



Storage Stability of Sugarcane Juice in Polypropylene-Based Nanocomposite Packaging Films

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Abstract Polypropylene-based nanocomposite films of 15 different compositions of nanoclay, compatibilizer and thickness were evaluated for packaging and storage of sugarcane juice of ‘Mandya’ variety Co 62175. The effect of nanocomposite films on the juice quality characteristics under ambient condition at every 15-day interval was studied for 60 days. The various biochemical quality parameters, viz. total soluble solids, pH, total sugars and overall acceptability scores of stored sugarcane juice, decreased with the elapse of storage period as well as with increased proportion of both nanoclay and compatibilizer but decreased by reducing the thickness of film. Among all the nanocomposite films, polypropylene packaging material having 5% compatibilizer, 2% nanoclay and 100 µm thickness showed better stability of measured biochemical properties with zero microbial population. Polypropylene packaging material with 15% compatibilizer, 6% nanoclay and 100 µm thickness showed better stability in maintaining the total color value than any other treatment.

Keywords Sugarcane juice · Storage · Nanocomposite · Packaging · Polypropylene · Quality

Introduction

India is the second largest producer of sugarcane next to Brazil. Out of 359 million tonnes of sugarcane produced in India during 2014–2015, about 67.64% is utilized by sugar mills for the production of white sugar and the rest for the preparation of different forms of jaggery, seed, feed and chewing (Murali and Puthira Prathap 2016). Indian system of medicine recommends sugarcane juice to cure a wide range of ailments such as fever, jaundice and urinary disorders (Subbannayya et al. 2007). Sugarcane varieties cultivated in India contain 20% of total soluble solids in the juice at the age of about 12 months, of which a major part of is sugar and the rest are minerals and health-promoting substances (Khare et al. 2012). Fresh sugarcane juice is a refreshing, natural and popular thirst-quenching drink in many countries due to its typical cane flavor and sweetness (Ghazal et al. 2003). Cane juice is an opaque liquid, and its color varies from light gray to dark green, depending on the rind color of the cane variety crushed. A major problem associated with the fresh sugarcane juice is its poor shelf life. Raw sugarcane juice is more susceptible to the growth of yeasts, bacteria and fungi (Karmakar et al. 2011). Different methods are suggested to preserve the sugarcane juice include refrigeration, heat treatments, herbal clarificant (Begum et al. 2015) and freezing by adding preservatives. The present study is an attempt to develop a suitable improved packaging material for sugarcane juice by using nanocomposite films.

Commercially available polymer-based food-packaging materials exhibit both oxygen and water vapor permeability. Food processing industry demands a packaging material with less permeability and more bearing strength which will be an alternative to the expensive multilayer films. Nanocomposite technology is one of the approaches to

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achieving the above requirement. Polymer nanocomposite consists of resins (either thermoset or thermoplastics) and nanofillers which enhances the barrier performance to ultraviolet rays, strength, stiffness, dimensional stability, optical properties and heat resistance (Sinha Ray and Okamoto 2003). Polypropylene (PP) has the lowest density and highest melting point of all the highly used thermoplastics and has a relatively low cost. This versatile plastic can be processed in many ways and has many food-packaging applications in both flexible film and rigid form. PP is chemically inert and resistant to most commonly found chemicals, both organic and inorganic. It is a barrier to water vapor and is oil and fat resistant. PP is not subject to environmental stress cracking (Kirwan and Strawbridge 2003).

Manikantan and Varadharaju (2011) studied the effect of compatibilizer, nanoclay and thickness of film on oxygen transmission rate (OTR), water vapor transmission rate (WVTR), tensile strength and percent elongation of PP-based nanocomposite films and found 21.4 and 28.1% reduction in OTR and WVTR, respectively, and about 71.7% increase in the tensile strength of PP-based nanocomposite films over the control. OTR and WVTR decreased with decrease in both nanoclay and compatibilizer and increase in film thickness, whereas opposite trend was observed in the case of tensile strength and percent elongation.

Rao (1990) developed a process for bottling sugarcane juice. The process consists of pasteurization for 10 min at 80 °C in a stainless steel vessel to which 125 ppm potassium metabisulfite (KMS) was added as a preservative. After packaging in presterilized bottles, these were kept at 80 °C for 15 min before storage at 30 °C. Finally, it was found that quality and palatability of sugarcane juice were still good after 10–12 weeks. Bhupinder et al. (1991) developed a process for conversion of sugarcane juice into acceptable ready-to-serve beverage and its long-term storage.

Kaur et al. (1995) also developed a process for producing bottled cane juice, and they blended the initial juice with 0.3% lemon juice and 0.1% ginger juice to improve the flavor. Banerji et al. (1997) attempted to provide technology for long-term storage of sugarcane juice. They found that major problems that have not been overcome were browning of the juice, loss of its typical flavor and sedimentation. Chauhan et al. (1997) carried out the study on the preparation and evaluation of sugarcane juice beverages incorporating ginger, mint and lemon extracts. They found that the maximum shelf life was obtained using 0.5% lemon juice. The increased proportions of additives to cane juice increase the titratable acidity, color and ascorbic acid content but decrease the total ash, pH and red color moderately. Chauhan et al. (2002) reported that the changes in

different attributes of sugarcane juice were significantly higher at room temperature as compared to the refrigeration temperature because of high microbial action. Singh et al. (2002) developed a process for the preparation of sugarcane juice concentrate with acceptable quality for use as an alternative sweetener. Krishnakumar (2003) found that the sugarcane juice stored in glass bottle was better for the storage period of 2 months than polyethylene, polypropylene and aluminum pouch with regard to biochemical, microbiological and organoleptic characteristics.

The effect of nanocomposite and compatibilizer-based packaging material on the shelf life of sugarcane juice has not been studied so far. Most of the studies on processing of sugarcane juice are confined to bottling sugarcane juice, and very limited work has been reported on storing sugarcane juice in pouches under refrigerated condition. Hence, the present study was undertaken to explore the storage stability of sugarcane juice in developed polypropylene (PP)-based nanocomposite food-packaging films under ambient condition.

Materials and Methods

Experimental Design

Polypropylene-based nanocomposite films of 15 different compositions of nanoclay and compatibilizer were developed, based on the procedure followed by Manikantan and Varadharaju (2011), and evaluated for storage stability of sugarcane juice. The treatment details for the developed PP-based nanocomposite films of different compositions of nanoclay, compatibilizer and thickness and their barrier characteristics (OTR and WVTR) are given in Table 1.

Sample Preparation

‘Mandya’, a variety of sugarcane Co 62175, was used for the extraction of cane juice. The rind of the sugarcane was removed and the juice was extracted using a three-roller power crusher. Lemon and ginger were also added to enhance the taste (Khare et al. 2012). The juice was filtered for further processing and analyzed for microbial load (total plate count), biochemical parameters (total soluble solids, pH, color and total sugars) and sensory evaluation (Kapur et al. 1978). The total soluble solids, pH, total sugar, total plate count and overall acceptability score of fresh filtered sugarcane juice were 19.5° Brix, 5.1, 16.5%, 52×10^6 CFU and 8.6, respectively. The filtered sugarcane juice was pasteurized at 80 °C for 15 min in a stainless steel vessel. The pasteurized sugarcane juice was then cooled to room temperature and decanted properly, and sodium benzoate @ 180 ppm was added as a preservative.

Table 1 Composition and barrier characteristics of developed nanocomposite films used for packaging of sugarcane juice

Treatment	Composition of packaging film				Barrier characteristics	
	Polypropylene, %	Compatibilizer, %	Nanoclay, %	Thickness, μm	OTR ($\text{cc m}^{-2} \text{ day}^{-1} \text{ atm}^{-1}$)	WVTR ($\text{g m}^{-2} \text{ day}^{-1}$)
A	93	5	2	50	1398	3.1
B	83	15	2	50	1524	4.1
C	89	5	6	50	1477	3.6
D	79	15	6	50	1541	5.0
E	93	5	2	100	924	1.7
F	83	15	2	100	1072	1.9
G	89	5	6	100	950	1.8
H	79	15	6	100	1094	2.0
I	86	10	4	75	1498	3.7
J	94.4	1.6	4	75	1289	1.9
K	77.6	18.4	4	75	1446	2.2
L	89.4	10	0.6	75	1139	2.4
M	86	10	4	35	2035	5.7
N	86	10	4	120	929	2.0
Control	100	0	0	100	1169	3.3

OTR oxygen transmission rate, WVTR water vapor transmission rate

The pouches (15 × 10 cm) of developed nanocomposite material were prepared using a sealing machine (Sevana, India). Fifty milliliter of juice was filled in pouches of nanocomposite films and sealed properly. These pouches were pasteurized by keeping in hot water at 80 °C for 15 min. The in-pouch pasteurized sugarcane juice was kept at ambient condition (mean temperature and relative humidity were 28.8 °C and 60.5%, respectively) for storage studies for a period of 60 days (Parvathy 1983). The pasteurized sugarcane juice packaged in prepared nanocomposite-based pouches was considered as treated and the juice packed in plain polypropylene pouches was considered as untreated (control) samples (Table 1). The pasteurized sugarcane juice was analyzed for total soluble solids (TSS), color, pH, total sugar, sensory evaluation and microbial load (total plate count—TPC) once in 15 days for 60 days. The pasteurized sugarcane juice was subjected to initial quality evaluation before packaging.

Storage Studies

Around 50 ml of the sugarcane juice was filtered through muslin cloth, and a drop of filtrate was taken to determine the TSS using ERMA Hand Refractometer. TSS was expressed as °Brix (Ranganna 1995). The pH of juice was measured with a digital pH meter (Elico pH meter, model LI120). The total sugar of the juice was measured by using automatic polarimeter (Atago Brand, Japan, model AP-300). The color of the juice was determined using

Lovibond RT Color (The Tintometer Ltd., UK) version 3.x. The sugarcane juice was placed in the sample holder and the light was directed toward the sample holder from the light source, and the basic color dimensions ‘L,’ ‘a’ and ‘b’ were recorded in the computer database attachment. The color dimensions ‘L,’ ‘a’ and ‘b’ of fresh juice were 87.1, −2.8 and 15.8, respectively, whereas for pasteurized juice, they were 82.3, −3.7 and 14.6, respectively. The total color difference (‘dE’) with reference to the fresh packaged juice was calculated for the nanocomposite films (Fernande et al. 2011). Total plate count of fresh and stored sugarcane juice samples was also analyzed by the procedure described in Anonymous (1992).

Sensory Evaluation

The sensory attributes for overall acceptability were carried out using nine-point hedonic scale (liked extremely = 9, liked very much = 8, liked moderately = 7, liked slightly = 6, neither liked nor disliked = 5, disliked slightly = 4, disliked moderately = 3, disliked very much = 2, disliked extremely = 1). A group of semi-trained panelists consisting of 15 faculty members (ten males and five females, age 23–55) was selected voluntarily from the Department of Food and Agricultural Process Engineering, Agricultural Engineering College and Research Institute, Tamil Nadu Agricultural University, Coimbatore. Before the actual sensory evaluation, the group was trained and instructed for the sensory attributes

to be evaluated so as to get familiar with the sensory procedure. The attributes evaluated for the pasteurized cane juice were color, taste, flavor and overall acceptability. Perceived intensities were recorded on hedonic scale readings (Armbrister and Sester 1994; Xiong et al. 2002).

Statistical Analysis

Duncan's multiple range test (DMRT) was used to separate significant differences in mean values of the measured parameters (Ananthan et al. 2012). The analysis of variance test (ANOVA) was carried out using SPSS 7.5 software and statistical procedures described by Gomez and Gomez (1984) to examine the effect of storage period and nanocomposite films on the measured quality parameters of stored sugarcane juice.

Results and Discussion

Biochemical Parameters

The effect of different treatments on the biochemical parameters of pasteurized sugarcane juice stored in PP nanocomposite films during 60 days of storage is given in Table 2. Biochemical parameters, viz. TSS, pH and total sugars of sugarcane juice stored in PP nanocomposite films, were decreased with storage period, and it might be due to the action of microorganisms on utilization of sugar component for their growth and converting into acids. This could also be due to increase in reducing sugars in juice during storage due to the hydrolysis of non-reducing sugars (Krishnakumar 2003). There was no change in TSS till 15 days of storage, and thereafter, it started decreasing gradually. Since there was no microbial population in treatments E, G and N (Table 3), no change in TSS was observed. The minimum TSS of 18.50 and 18.60° Brix was observed in control and treatment M, respectively. These observations are in agreement with earlier findings (Bhupinder et al. 1991; Chauhan et al. 2002; Singh et al. 2002; Sangeetha et al. 2013; Krishnakumar et al. 2013). This could be related to the level of nanoclay, compatibilizer and thickness of film. The change in TSS was high in packaging films with less thickness, more proportion of nanoclay and compatibilizer. From the analysis of variance (Table 2), it was observed that the total soluble solids were significantly ($p \leq 0.01$) influenced by the treatments, storage period and their interaction. Table 2 shows that the decrease in pH was minimum (0.06) in treatment E and maximum (0.16) in treatments C and control. The analysis of variance revealed that the change in pH due to the effect of treatments and storage period was not significant (Table 2). In contrast to present findings, Krishnakumar

and Devadas (2004), Chauhan et al. (1997), Sankhla et al. (2012) and Ali et al. (2015) reported that the pH of stored sugarcane juice significantly decreased during storage period due to acetic acid production. The minimum reduction (0.24) in total sugar content was observed in treatment E and maximum (0.56) in treatment M. The microbial loads of sugarcane juice in treatment E were less and in treatment M were more (Table 3) and thus contributed to reduction in total sugar content accordingly. The results on decrease in TSS, pH and total sugars of pasteurized sugarcane juice in polypropylene-based nanocomposite films during storage were in good accordance with the results of Krishnakumar (2003) who stored pasteurized sugarcane juice in polypropylene films. Table 2 shows that the total sugar content in sugarcane juice did not change significantly due to the effect of treatments, storage period and the interaction between the storage period and treatments. Overall, the change in biochemical parameters was less in treatment E than in other treatments during the storage period.

Total Plate Count

The number of colony-forming units (CFU) in stored sugarcane juice in the nanocomposite films of different treatments was observed at 15-day interval for 2 months, and the results are given in Table 3. It was found that the number of colonies in fresh untreated sugarcane juice was 52×10^6 . There was no microbial load in all the treatments up to 15 days of storage. After 15 days of storage, increase in the microbial load was observed in all treatments except E, G and N. Treatments E, G and N had comparatively less OTR and WVTR than other treatments (Table 1). Minimum OTR and WVTR were achieved in the packaging films having higher thickness with less proportion of nanoclay and compatibilizer (Manikantan and Varadharaju 2011). At the end of 60 days of storage, the maximum numbers of colonies were found in the treatment M (56.70×10^5 CFUs) followed by control having comparatively more OTR and WVTR. The possible reason for microbial growth might be due to the presence of oxygen and water vapor in the package material. Hence, the microbial population is expected to be less in the films having low oxygen and water vapor permeability. A similar result on increase in microbial population during storage of sugarcane juice in polypropylene films was reported by Krishnakumar (2003) and Krishnakumar and Devadas (2006). Chauhan et al. (2002) observed that the microbiological population increased during storage of sugarcane juice and the extent of increase in microbial population was also higher at room temperature as compared to refrigerated condition. Karmakar et al. (2010, 2011) reported that bacterial contamination may occur at different stages of

Table 2 Effect of treatments on biochemical parameters of pasteurized sugarcane juice stored in PP nanocomposite films

Treatments	TSS, °Brix				pH				Total sugars, g per 100 cc			
	Storage period, days				Storage period, days				Storage period, days			
	15	30	45	60	15	30	45	60	15	30	45	60
A	19.40	19.30	19.20	19.10	5.18	5.16	5.14	5.11	18.22	18.12	18.07	17.99
B	19.40	19.30	19.20	19.10	5.18	5.16	5.14	5.11	18.27	18.18	18.08	18.00
C	19.40	19.30	19.20	19.20	5.15	5.12	5.09	5.05	18.25	18.13	18.09	18.01
D	19.40	19.30	19.20	19.20	5.18	5.16	5.14	5.11	18.24	18.14	18.12	18.11
E	19.40	19.40	19.40	19.40	5.20	5.19	5.17	5.15	18.38	18.28	18.20	18.18
F	19.40	19.40	19.30	19.20	5.18	5.16	5.14	5.11	18.36	18.26	18.19	18.17
G	19.40	19.40	19.40	19.40	5.18	5.15	5.12	5.10	18.28	18.14	18.13	18.11
H	19.40	19.30	19.30	19.20	5.15	5.14	5.13	5.12	18.25	18.13	18.10	18.08
I	19.40	19.20	19.00	18.70	5.20	5.18	5.16	5.13	18.25	18.18	18.11	18.02
J	19.40	19.00	18.90	18.80	5.18	5.16	5.14	5.11	18.31	18.19	18.07	18.01
K	19.40	19.20	19.10	19.00	5.15	5.14	5.13	5.12	18.29	18.14	18.08	18.02
L	19.40	19.30	19.20	19.10	5.15	5.13	5.11	5.09	18.22	18.13	18.05	18.00
M	19.40	19.20	18.70	18.60	5.15	5.11	5.10	5.07	18.19	17.98	17.95	17.86
N	19.40	19.40	19.40	19.40	5.18	5.16	5.14	5.12	18.32	18.23	18.19	18.15
Control	19.40	19.10	18.90	18.50	5.18	5.14	5.10	5.05	18.26	18.12	18.06	17.98
'F' value	E_S (96.78**)		E_T (20.24**)		E_S (1.33 ^{ns})		E_T (0.05 ^{ns})		E_S (1.81 ^{ns})		E_T (0.06 ^{ns})	
	$E_S \times E_T$ (5.44**)				$E_S \times E_T$ (0.01 ^{ns})				$E_S \times E_T$ (0.01 ^{ns})			
CD ($p \leq 0.01$)	E_S (0.06)	E_T (0.10)	$E_S \times E_T$ (0.21)		E_S (0.13)	E_T (0.22)	$E_S \times E_T$ (0.50)		E_S (0.45)	E_T (0.79)	$E_S \times E_T$ (1.76)	

TSS at 0th day: 19.4° Brix; pH at 0th day: 5.21; total sugars at 0th day: 18.42 g per 100 cc

E_S Storage period, E_T treatments

** Significant at $p \leq 0.01$

^{ns} Not significant at $p \leq 0.05$

juice processing such as contamination of sugarcane, roller crusher, collecting vessel, ice, hands of the personnel and filter cloth. The statistical analysis of experimental results presented in Table 3 revealed that the effect of treatments, storage period and their interaction on microbial population was significant at 1% level.

Color Difference Value 'dE'

The data on the effect of treatments and storage period on 'dE' are presented in Table 3. Results obtained indicated that the maximum difference of 21.65 was observed at the end of the storage period in control and minimum in treatment H (9.34). This might be due to the differences in the transmittance of light in the nanocomposite films of the above treatments as observed from the differences in the color values of the sugarcane juice, wherein similar kind of color changes was observed for banana chips as reported by Manikantan et al. (2014). Generally, PP films are clear and more transparent than other polymer films. Hence, light is able to enter into the pouch and influence the color of the packaged material (Kirwan and Strawbridge 2003).

But, on addition of nanoclay and compatibilizer, the light transmission inside the polymer matrix due to the dispersion of nanoclay is reduced and hence the color difference of stored pasteurized sugarcane juice in the developed nanocomposite films with higher clay and compatibilizer content (treatment H) was significantly less than control. This may be partly due to the opaque appearance caused by the interaction between polymer matrix and nanoclay. The opaque appearance of the nanocomposite films hinders light transmission through the films resulting in the reduced film transparency. However, the main reason that the films lost transparency when adding the clay at higher proportions might be due to the aggregation of nanoparticles which, in turn, obstruct the transmission of light (Sothornvit et al. 2010). Hong and Rhim (2012) also observed that the transparency of the linear low-density polyethylene (LLDPE)/clay nanocomposite films decreased significantly compared to the neat LLDPE films. The ANOVA data presented in Table 3 clearly indicated that the effect of treatments, storage period and their interaction on total color difference was significant at 1% level.

Table 3 Effect of treatments on TPC, ‘dE’ value and overall acceptability score of pasteurized sugarcane juice stored in PP nanocomposite films

Treatments	TPC in sugarcane juice, $\times 10^5$ CFUs				‘dE’ value				Overall acceptability (O.A.) score			
	Storage period, days				Storage period, days				Storage period, days			
	15	30	45	60	15	30	45	60	15	30	45	60
A	0.00	3.30	6.70	10.00	2.70	10.79	13.39	15.28	7.4	7.0	6.4	6.0
B	0.00	3.30	6.70	10.00	1.80	7.21	12.25	15.60	7.2	6.8	6.2	6.0
C	0.00	3.30	6.70	6.70	2.10	8.39	11.77	14.12	7.4	7.0	6.4	6.2
D	0.00	3.30	6.70	6.70	3.71	12.37	13.73	14.65	7.4	7.0	6.4	6.2
E	0.00	0.00	0.00	0.00	1.19	5.74	10.08	13.07	7.6	7.2	6.8	6.6
F	0.00	0.00	0.00	3.33	1.33	5.33	9.39	12.89	7.4	7.0	6.6	6.4
G	0.00	0.00	0.00	0.00	1.57	4.30	8.76	11.77	7.6	7.2	6.6	6.4
H	0.00	0.00	0.00	6.70	0.58	2.32	6.50	9.34	7.4	7.0	6.8	6.4
I	0.00	6.70	13.30	26.70	1.66	6.64	11.35	14.54	7.4	7.0	6.6	6.2
J	0.00	13.30	16.70	23.30	1.76	7.05	11.17	13.98	7.4	7.2	6.8	6.2
K	0.00	6.70	10.00	13.30	0.91	3.65	8.60	11.95	7.4	7.0	6.6	6.2
L	0.00	3.30	6.70	10.00	1.45	5.82	11.72	15.82	7.4	7.0	6.4	6.2
M	0.00	6.70	26.70	56.70	2.37	9.50	15.00	18.70	7.2	6.8	6.4	6.0
N	0.00	0.00	0.00	0.00	1.41	5.63	9.15	12.18	7.6	7.2	6.8	6.4
Control	0.00	0.00	16.70	43.30	3.59	14.34	18.63	21.65	7.0	6.6	6.0	5.6
‘F’ value	E_S (1691.73**) E_T (416.62**)			E_S (10377.79**) E_T (310.68**)			E_S (38.00**) E_T (0.67 ^{ns})					
	$E_S \times E_T$ (159.76**)				$E_S \times E_T$ (42.27**)				$E_S \times E_T$ (0.08 ^{ns})			
CD ($p \leq 0.01$)	E_S (0.55) E_T (0.95) $E_S \times E_T$ (2.12)			E_S (0.23) E_T (0.39) $E_S \times E_T$ (0.88)			E_S (0.42) E_T (0.72) $E_S \times E_T$ (1.62)					

TPC at 0th day: 0.00; ‘dE’ at 0th day: 0.00; O.A. score at 0th day: 8.2

E_S Storage period, E_T treatments

** Significant at $p \leq 0.01$

^{ns} Not significant at $p \leq 0.05$

Overall Acceptability Score

Table 3 shows that the overall acceptability decreased gradually with storage period. This decrease could be due to the loss of volatile aromatic substances responsible for taste as stated by Reddy (2004). The overall acceptability of pasteurized sugarcane juice at 0th day was 8.2. The overall acceptability at the end of storage period ranged between 5.6 (control) and 6.6 (treatment E). This indicates that the score value falls between ‘Neither like nor dislike’ and ‘like moderately.’ The possible reason for more overall acceptability score might be due to the retention of color, taste and flavor as fresh pasteurized sugarcane juice. The attainment of this condition might be possible only due to the high barrier characteristics of films. In this case, the films of the treatment E had comparatively less OTR and WVTR than that of control (Table 1). Chauhan et al. (2002), Khare et al. (2012) and Sankhla et al. (2012) also observed the significant reduction in sensory scores with the advancement of storage. The effect of storage period on overall acceptability scores was significant at 1% level; however, the effect of treatments and the interaction

between the treatments and storage period was not significant (Table 3).

Conclusion

The quality characteristics, viz. total soluble solids, pH, total sugars, total color difference, total plate count and overall acceptability score of ‘Mandya’ variety Co 62175 sugarcane juice, were studied under ambient condition at every 15-day interval for 60 days. The biochemical parameters and overall acceptability scores of stored sugarcane juice decreased during the storage study. On the basis of the stability of measured biochemical parameters, total plate count and overall acceptability scores, polypropylene packaging material having 5% compatibilizer, 2% nanoclay and 100 μm thickness (treatment E) showed better stability of measured quality characteristics of sugarcane juice than any other treatments. PP-based films are widely used in food industry for packing food products such as biscuits, crisps (chips), snack foods, chocolate, sugar confectionery, ice cream, frozen food, tea

and coffee. Due to the enhancement of strength and barrier characteristics, this study will definitely find place for PP-based nanocomposite food-packaging films' applicability in other high-value food products also.

Compliance with Ethical Standards

Conflict of interest The authors declare that they have no conflict of interest.

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