
5	18.88	18.94	18.95	18.99	19.18	19.27

Table 5: Effect of edible coating on TSS measurement of fresh cut taro stored for 20 days at 4°C

	Storage period (days)					
Treatments	0	4	8	12	16	20
Control	15	14.5	14.0	13.5	13.5	13.0
1	15	15.0	15.0	15.0	14.5	14.5
2	15	15.0	14.5	14.5	14.0	14.0
3	15	14.5	14.5	14.0	13.5	13.5
4	15	14.5	14.0	13.5	13.5	13.0
5	15	15.0	15.0	15.0	15.0	15.0

Table 6: Effect of edible coating on moisture content of fresh cut taro stored for 20 days at 4°C

	Storage period (days)					
Treatments	0	4	8	12	16	20
Control	69.4	68.15	60.28	55.25	44.52	34.41
1	69.4	68.23	67.07	65.71	64.62	62.86
2	69.4	67.84	66.98	65.01	63.55	61.98
3	69.4	67.55	66.46	64.22	63.17	61.58
4	69.4	66.21	65.65	63.14	61.91	59.20
5	69.4	68.62	68.53	67.43	66.72	66.28

Table 7: Effect of edible coating on the growth of total bacterial and yeast, mold counts (log CFU g^{-1}) of fresh cut taro stored during 20 days at 4°C

Storage period (day)	Treatments	Total bacteria count	Yeast and mold count
0	Control	1.6000±0.0000[a]	1.3000±0.3000[a]
	1	1.6000±0.0000[a]	1.3000±0.3000[a]
	2	1.6000±0.0000[a]	1.3000±0.3000[a]
	3	1.6000±0.0000[a]	1.3000±0.3000[a]
	4	1.6000±0.0000[a]	1.3000±0.3000[a]
	5	1.6000±0.0000[a]	1.3000±0.3000[a]
	LSD	0.0410	0.5337
4	Control	3.3450±.0050[d]	2.4100±0.9400[c]
	1	1.6850±0.0850[b]	1.5700±0.0300[a]
	2	1.8400±0.3000[c]	1.8250±0.0550[b]
	3	1.8700±0.0300[c]	1.8400±0.1700[b]
	4	2.0200±0.0200[d]	2.0000±0.3600[c]
	5	1.6450±0.0450[a]	1.4750±0.2850[a]
	LSD	0.0747	0.7711
8	Control	3.8600±0.0200[e]	2.9300±0.5400[c]
	1	1.8700±0.0300[b]	1.8050±0.7250[a]
	2	2.5100±0.0400[c]	2.2200±0.2700[b]
	3	2.7150±0.0250[d]	2.4550±0.0550[b]
	4	3.2100±0.0100[e]	2.5850±0.2850[c]
	5	1.8400±0.0200[a]	1.6500±1.1400[a]
	LSD	0.5237	1.0952
12	Control	4.0600±0.0100[f]	3.5050±1.0550[d]
	1	2.0000±0.0000[b]	1.9050±0.5350[b]
	2	3.4900±0.0000[c]	2.6300±0.3600[c]
	3	3.6100±0.0700[d]	2.7800±0.4200[c]
	4	3.9950±0.0150[e]	2.9200±1.1500[c]
	5	1.9250±0.0250[a]	1.7700±0.7600[a]
	LSD	1.0555	1.3790
16	Control	-	-
	1	2.5500±1.0850[a]	2.0000±0.3100[b]
	2	-	-
	3	-	-
	4	-	-
	5	2.2210±1.1250[a]	1.8850±1.1250[a]
	LSD	1.7389	1.5851
20	Control	-	-
	1	3.7033±1.9185[c]	2.7821±1.8600[b]
	2	-	-
	3	-	-
	4	-	-
	5	2.8381±1.1377[b]	1.9550±1.4250[a]
	LSD	2.6732	1.9865

For each treatment within a column, means not sharing the same alphabetical letter are significantly different at 0.05, SD: Standard error

Treatment 5, consisting of 100% chitosan was the most efficient in controlling the microorganisms evaluated, normally present in fresh cut taro, stored at refrigerator temperature for 20 days, where, it is gave less microbial load at the end storage 2.83 and 1.95 log CFU g^{-1} in TBC, Y and M, respectively. Such reduction is considerable, when compared to other methods applied to reduce the microbial load.

Chitosan has widely been used in antimicrobial films and coatings due to its property of inhibiting the growth of many pathogenic bacteria and fungi[33]. Studies have shown that the effect of chitosan on some fungi is mainly due to alterations in the functions of the cellular membrane[34]. Chitosan based coatings have the potential to increase the shelf life of fresh fruits and vegetables, inhibiting the growth of microorganisms, reduced ethylene production, increased internal carbonic gas and decreased oxygen levels and provide the quality[35].

No significant differences ($p<0.05$) between treatment 4 and control, because starch coated samples treatment 4 presented the highest total bacterial counting throughout the storage period after control, starting at 1.60 log CFU g^{-1} and reaching 3.99 log CFU g^{-1} after 12 days of storage. Treatments 2, 3 did not inhibit the growth of this microbiological group, compared[36] to treatments 5 and 1.

Furthermore, if a maximum tolerable level of microorganisms is set as 4 log CFU g^{-1}, the uncoated taro will only last 8 days at 4°C, while all the coated samples will have an extended shelf life between 16 and 20 days, particularly these samples coated with the treatments 5 and 1.

Sensory evaluation analysis: Organoleptic evaluation could be considered one of the most important aspects in vegetables since it reflects the consumer preference. The sensory evaluation for fresh cut taro are presented in Table 8. These treatments were sensory evaluated for color, odor, texture and overall all appearance. From these data, the best treatment having the highest acceptability is the treatment 5 followed by treatment 1 (7.30 and 6.00) respectively. Also, the results revealed that, no significant difference ($p>0.05$) between treatment 2 and 3 compared with other treatments.

Boumail *et al.*[37] reported that, the effect of the addition of antimicrobials in different edible coating was tested on the odor and the texture. Results showed that the addition of antimicrobial coatings did not induce any detrimental effects on the odor.

Two main aspects that consumers use to make judgments about the quality of fresh cut foods are appearance and freshness at the time of purchase[5]. Control acceptability decreases gradually with increasing storage period followed by treatment 4, may be increased growth of microbial count[38].

Concerning the sensory evaluation, no differences were observed between treatment 5 and 1 compared with other treatments, with scores ranging around 7.00, 6.00 after 20 day from storage. On the other hand, treatment 4 (100% starch) showed that, low acceptability compared with other treatments. Starch contains about 30% of amylose and amylose is responsible for the film forming capacity of starches and increases the sticky texture, making it unacceptable in certain coating foods in particular texture[39].

Table 8: Effect of edible coating on Sensory evaluation of fresh cut Taro stored for 20 days at 4°C

Storage period (day)	Treatments	Color 10	Odor 10	Texture 10	Over all 10
4	Control	7.18±1.23^{b}	7.00±0.94^{b}	7.90±0.95^{a}	7.52±1.05^{ab}
	1	8.40±0.82^{a}	8.44±1.27^{a}	8.20±0.74^{a}	8.40±0.88^{a}
	2	7.97±0.82^{a}	8.36±0.71^{a}	8.10±0.79^{a}	8.21±0.71^{a}
	3	7.90±1.10^{a}	8.11±0.97^{a}	8.10±0.92^{a}	7.93±0.79^{a}
	4	7.70±1.43^{a}	7.53±1.10^{a}	7.60±1.43^{a}	7.69±1.35^{a}
	5	8.68±1.57^{a}	8.60±0.70^{a}	8.40±0.70^{a}	8.70±1.32^{a}
	LSD	0.872	0.868	0.854	0.938
8	Control	6.00±1.17^{b}	5.80±1.03^{bc}	6.60±0.94^{b}	6.23±0.92^{b}
	1	7.56±0.52^{a}	7.66±0.74^{a}	7.67±0.70^{a}	7.71±0.63^{a}
	2	6.88±0.48^{b}	7.73±0.82^{a}	7.48±0.88^{ab}	7.38±0.42^{ab}
	3	6.80±0.70^{b}	7.23±0.88^{ab}	7.20±0.92^{ab}	6.92±0.70^{b}
	4	6.15±1.03^{b}	5.84±0.67^{bc}	6.61±1.06^{b}	6.34±1.03^{b}
	5	8.49±0.97^{a}	8.33±0.99^{a}	8.27±0.57^{a}	8.56±0.82^{a}
	LSD	0.783	0.795	0.788	0.769
12	Control	5.21±1.32^{bc}	5.00±1.19^{c}	5.18±1.11^{bc}	5.14±1.36^{c}
	1	6.98±1.22^{ab}	6.74±1.77^{ab}	6.86±1.15^{ab}	6.78±1.12^{ab}
	2	6.57±1.41^{ab}	6.43±1.16^{b}	6.46±1.23^{b}	6.49±1.22^{b}
	3	6.33±1.32^{abc}	5.66±1.13^{bc}	5.31±1.25^{c}	5.43±1.28^{b}
	4	5.49±1.27^{bc}	5.23±1.12^{c}	5.11±1.16^{c}	5.14±1.36^{bc}
	5	7.96±1.33^{a}	7.78±1.44^{a}	7.81±1.13^{a}	7.72±1.25^{a}
	LSD	0.764	0.775	0.770	0.698
16	Control	4.30±1.50^{c}	4.00±2.13^{c}	4.00±1.19^{c}	4.10±1.50^{c}
	1	6.72±1.18^{ab}	6.44±1.78^{bc}	6.67±1.12^{bc}	6.51±1.13^{abc}
	2	5.67±1.35^{bc}	6.21±2.17^{bc}	6.56±1.31^{bc}	6.33±1.41^{bc}
	3	5.15±1.29^{bc}	5.17±2.14^{bc}	5.20±1.26^{bc}	5.40±2.11^{bc}
	4	4.54±1.22^{c}	4.70±2.06^{c}	4.70±2.14^{c}	4.68±2.03^{c}
	5	7.40±1.08^{a}	7.51±1.21^{a}	7.31±1.20^{ab}	7.46±1.75^{ab}
	LSD	1.093	1.551	1.112	1.251
20	Control	3.20±1.45^{c}	3.63±1.89^{c}	4.00±1.16^{c}	3.90±1.42^{c}
	1	5.82±1.14^{bc}	5.98±1.25^{bc}	6.43±1.15^{b}	6.00±0.84^{bc}
	2	5.13±1.29^{c}	5.00±1.78^{c}	4.86±1.35^{c}	5.26±1.42^{c}
	3	4.18±1.25^{c}	4.64±1.85^{c}	4.19±1.32^{c}	4.35±1.70^{c}
	4	4.02±1.20^{c}	3.71±2.11^{c}	3.18±1.52^{c}	3.65±1.78^{c}
	5	7.00±0.94^{ab}	6.70±1.34^{b}	7.22±0.82^{ab}	7.30±0.95^{ab}
	LSD	1.153	1.571	1.127	1.311

For each treatment within a column, means not sharing the same alphabetical letter are significantly different at 0.05, SD: Standard error

Results in Table 8 revealed that, fresh cut taro coated with 100% chitosan followed that 40% chitosan no significant differences ($p>0.05$) until the end storage period. It should be noted, shelf life of fresh cut produces can be determined when microbial counts reach such limit and/or when sensory attributes reach unacceptable limit[40].

CONCLUSION

The objective of this study was to prepare of chitosan/starch edible coatings studying flow behaviour which found to be pseudoplastic. Chitosan/starch edible coatings were successfully extend the shelf life of fresh cut taro samples coated with 100% chitosan coating solution extend shelf life to 20 days also coating samples with chitosan/starch solutions decrease weight loss percent and loss of moisture of all samples compared with uncoated samples.

The results of the present research showed also that edible coatings based on antimicrobial material chitosan effectively inhibited microbial growth and enhance quality and general appearance of fresh cut taro.

ACKNOWLEDGMENT

The researchers are grateful to Mefad company for providing starch as free gift.

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