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The Migration of Chemical Contaminants from Polyethylene Terephthalate Bottles Into Shani Soft Drink

Raad J. Nashmi , Tariq N. Musa
Department of Food Science, College of Agricultural Engineering Sciences, University of Baghdad, Iraq.

ABSTRACT

Conducted a comparison between the effect of different storage conditions and durations on the migration of polyethylene terephthalate contaminants to Shani soft drink (SH) to refer to the most suitable condition for storing this drink. A sample of the drink under study was obtained immediately after filling into 1-liter PET-bottles and stored at varying conditions including -18, 0, 4, 25˚C, shade and the sun, at beginning of the storage, GC-MS was employed to identify potential chemical contaminants, during storage concentrations of identified contaminants were monitored by using HPLC. Also FTIR-spectra of drinks stored at the three worst conditions (-18, 0 and the sun) were compared and the inner surfaces of the same bottles were electron-microscopically scanned before and after storage to assess the morphological changes caused by each of them. The findings stated that cooling is the most suitable condition while the sun storage was the most detrimental among the other conditions, since the sample stored in the sun for 180 days was recorded the lowest value of pH and the highest concentrations of detected contaminants, as well comparison of FTIR-spectra revealed the presence of esters and carbonyl compounds at the highest concentration in the sample stored in the sun for 30 days. Similarly, comparison of captured SEM-images confirmed that PET-bottles stored at the sun were the most damaged compared to their counterparts stored at freezing temperatures, -18 and 0 ˚C.

Key words: Carbonated beverages, Packaging materials, Storage conditions, Transfer of impurities.

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INTRODUCTION

Shani is one of the distinctive and beloved carbonated soft drinks that is widely consumed in many countries and this is due to the combination of its wonderful rich strawberry flavor, acidity, exciting fizzy effect and the pleasant coolness that distinguishes carbonated soft drinks making it a favorite choice for many people especially when they need to refresh themselves after a long day (Al-halmi *et al.*, 2024). Moreover, thanks to its bright red color, Shani has a positive cultural impact in both Eastern and Western societies as enhancing consumers' feelings of happiness and joy. Recently, its consumption has expanded with its use in desserts (such as ice cream and jelly) in addition to its availability in plastic bottles are more resistant to damage (Maghraby *et al.*, 2024). Shani-bottles are manufactured from polyethylene terephthalate (PET) polymer thanks to its many exciting properties such as high thermal stability, solvent and breakage resistance, ease of shaping, flexibility, light weight and transparency which make it an ideal choice for food and beverage packaging (Bharati and Gaikwad, 2025). Despite the numerous advantages, PET bottles have still been a source of ongoing concern as it's made from some chemical substances, these substances could leach from bottles into carbonated soft drinks at stored incorrectly; as a result, it can affect human health leading to major issues such as liver harm, reproductive toxicity and

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overall disruption of the endocrine system (Oyedeji *et al.*, 2025). Due to the potential health risks involved, the migration of PET chemical contaminants from bottles to beverages along with the factors influencing this process has generated substantial debate in the research community and numerous studies have been conducted on this subject, but their findings remain inconclusive. This is because the studies have largely examined individual factors such as the chemical composition of beverage, storage duration and storage conditions, which may demonstrate effect when considered separately but show an opposing effect when interacting with other variables (Becerra-Herrera *et al.*, 2022). Moreover, several previous studies have concluded results regarding the migration of PET contaminants on the basis of bottle manufacturing simulations, computing and storage modeling, however, these conclusions are often flawed, since the temperature used in laboratory manufacturing processes usually exceeds the temperature used in industrial-scale production. Additionally, the migration of contaminants is not consistent meaning it cannot be precisely calculated or modeled (Same *et al.*, 2023). Therefore, this research was aimed to provide conclusive results regarding the effect of different storage conditions and periods on the concentration of polyethylene terephthalate contaminants in Shani drink to refer to the most suitable condition for storing this drink.

MATERIALS AND METHODS

Sampling and storage of Shani drink: randomly, a sample of Shani drink was obtained immediately after filling into 1-liter PET-bottles and stored at varying conditions including -18, 0, 4, room temperature, shade and the sun, to simulate storage for 6 months in the sun accelerated weathering tester was used (1day equal to 9 days), The temperature was continuously recorded during storage with a digital thermometer.

PH Testing: The pH value was determined following the AOAC (2012) method, utilizing a Hanna HI 221 pH meter (Italy) at a temperature of 25 $^{\circ}$C.

Extraction of chemical contaminants: Prior to extraction, a rotary evaporator (Yamato RE-300, Japan) was used to evaporation of 1 liter of SH-drink to 200 ml, extraction of phthalates esters [Dibutyl phthalate (DBP) , Diethyl phthalate (DEP), Dimethyl phthalate (DMP), Diethylhexyl phthalate (DEHP), Benzyl butyl phthalate (BBP)] , ethylene glycol (EG) and bisphenol-A (BPA) were carried out according to The method outlined by (44) while extraction of formaldehyde (Form.) and acetaldehyde (Acet.) were carried out according to Keresztes *et al.* (2013).

Gas chromatography mass spectrometry (GC-MS): The identification of chemical contaminants was performed following the procedure outlined by Selvaraj *et al.* (2014), utilizing a Gas Chromatograph (Hitachi 7000 Series, Japan) equipped with a mass Spectrometer detector (PerkinElmer, USA).

High performance liquid chromatography (HPLC): Standard solution of the target chemical compounds(EG, BPA, acetaldehyde, formaldehyde, DBP, DEP, DMP, DEHP and BBP) were prepared at 0.1 ppm, Detection and quantification of these compounds were performed following Redžepović *et al.* (2012) via HPLC (JASCO Corporation, Japan) with the following specifications: the column was JASCO C18 Column (5µm, 4.6×250 mm) with mobile phase Acetonitrile: Water (65:35 v/v), the injection volume was 20 µl, flow rate1 ml/min and UV detection was performed at 360 nm.

Fourier Transform Infrared Spectroscopy (FT-IR): FTIR-Spectra of samples were recorded in accordance with Mitchell *et al.* (2013) by PerkinElmer Spectrum 100 (USA) equipped with a deuterated tri-glycine sulphate detector and the spectra were collected within over a wavenumber range of 400 to 4000 cm^{-1}.

Scanning Electron Microscopy (SEM): Scanning electron microscopy (Thermo Scientific Apreo S, USA) at an acceleration voltage of 20 kV was used to examine the inner surfaces of PET-bottles according to Akbulut *et al.* (2024) after the surfaces were coated with gold (999) via vaporization and analyzed

Statistical analysis: Data were subjected to the statistical analysis according to Othman *et al.* (2024) using program of Statistical Package for the Social Sciences virision 20 (SPSS

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V.20), T-test or Least significant difference-LSD (ANOVA: Completely randomized design CRD) was used to significant compare between means in this study.

RESULTS AND DISCUSSION

Effect of different storage conditions on pH of bottled SH drink: pH of bottled SH drink stored at various conditions was tracked and the results were shown in Tables (1-3). From the presented data in Table (1) it can be noted that pH values of samples were insignificantly increased (P≤0.05) after storage at -18 and 0 °C, since pH value were 4.61 at zero time then increased to 4.68 and 4.74 after 15 day of storage at -18 and 0°C respectively, these results are comparable to the results founded by Irshad *et al.* (2024) and this probably because of the destructive effect of freezing on the bottle wall and decomposes some migrated compounds from PET bottles into beverages such as phthalate esters and ethylene glycol into alkaline reaction products such as ethylene glycol and di ethylene glycol and sodium terephthalate (Yang *et al.*, 2024).

Table 1. PH of bottled SH drink stored under freezing conditions at -18 °C and 0 °C

Storage conditions	Time (day)		T-test
	0	15	
-18 °C	4.61	4.68	0.203 NS
0 °C	4.61	4.74	0.178 NS
T-test	0.140 NS	0.221 NS	---

NS: Non-Significant.

Table 2. PH of bottled SH drink stored at different conditions (4 °C, Room, Shade).

Storage conditions	Time (day)				L.S.D.
	0	10	20	30	
4 °C	4.61	4.63	4.65	4.69	0.189 NS
Room	4.61	4.57	4.50	4.41	0.226 NS
Shade	4.61	4.50	4.38	4.19	0.337 *
L.S.D	0.142 NS	0.156 NS	0.298 NS	0.377 *	---

* (P≤0.05), NS: Non-Significant.

Table 3. PH of bottled SH drink stored under sun condition

Storage condition	Time (day)									L.S.D.
	0	10	20	30	60	90	120	150	180	
Sun	4.61	4.43	4.16	3.93	3.58	3.23	2.95	2.66	2.58	1.006 *

* (P≤0.05).

Similarly, pH values of samples stored at 4 °C were showed the same behavior and insignificantly increased (P≤0.05) with the gradual increase in storage period until reached to 4.69 after 30 day, these results were in line with Zahan *et al.* (2024 and the reason for this increase may be some alkaline compounds resulting from the decomposition of PET and phthalate esters as a result of storage (Yang *et al.*, 2024), while Naz *et al.* (2018) attributed these to that carbon dioxide (CO_2) is an important component associated with the acidity of carbonated beverages and due to the low gas barrier properties of PET bottles, the level of CO_2 in soft drinks decreases and thus the acidity decreases (increases pH value). From a different perspective, Mierczynska-Vasilev (2024) and Wang *et al.* (2024) explained this increase by the infiltration of oxygen from outside the bottle into it and oxidation of some acidity causes such as ascorbic, citric and phosphoric acid in conjunction with traces of oxygen present in the apical space of the bottle. On the contrary, pH values corresponding to the samples stored at room temperature and shade showed a non-significant decrease (P≤0.05) with increase of storage period. Also, the results in Table (3) showed that the pH values of samples stored in the direct sun were significantly decreased (P≤0.05) until recorded the lowest value (2.58) after 180 day of storage in the sun, these results were close to the results reported by Umeocho *et al.* (2024) and Shah *et al.* (2024) and this is may be due the combined effect of high temperature and UV, since high temperatures are accelerates the oxidation organic constituent via oxygen leaking from the bottle walls to form several acids and hydrolysis of sugars by acids added

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to soft drinks such as ascorbic acid and citric acid, which may lead to the formation of more acids and thus a decrease in the pH value (De Assis *et al.*, 2024 and Prajapati *et al.* 2024), as well UV is stimulate some side reactions of chemical additives (Omokpariola *et al.*, 2022) and this is supported by the statement of that acid generation rate increases when storage under sunlight conditions, as UV lead to photoaging of plastic bottles which reduces the original thickness of plastic and thus, it becomes more porous and permeable to oxygen Huang and Wang (2024).

Identify of target chemical contaminants by (GC-MS): In this study the most dominant chemical contaminants in SH drink were identified accurately and GC-MS chromatogram of detected compounds was framed in Figure (1) and Table (4).

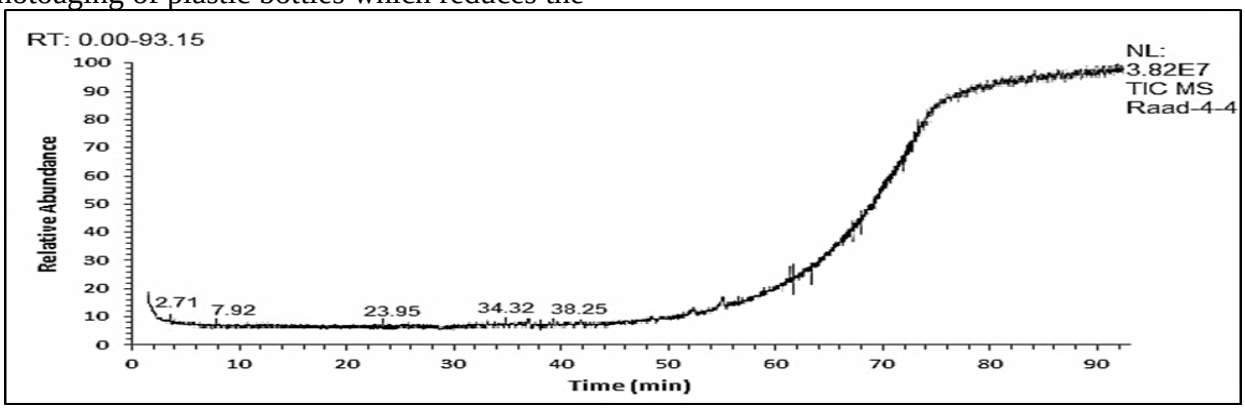


Fig. 1. GC-MS chromatograms of SH drink at zero time

Table 4. Identified chemical contaminants by GC-MS

Ret. Time	Identified Compound	Molecular Formula	Molecular Weight
2.71	Ethanal [Acetaldehyde]	C_2H_4O	44.05
34.32	Dibutyl Benzene-1,2-Dicarboxylate [Dibutyl Phthalate]	$C_{16}H_{22}O_4$	278.34

GC-MS chromatogram (Fig. 1) and Table (4) emphasized that all chemical contaminants in SH drink at zero time were acetaldehyde and DBP which belong to carbonyl compounds and phthalate esters, the dominance of this category of chemical contaminants alone may be due to that the production of global brands of carbonated soft drinks is carried out under strict requirements and controlled conditions (Yang and Chen, 2025), on the other hand the appearance of these compounds may be due to their close relationship with the production of PET bottles, either as a basic compound, a catalyst, property enhancers or as by-products of the thermal decomposition of PET polymer (Razzaque *et al.*, 2024). Based on these results, in the present study it was proposed to target and studing the migration of ethylene glycol as the backbone of PET, five of the most common phthalate esters as polymer property enhancers, bisphenol-A as a potential contaminant transferred through plastic recycling, as well acetaldehyde and formaldehyde were taken into consideration for their potential emission as a result of thermal degradation becaus of high temperature required for polymer synthesis.

Effect of different storage conditions on migration of chemical contaminants into bottled SH drink: Standards of targeted chemical compounds were calibrated by HPLC to accurately identify the compounds in the samples and their properties were summarized in Table (5), then these contaminants were tracked (quantitatively and qualitatively) in samples stored at different conditions and the results were tabulated in Tables (6-10).

Table 5. Standards of target chemical contaminants by HPLC

	Standards for chemical contaminants (100 ppb)								
conditions	Acet.	EG	Form.	DMP	BPA	DEHP	DEP	BBP	DBP
Ret. Time	2.419	3.475	5.961	7.142	7.218	7.940	8.853	9.325	9.873
Area	112716.0445	94665.9685	185271.0038	110280.0133	110985.3761	118873.9994	139963.5889	104406.6662	91258.3667

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Table 6. Effect of storage at -18 and 0 ˚C on migration of chemical contaminants into bottled SH drink

Compound	Freezing at – 18˚C						Freezing at 0˚C			L.S.D P≤0.05
	Time (0 day)			Time (15 day)			Time (15 day)			
	Ret.time	Area (Uv.Sec)	Conc. (µg/L)	Ret.time	Area (Uv.Sec)	Conc. (µg/L)	Ret.time	Area (Uv.Sec)	Conc. (µg/L)	
Acet.	2.461	29644.31	26.30	2.440	38548.887	34.20	2.449	58578.5283	51.97	8.02*
DBP	9.816	419.7885	0.46	9.875	1907.2999	2.09	9.885	5238.2302	5.74	1.96*
BPA	-	-	-	7.240	3440.5470	3.10	7.266	7014.2760	6.32	2.07*
DEHP	-	-	-	7.937	4576.6490	3.85	-	-	-	1.89*
BBP	-	-	-	9.347	4541.6900	4.35	9.355	9427.9220	9.03	2.27*
DEP	-	-	-	-	-	-	8.839	6690.2596	4.78	1.04*
DMP	-	-	-	-	-	-	7.173	6197.7370	5.62	1.66*

Table 7. Effect of storage at cooling temperature (4 ˚C) on migration of chemical contaminants into bottled SH drink

Compound	Cooling at 4˚C									L.S.D P≤0.05
	Time (10 day)			Time (20 day)			Time (30 day)			
	Ret.time	Area (Uv.Sec)	Conc. (µg/L)	Ret.time	Area (Uv.Sec)	Conc. (µg/L)	Ret.time	Area (Uv.Sec)	Conc. (µg/L)	
Acet.	2.434	31008.1838	27.51	2.441	32383.3196	28.73	2.474	33780.9985	29.97	2.85*
DBP	9.861	638.8086	0.70	9.828	876.0803	0.96	9.825	1140.7296	1.25	0.58*
DEHP	-	-	-	7.928	2948.0750	2.48	7.973	3340.3590	2.81	1.06*
Form.	-	-	-	-	-	-	5.941	19731.3619	10.65	2.07*

Table 8. Effect of storage at room temperature (25±2 ˚C) on migration of chemical contaminants into bottled SH drink

Compound	Room temperature (25±2 ˚C)									L.S.D P≤0.05
	Time (10 day)			Time (20 day)			Time (30 day)			
	Ret.time	Area (Uv.Sec)	Conc. (µg/L)	Ret.time	Area (Uv.Sec)	Conc. (µg/L)	Ret.time	Area (Uv.Sec)	Conc. (µg/L)	
Acet.	2.441	36328.3811	32.23	2.444	43068.8006	38.21	2.487	49910.6645	44.28	5.39*
DBP	9.872	1496.6372	1.64	9.829	2655.6185	2.91	9.827	3951.4873	4.33	0.90*
Form.	-	-	-	5.937	25715.6153	13.88	5.964	30347.3904	16.38	3.56*
DEHP	-	-	-	7.922	5777.2760	4.86	7.961	7703.0350	6.48	1.96*
BBP	-	-	-	9.334	5648.4006	5.41	9.357	7485.9580	7.17	1.79*
DEP	-	-	-	-	-	-	8.880	5038.6892	3.60	0.75*

Table 9. Effect of storage in shade (37±2 ˚C) on migration of chemical contaminants into bottled SH drink

Compound	Shade temperature (37±2 ˚C)									L.S.D P≤0.05
	Time (10 day)			Time (20 day)			Time (30 day)			
	Ret.time	Area (Uv.Sec)	Conc. (µg/L)	Ret.time	Area (Uv.Sec)	Conc. (µg/L)	Ret.time	Area (Uv.Sec)	Conc. (µg/L)	
Acet.	2.418	43947.9857	38.99	2.442	58364.3678	51.78	2.479	73017.4536	64.78	7.02*
DBP	9.833	2719.4993	2.98	9.832	5247.3561	5.70	9.821	7975.9812	8.74	2.16*
DEP	8.858	3709.0351	2.65	8.825	6648.2705	4.75	8.875	9727.4694	6.95	1.84*
Form.	-	-	-	5.938	35664.6682	19.25	5.985	45558.1398	24.59	4.19*
BPA	-	-	-	7.228	6969.8820	6.28	7.252	10576.9060	9.53	2.52*
BBP	-	-	-	-	-	-	9.364	13322.2906	12.76	2.07*

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Table 10. Effect of storage in the sun (45±5 ˚C) on migration of chemical contaminants into bottled SH drink

Compound	The sun (45±5 ˚C)												L.S.D
	Time (10 day)			Time (20 day)			Time (30 day)			Time (60 day)			
	Ret.time	Area (Uv.Sec)	Conc. (µg/L)	Ret.time	Area (Uv.Sec)	Conc. (µg/L)	Ret.time	Area (Uv.Sec)	Conc. (µg/L)	Ret.time	Area (Uv.Sec)	Conc. (µg/L)	
Acet.	2.451	57530	51.04	2.445	85652	75.99	2.499	114226	101.34	2.418	241020	213.83	P≤0.05
DBP	9.840	5411.6	5.93	9.835	9746.3	10.68	9.855	15158	16.61	9.841	31986	35.05	
Form.	5.983	35182	18.99	5.942	53376	28.81	5.994	72700	39.24	5.964	153385	82.79	
DEP	8.826	6368.3	4.55	8.827	12078	8.63	8.869	18097	12.93	8.817	38182	27.28	
BPA	-	-	-	7.234	11842	10.67	7.257	18878	17.01	7.215	39821	35.88	
DEHP	-	-	-	7.926	17046	14.34	7.977	25070	21.09	7.934	52898	44.50	
BBP	-	-	-	9.339	16036	15.36	9.378	23721	22.72	9.385	50042	47.93	
EG	-	-	-	-	-	-	3.496	9154.1	9.67	3.431	27159	28.69	
DMP	-	-	-	-	-	-	7.162	16299	14.78	7.167	34396	31.19	
	Time (90 day)			Time (120 day)			Time (150 day)			Time (180 day)			
Acet.	2.469	376077	333.65	2.486	520612	461.88	2.425	663694	588.82	2.438	814666	722.76	47.61*
DBP	9.820	46706	51.18	9.864	69100	75.72	9.868	85417	93.60	9.869	108132	118.49	11.03*
Form.	5.973	230736	124.54	5.930	323649	174.69	5.910	414562	223.76	5.983	518462	279.84	19.02*
DEP	8.827	54445	38.90	8.832	82466	58.92	8.841	100857	72.06	8.817	129046	92.20	8.72*
BPA	7.245	58256	52.49	7.243	86024	77.51	7.207	106423	95.89	7.284	134603	121.28	14.81*
DEHP	7.918	78587	66.11	7.946	114261	96.12	7.915	142375	119.77	7.922	178810	150.42	13.95*
BBP	9.315	74682	71.53	9.375	108102	103.54	9.356	134966	129.27	9.326	169159	162.02	16.57*
EG	3.432	41955	44.32	3.458	64902	68.56	3.438	78156	82.56	3.455	96919	102.38	12.74*
DMP	7.169	49703	45.07	7.169	74284	67.36	7.181	91400	82.88	7.163	116246	105.41	9.60*

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From described results in Table (6) it can be seen that control sample contained acetaldehyde and DBP, in this context, **Shah *et al.*** (2024) pointed out that freshly bottled carbonated beverages may be contaminated with phthalate esters and carbonyl compounds because of traces of these contaminates in the water source and raw material containers, in addition to the compounds migrating from filters, tanks and plastic parts in production lines. From the same results, it could be noted that chemical contaminants were significantly increased (P≤0.05) after storage at -18 ˚C for 15 day, since concentrations of Acet., BPA, DEHP, BBP and DBP were increased to (34.20, 3.10, 3.85, 4.35 and 2.09 µg/L), and according to what mentioned by Chen *et al.* (2023) and Khanniri *et al.* (2024) this may be due to that freezing causes the liquid to expand and applied internal pressure on bottle, thus causing physical damage to the inner wall of the PET bottle which leading to the migration of some chemical contaminants into the stored drinks. Also, the chemical contaminants of samples stored at 0 ˚C for 15 day were significantly increased (P≤0.05) to (51.97, 5.62, 6.32, 4.78, 9.03 and 5.74 µg/L) for both Acet., DMP, BPA, DEP, BBP and DBP respectively, these results were close to the results reported by Chen *et al.* (2023) and Nikolić *et al.* (2024), by comparing the results of samples stored at -18 and 0 ˚C, it is noted that the migration rate of contaminants into sample stored at 0 ˚C is significantly higher (P≤0.05) than those stored at -18 ˚C, this is probably due to that the damage caused by slow freezing (0 ˚C) is greater than the damage caused by rapid freezing (-18 ˚C), as in addition to the mechanical stress and the smashing resulting from the expansion of frozen liquids by either technique, freezing at 0 ˚C creates large, sharp and needle-shaped ice crystals which increases the damage of bottles and thus the migration of contaminants to drinks bottled in it, this explanation were compatible with Barham (2021) and comes in harmony with SEM visualizations (7 and 8). From the findings recorded in Table (7), It could be seen that the migration of contaminants into samples stored at 4 ˚C were significantly increased (P≤0.05) with increase of storage period until the concentrations were reached to (29.97, 10.65, 2.81 and 1.25 µg/L) for Acet., Form., DEHP and DBP respectively after 30 day, these results were in line with Shah *et al.* (2024), in the same field, Chen *et al.* (2023) attributed these to that low temperatures generate large amounts of tiny carbon dioxide bubbles which despite their extremely small size, generate destructive forces on bottles as a result of the internal pressure increase when they collide together and surface scratching when directly collide with the bottles walls, and this is strongly supported by Juan *et al.* (2020) and İşçi (2024) who observed a direct relationship between the volume of CO_2 injected and the migration of plastic materials into soft drinks. However, the migration rate is lower than under other conditions, perhaps because the refrigeration temperature (4˚C) doesn't cause direct damage as in the freezing case, doesn't stimulate hydrolysis of PET bottles as in the case with storage at high temperatures (Shah *et al.,* 2024). From the data recorded in Table (8), It could be noted that the migration of contaminants into all samples stored at room temperature were significantly increased (P≤0.05) with gradually progress of storage period until the concentrations were reached to (44.28, 16.38, 6.48, 3.60, 7.17 and 4.33 µg/L) for Acet., Form., DEHP, DEP, BBP and DBP respectively after 30 day, this results were compatible with Ayofe *et al.* (2018) and Shah *et al.* (2024) who attributed these increase a result of natural and expected bottle aging associated with long storage periods, while Chen *et al.* (2023) suggested that these increase can be due to that room temperature stimulates the hydrolysis of sugars and oxidation of organic compounds which creates an ideal acidic environment for the migration of microplastics from PET bottles and this is consistent with the results in Table (2), since pH value were decreased when stored at room temperature from 4.61 to 4.41. Also, data tabulated in Table (9) demonstrated that the migration of contaminants into investigated beverage were gradually and significantly increased (P≤0.05) with increase of storage period in shade (37±2 ˚C), as the highest concentrations of detected compounds were

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(64.78, 24.59, 9.53, 6.95, 12.76 and 8.74 µg/L) at 30 days for Acet., Form., BPA, DEP, BBP and DBP respectively, these results were similar to those obtained by Evarist (2024). Also, by comparing Table (9) with table (8) it can be noted that the migration rate of contaminants into sample stored in shade was higher than the sample stored at room temperature, this is due to the existence of a direct relationship between storage temperature and rate of microplastics migration, as in addition to aging and the ability of room temperature to stimulate the hydrolysis of sugars and the synthesis of acids, the shade temperature is sufficient to deteriorate PET bottles and release plastic contaminants (Shah *et al.,* 2024). The results in Table (10) depicted that the increasing storage period in the sun caused a significant increase (P≤0.05) in levels of chemical contaminants, phthalates esters were surged to (105.41, 150.42, 92.20, 162.02 and 118.49 µg/L) for DMP, DEHP, DEP, BBP and DBP respectively. Also, acetaldehyde and formaldehyde were surged to (722.76 and 279.84 µg/L) while EG and BPA were recorded (102.38 and 121.28 µg/L), this findings was similar to what founded by Ajai *et al.* (2024) and Shah *et al.* (2024) who attributed this clear increase in contaminants to that storage in the sun combines all the factors of deterioration, the high acidity of beverages, aging due to the storage period and breakage of polymers due to high temperature of the sun, in addition to photodegradation resulting from exposure to sunlight. Also, Huang and Wang (2024) explained this noticeable deterioration to that sunlight (UV) creates microplastics and nanoplastics from the original surface which leads to a reduction in the thickness of the plastic and its susceptibility to smashing and thus increases its content in the beverages, Moreover, the rough plastic surface improves the absorption performance of more light and oxygen because of the large surface area which leads to an exacerbation of damage.

Spectroscopic characteristics of bottled SH drink stored at -18, 0 ˚C and the sun by FTIR: In the present study FTIR was employed to elucidate the spectroscopic characteristics of SH drink stored at -18, 0 ˚C and sun at beginning and end of the storage period, spectra were showed in Figures (2-5) and summarized in Table (11).

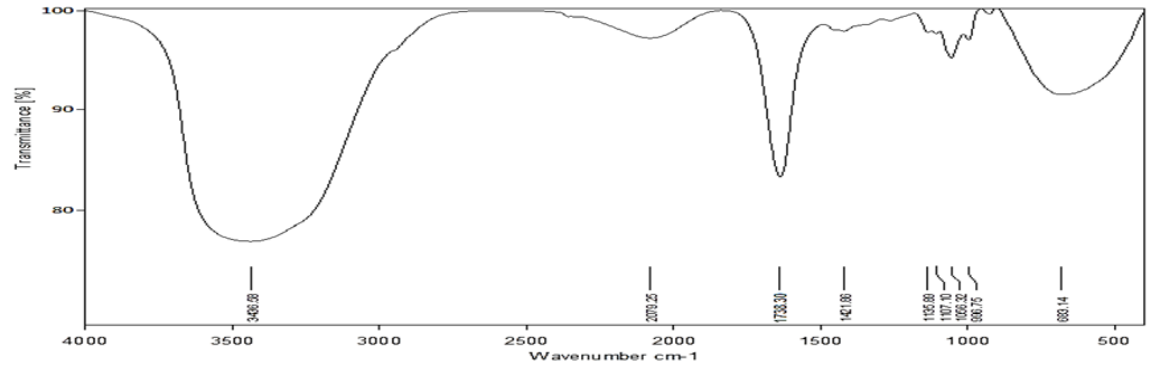


Fig. 2. Spectrum of SH drink at zero time

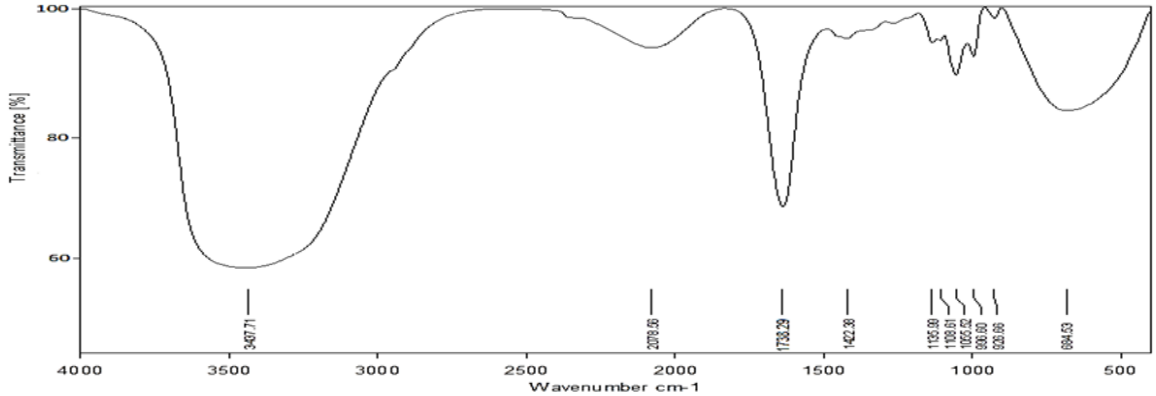


Fig. 3. Spectrum of SH drink stored at -18 ˚C for 15 days

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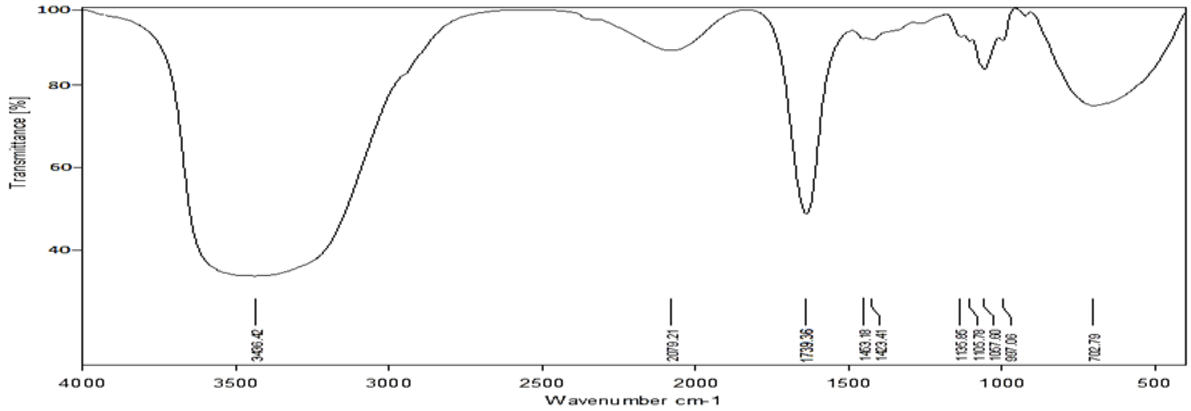


Fig. 4. Spectrum of SH drink stored at 0 ˚C for 15 days

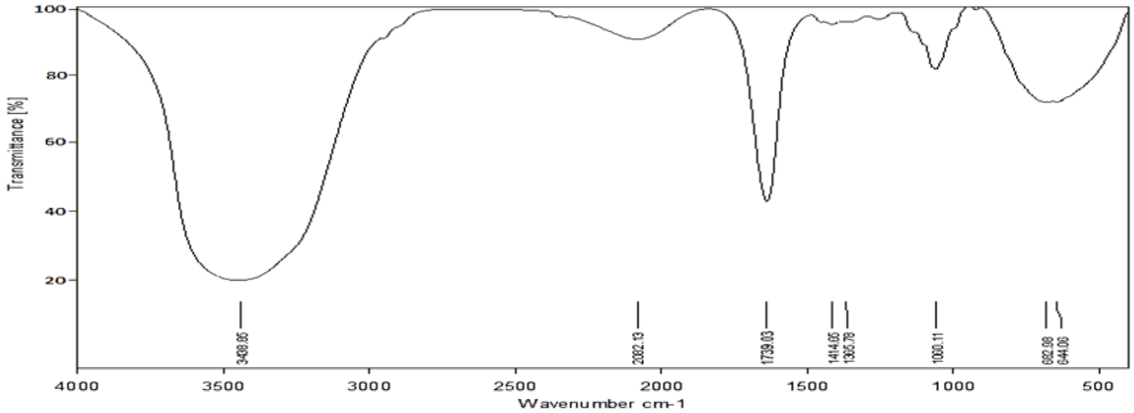


Fig. 5. Spectrum of SH drink stored in the sun for 30 days

Table 11. Spectroscopic characteristics of bottled SH drink stored at -18, 0 ˚C and the sun by FTIR

Group	Zero time		-18 ˚C		0 ˚C		The sun	
	cm^{-1}	T (%)	cm^{-1}	T (%)	cm^{-1}	T (%)	cm^{-1}	T (%)
O-H	3436.58	77.10	3437.71	58.52	3436.42	33.11	3438.85	20.79
C≡N	2079.25	97.56	2078.56	95.11	2079.21	89.05	2082.13	90.85
C=O	1738.30	83.12	1738.29	68.32	1739.36	48.36	1739.03	41.50
C-O	1056.32	95.28	1055.52	90.01	1057.60	82.54	1060.11	81.62
C-H	683.14	91.76	684.53	85.64	702.79	76.25	644.06	72.45

Results in Table (11) and Figs. (2), it shows appearance of absorption peak in infrared spectrum for sample before storage at 1738.30 cm^{-1} which characterize C=O group belonging to carbonyl compounds such as acetaldehyde and formaldehyde (Öztekin and Sponza, 2023). Also, the spectrum of the same sample showed peak at 1056.32 cm^{-1} which is assigned to C-O group and indicates the presence of esters (Aditi *et al.*, 20252), this comes in harmony with the results obtained by HPLC, and as mentioned earlier, this may be due to contamination of the samples with one or more of these compounds by water tanks, filters system, plastic filling nozzles, etc. (Zajác *et al.*, 2025 and Das *et al.*, 2025). On the other hand, from Fig. (3) and by comparing FTIR data at zero time and -18 ˚C, it can be noted the transmittance decrease of the peak corresponding to the (C=O) group from (83.12 %) at zero time to (68.32 %) at -18 ˚C. Likewise, the peak corresponding to the (C-O) group was decreased from 95.28 to 90.01% for the same samples respectively, this may be due to increase of studied compounds concentration (phthalates and carbonyl compounds) after storage beverages at -18 ˚C (Khanniri *et al.*, 2024). Similarly, the obtained data at 0 ˚C and Fig. (4) showed that the transmittance at the same peaks in the spectrum of sample stored at 0 ˚C were decreased compared to the transmittance recorded at zero time from 83.12 to 48.36% at peak of (C=O) group and from 95.28 to 82.54% at peak of (C-O) group, also by comparing data at -18 and 0 ˚C it is noted that the decrease of transmittance at 0 ˚C was a greater than its counterpart at -18 ˚C,

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according to Nikolić *et al.,* (2024) and Shah *et al.,* (2024), this is may be due to that migration rate of phthalates and carbonyl compounds from PET bottles into beverages stored at 0 ˚C greater than it when stored at -18 ˚C. Also, the spectroscopic characteristics of sample stored in the sun showed the same behavior, as the transmittance was decreased at each of peaks signed to carbonyl and esters to 41.50 and 81.62% respectively compared to the samples before storage, the reason may be the migration of carbonyl compound and phthalate esters from PET bottles into SH drink stored in the sun (Ishihara *et al.,* 2024).

Surface morphology for bottles of SH drink stored at -18, 0 ˚C and the sun conditions by (SEM): internal surface of control and stored bottles at -18, 0 ˚C and the sun after the end of the storage experiment were microscopically examined and SEM images were compared in Figures (6-9).

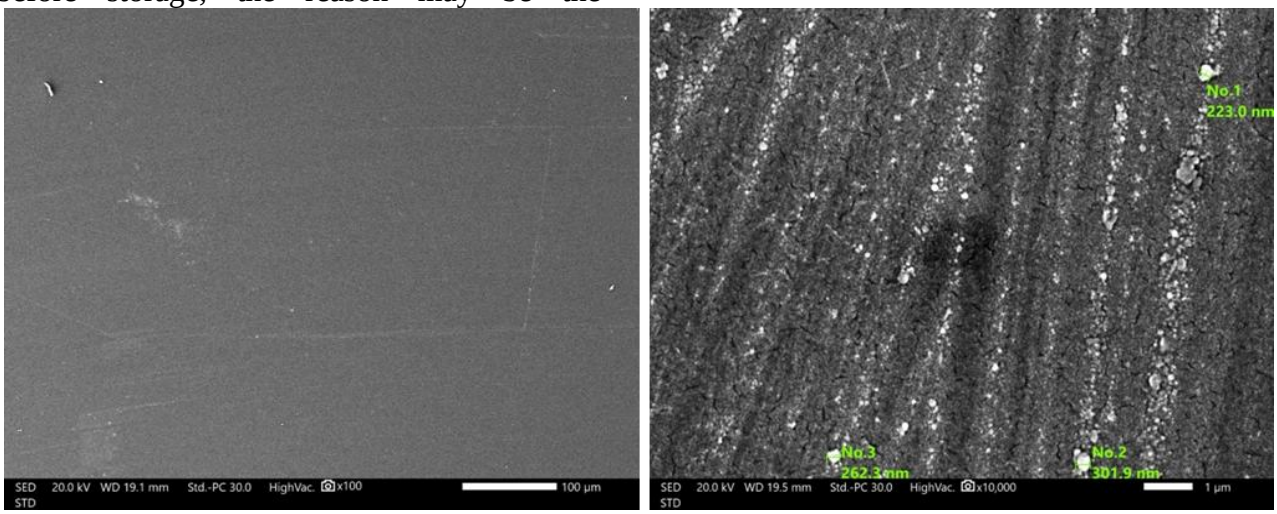


Fig. 6. SEM of SH drink at zero time

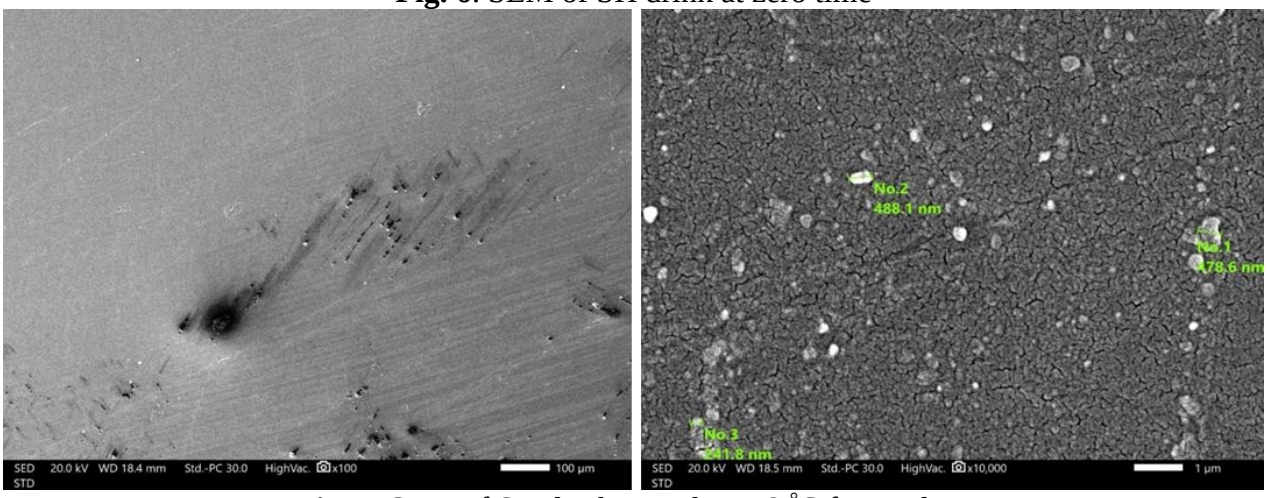


Fig. 7. SEM of SH drink stored at -18 ˚C for 15 days

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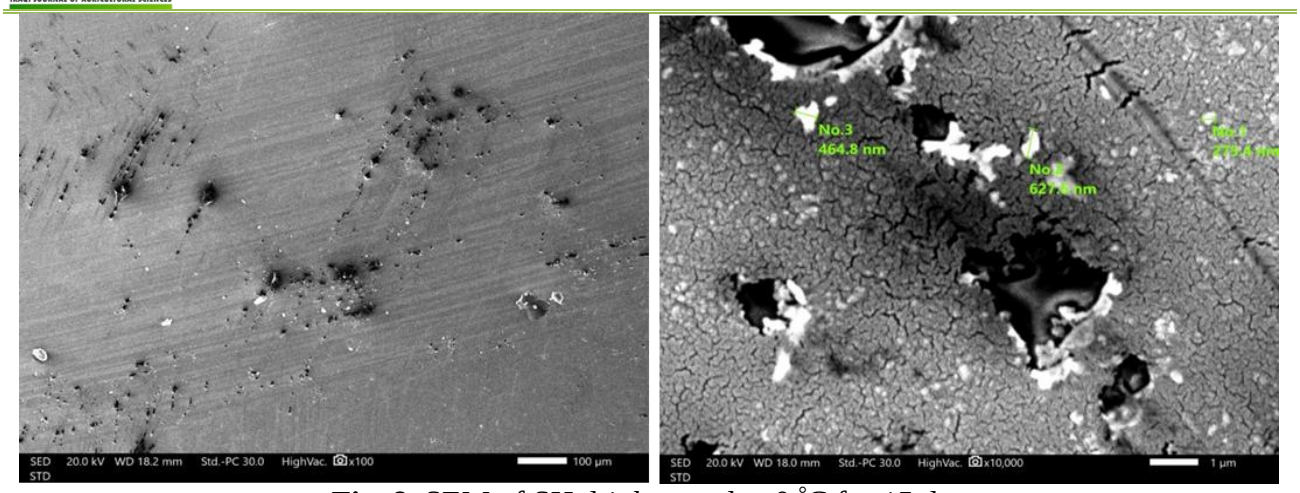


Fig. 8. SEM of SH drink stored at 0 ˚C for 15 day

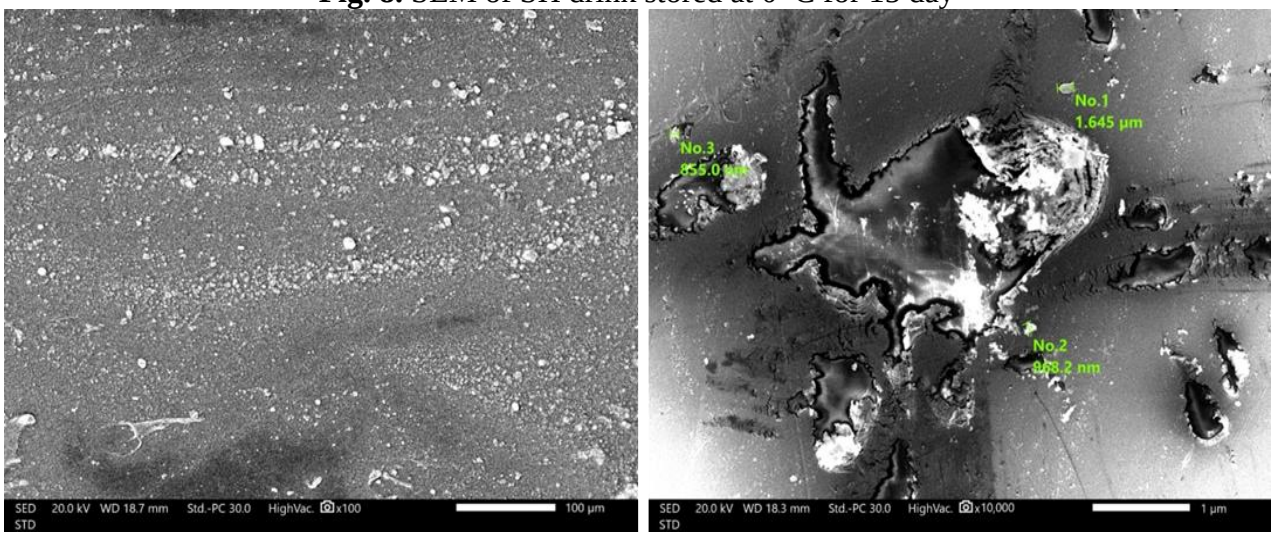


Fig. 9. SEM of SH drink stored in the sun for 30 days.

Fig. (6) it shows that the surfaces of the sample at zero time were almost smooth and free of signs of damage while the surfaces of the sample stored at -18 ˚C for 15 days (Fig. 7) were severely cracked and this may be due to the internal pressure applied to the bottle as a result of the expansion of the frozen liquid (Chen *et al.*, 2023). By comparing the SEM images of the sample stored at 0 ˚C (Fig. 8) with both the sample at zero time and the sample at -18 ˚C, it is possible to detect signs of damage as well it can be noted that it are more prominent than their counterparts stored at -18 ˚C, in addition to the cracking, changes similar to penetrating holes can be seen in the surfaces, Barham (2021) attributed this to the damage resulting from the sharp-needle shaped of the ice crystals formed at 0 ˚C in addition to the highly cracking resulting from the expansion of the liquid as in the case of freezing at -18 ˚C. Also, the microscopic images (Fig. 9) reflected the extreme destructive powers of direct sunlight on PET, as radical changes in the surface topography at general and close level of these samples were observed compared to control samples (at zero time) such as crazing cracks, surface roughness, surface tearing, micro and Nano-knots and debris formation, this changes were largely identical to the SEM images embodied by Huang and Wang (2024) who attributed this apparent destruction to the combined photo-thermal effects of the sun in addition to the chemical effects of the compounds resulting from possible side reactions. The cracks may be due to that some quenched material is added to PET as flexibility improvers its principle is that it is always in a thermodynamically unbalanced state within the molecule, which creates sliding bonds and thus increases the flexibility of polymer chain, on the other side and at high temperatures, these state change from the thermodynamically unbalanced to balanced

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state and thus the molecule loses its flexibility and becomes more susceptible to cracking (Panowicz *et al.*, 2021). On the other hand, Huang and Wang (2024) explained surface roughness by the formation of microplastics (diameter< 5 mm) and nanoplastics (diameter< 1 µ) by UV, as well they were justified surface tearing by that microplastics and nanoplastics arise from the original surface which leads to a reduction of plastic thickness and its susceptibility to tearing as one of the most important manifestations of photoaging. Also, Ibrahim (2024) and Ye *et al.* (2024) indicated that UV leads to stimulation of some reactions such as "photo-fries", "Norrish-I" and "Norrish-II" which leads to a major disturbance in the chemical structure and ultimately leads to the loss of mechanical stability. In this regard, Panowicz *et al.* (2021) pointed out that sun deterioration is the greatest among the other storage conditions to the extent that it can be said that its destructive effects can be inferred by simply morphological observation of some symptoms such as roughness of plastic surfaces, decrease of transparency (increase of opacity), decrease of elongation ratio at breakage and fragility of breakage cross section of sample.

CONCLUSION

This research concluded that storage conditions vary in accelerating the migration of PET contaminants into shani drink, while cooling (4 °C) was the safest, the concentration of contaminants increased at the highest pace in samples stored in the sun. Hence, this research recommends conducting awareness campaigns targeting both distributors and consumers about the safe conditions for storing bottled carbonated soft drink with the enforcement of stricter regulations on storage throughout the supply chain to ensure product safety from production to consumption.

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CONFLICT OF INTEREST

The authors declare that they have no conflicts of interest.

DECLARATION OF FUND

The authors declare that they have not received a fund.

AUTHOR/S DECLARATION

We confirm that all Figures and Tables in the manuscript are original to us. Additionally, no figures or images that do not belong to us have been incorporated into the manuscript, and the required permissions for re-publication are included with the manuscript. -Author/s signature on the Ethical Approval Statement.

AUTHOR'S CONTRIBUTION STATEMENT

R.J. N. designed the project data collection, analysis, and paper writing. Author T.N. M. reviews the article and participates in its design and analysis.

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هجرة الملوثات الكيمياوية من قناني البولي إيثيلين تيرافثليت الى المشروب الغازي الشاني

رعد جمار نشمي ، طارق ناصر موسى
قسم علوم الأغذية، كلية علوم الهندسة الزراعية، جامعة بغداد، العراق.

المستخلص

أجريت مقارنة بين تاثير ظروف وفترات الخزن المختلفة على هجرة ملوثات البولي إيثيلين تيرافثليت الى المشروب الغازي الشاني للإشارة إلى الظرف الأكثر ملائمة لتخزين هذا المشروب. حصل على عينة من المشروب محل الدراسه فورا بعد التعبئة في عبوات سعة 1لتر وخزنت في ظروف متباينة شملت -18، 0، 4، 25 °م، الظل والشمس، وفي بداية التخزين استخدم جهاز GC-MS لتحديد الملوثات الكيميائية المحتملة، واثناء التخزين روقبت تراكيز الملوثات المحددة باستخدام جهاز HPLC. ايضا قورنت أطياف الاشعه تحت الحمراء للمشروبات المخزنة في الظروف الثلاثة الأسوأ (-18 و0°م والشمس) ومسحت الاسطح الداخليه للعبوات نفسها ميكروسكوبيا قبل وبعد التخزين للوقوف على التغيرات المورفولوجية التي خلفها كل منهم. افادت النتائج بأن التبريد هو الظرف الأنسب للتخزين بينما كان التخزين الشمسي الأشد وطئا من بين الظروف الأخرى حيث سجلت العينة المخزنة في الشمس لمدة 180يوم أدنى قيمة لرقم الحموضة وأعلى التراكيز للملوثات المكتشفة، كذلك اسفرت مقارنة أطياف FTIR عن وجود الاسترات ومركبات الكاربونيل باعلى تركيز في العينة المخزنة في الشمس لمدة 30 يوما. بالمثل، اكدت مقارنة الصور الملتقطة بالميكرسكوب الالكتروني الماسح (SEM) ان العبوات المخزنة في الشمس هي الاكثر تدهورا مقارنة بنظيراتها المخزنة في درجتي التجميد -18 و0°م.

الكلمات المفتاحيه: المشروبات الغازية، مواد التعبئة ، ظروف التخزين، انتقال الشوائب.