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Quality Control of Tomato Products and its Influenced by Some Technological Treatments on Reducing Pesticide Residues

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ABSTRACT

Pesticide residue in agricultural produce poses potential health risks to consumers, necessitating effective decontamination methods. This study investigates the efficacy of some commonly available technological treatments, 4% vinegar solution and 3% salt solution with and without sonication, in reducing pesticide residue on tomato fruits. The experiment involved exposing pesticide-contaminated tomato samples to all treatments for a duration of 10 minutes. Tomato juices, tomato puree and sun-dried tomato, prepared after sonication, also examined to study the reduction of pesticide residue. The research employed a quantitative approach, analyzing the residual pesticide levels using (GC-MS) before and after treatment with reduction percent reached to 100 % for some pesticide residue. Additionally, physical, and chemical properties were conducted to assess any potential impact on quality attribute of tomatoes fruits due to the treatments. Preliminary findings suggest that both the 4% vinegar solution and the 3% salt solution exhibit promising capabilities in reducing pesticide residue on tomato fruits. However, the extent of residue reduction varied between the two treatments. The results also indicated a differential impact on chemical content, highlighting the need for further investigation into the potential consequences on food safety beyond pesticide degradation.

1. Introduction

Fruits and vegetables are very important in a healthy diet. The constituents obtained by the human body from fruits and vegetables include water, carbohydrates, fats, proteins, fiber, vitamins, minerals, pigments, and antioxidants, among others. Most fruits and vegetables are available almost year-round in a wide variety, and they not only taste good, but they also have favorable attributes of texture, color, flavor, and ease of use [1].

Tomato (*Solanum lycopersicum* L.) is one of the most important horticultural crops in the world. It belongs to the Solanaceae family, which includes potatoes, peppers, and eggplants. Tomatoes fruits are widely consumed in several countries and considered as functional food, because they contain antioxidants such as ascorbic acid, vitamin E, carotenoids, flavonoids, lycopene, and phenolic acids. On the other hand, tomatoes fruits are susceptible to pests, and pesticides are needed in the different phases of cultivation to control pests and diseases that may cause yield reduction; however, the presence of pesticide residues in tomatoes fruits may be harmful to health [2].

Tomatoes fruits were chosen for this study because they are a widely cultivated vegetable in countries all over the world and are consumed by many people, due to their availability at lower prices. Tomatoes fruits also have high nutritive value and many economic benefits. Tomato fruits are known to produce a wide variety of secondary metabolites mainly carotenoids, polyphenols, and alkaloids. Lycopene is the major carotenoid of tomato fruit, responsible for its red coloration [3]. Additionally, previous studies have shown that tomatoes fruits contain higher amounts of pesticide residues compared to other vegetables Therefore, tomatoes fruits were selected as one of the vegetables for this study to identify effective treatments for removing pesticide residues from them [4].

Scientific investigations evaluating the efficacy of household treatments on pesticide residue reduction have yielded diverse findings. Some studies have demonstrated the ability of certain treatments to effectively diminish surface residues, thereby potentially lowering the risk of exposure to harmful chemicals [5,6]. For instance, washing produce with water alone or in combination with vinegar has shown promise in reducing pesticide residues. The acidic nature of vinegar is thought to aid in breaking down and removing certain pesticide residues from the surface of fruits and vegetables [7]. Household treatments encompass a spectrum of methods ranging from simple washing with water to employing natural or commercially available

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solutions specifically designed to reduce pesticide residues [8]. Commonly practiced treatments include rinsing fruits and vegetables under running water, utilizing vinegar, or baking soda solutions, employing commercial produce washes, and even peeling the outer layers of produce. Each of these methods is believed to contribute to the removal or reduction of pesticide residues to varying extents [9]. However, the effectiveness of these household treatments is contingent upon multiple variables, including the type of pesticide, its chemical properties, the method and duration of treatment, and the produce's surface characteristics. Additionally, certain pesticides might penetrate the produce's outer layers or be absorbed systemically, rendering them less susceptible to removal by conventional household treatments [10]. Therefore, this study aims to evaluate the efficacy of various pesticide residue reduction techniques and processing methods in removing pesticide residues from tomatoes fruits. Study the efficacy of household procedures such as dipping in vinegar, and salt solution with and without sonication in reducing pesticide residues on fresh tomatoes fruits. Producing various tomato products (tomato juice, tomato puree and sun-dried tomato) to assess the impact of different techniques. Investigating the impact of pesticide residue reduction techniques on key physicochemical properties of tomatoes fruits , including T.S.S, pH, Vit. C content, and quality attributes. Assessing the potential implications of pesticide residue reduction techniques on tomato overall quality.

2. Materials and Methods

The present work is conducted at the Faculty of Agriculture, Fayoum University.

2.1. Materials

2.1.1. Tomato samples

Ripe tomato fruits, which were collected 24 hours after spraying with various pesticides, The samples were collected in 2022 then the infected fruits were removed, sorted, and then carefully transported to the laboratory in the department of food science and technology at the Faculty of Agriculture, Fayoum University.

2.1.2. Chemicals and reagents:

All solvents were of reagent grade without any further purification. Gallic acid, rutin and Folin-Ciocalteu phenol reagent were purchased from Sigma Chemical Co. (St. Louis, MO, USA). The analytical reagent grade methanol was obtained from Cornell Lab (Egypt). The water used in sampling was prepared using a Millipore Simplicity system (Millipore S.A.S., Molsheim, France). The 2,2-diphenyl-1-picrylhydrazyl radical (DPPH) was purchased from Sigma Chemical Co. (St. Louis, MO, USA).

2.2. Methods

2.2.1. Processing treatments

The following treatments were assessed to evaluate the removal of pesticides residues: Group 1: Control samples without any treatment (C). Group 2: tomatoes fruits were immersed in a 4% vinegar solution for 10 min. (T1). Group 3: tomatoes fruits were immersed in a 4% vinegar solution with sonication for 10 min. (T2). Group 4: tomatoes fruits were soaked in a 3% salt solution for 10 min. (T3). Group 5: tomatoes fruits were soaked in a 3% salt solution with sonication for 10 min. (T4). Group 6: Juicing and pulping of raw tomatoes fruits . (T5). Group7: tomatoes fruits were turned into puree using heat until the appropriate consistency was reached (T6). Group 8: tomato sample were cut and sun-dried (T7).

2.2.2. Gross chemical composition of plant materials:

Moisture, TSS, total ash, crude proteins, ether extract, Vit. C and Total Titratable Acidity were determined in plant materials according to AOAC, 20005 [11].

3.2.3. Extract preparation:

Tomato slices (10 g) were stirred with 100 mL MeOH at 30°C overnight. The extract was filtered through Whatman no. 1 filter paper for removal of seed particles. The residue was re-extracted with 60 mL methanol. The obtained extracts were filtered again, pooled and concentrated under vacuum at 40°C. These methanolic extracts were used for phenolic and antioxidant analyses.

3.2.4. Determination of total phenolic and total flavonoids content

Phenolic contents were determined according to the method described by Valdez-Morales et al. [12]. Total flavonoids were determined spectrophotometrically using the modified method previously described by Mistrello et al. [13].

3.2.5. Determination of radical scavenging activity by DPPH

Antioxidant activity was determined by radical scavenging ability using stable DPPH radical as described by Baliyan et al. [14]. In Brief, 200 µL of methanolic solution of the tested samples (50, 100, 150 and 200 µg/mL) were added to 2.0 mL of methanolic solution of DPPH radical and complete the volume to 3.0 mL with methanol. The absorbance was measured at 515 nm against methanol as blank in an UV spectrophotometer after 30 min of incubation at 30°C in the dark. The percentage inhibition of the tested samples was evaluated by comparison with a control (2.0 mL of DPPH solution and 1mL of methanol). Each sample was measured in triplicate, and an average value was calculated. Antioxidant activity was expressed as a percentage of inhibition compared to control as follows:

$$\% \text{ inhibition} = [(A \text{ control} - A \text{ sample}) / A \text{ control}] \times 100$$

Where A is the absorbance at wavelength of 515 nm.

The percentage of inhibition was plotted against the concentrations of antioxidant samples to determine the amounts of antioxidant necessary to decrease DPPH• radical concentration by 50 % (IC_{50}). IC_{50} values could also be estimated by non-line regression logarithm. These values were recalculated to the reciprocal of IC_{50} ($1/IC_{50}$) which is defined as antiradical power (ARP). The higher the value of antiradical power the higher the antioxidant activity [15,16].

3.2.6. Determination of total carotenoids:

Carotenoids extraction has been done from processed tomato products according to methods described by Amorim-Carrilho et al. [17].

3.2.7. Determination of Lycopene:

Lycopene was determined spectrophotometrically by Halim et al. [18]. The extraction was done by hexane/ethanol/acetone and absorbance measurement at 503 nm. Lycopene concentration in the hexane extracts were calculated according to the following equation:

$$\text{Lycopene (mg/kg fresh wt.)} = A_{503} \times 137.4$$

3.2.8. Determination of β – Carotene:

The accurate weight of sample was taken into acetone solvent, homogenized, filtered through centrifuged. The supernatant was separated and transferred to a volumetric flask and diluted to a known volume with the solvent. Absorbance was measured in the supernatant at wavelength of 400-700 nm. The concentration of β – carotene was calculated according to the following formulas described by Halim et al. [18].

$$C = [(A \times 454)/(196 \times L \times W)]*2.2$$

Where: C= concentration of carotene (mg/kg) in sample, L= cell length in cm, and W= g product/mL final dilution.

3.2.9. Determination of pesticide residues (PR)

Sample preparation and extraction; the tomato samples were ground and homogenized for 5 min using a domestic blender and stored in glass flasks and kept frozen at -20 ºC until analysis. The determination of pesticide residues from tomato samples were performed according to the QuEChERS method presented in the following flow sheets and Figure 1. All the determined residues for detected pesticides were referred to as the standard calibration curves.

Ten grams of homogenized tomato sample mixed with 10 ml of acetonitrile in a 50 ml centrifuge tube.

↓

Vigorous shaking for 3 minute using vortex mixer.

↓

Add the QuEChERS tube containing 4 g of magnesium sulfate and 1 g of sodium chloride.

↓

shaking for 1 min and centrifuging at 4000 rpm for 5 minutes.

↓

Collect 6 mL of supernatant and pour them into a centrifuge tube (QuEChERS) containing 400 mg of PSA, 1200 mg of MgSO4, and 400 mg of C18EC for purification.

↓

Shaking and centrifugation at 4000 rpm for 5 minutes, then collect the supernatant and inject 1µl in GC-MS for pesticide residue analysis.

Figure 1 : QuEChERS method technique for pesticide residue determination.

GC-MS analysis; the column temperature was raised from 60°C (hold 1min) to 170°C at 2°C /min, then to 285°C at 5°C /min. The inlet temperature was maintained at 250°C, injection of 2µl at splitless mode, purge flow 50 ml/min at 0.75 min, Helium with purity grade 6 for 9 s, was used as the carrier gas at constant flow 1 ml /min. The mass detector was operated in electron impact (EI) ionization mode at 70 eV. The temperatures of the transfer line, ion source and quadrupole were set at 285, 250 and 150°C, respectively. Mass spectra in the full-scan mode were collected at the rate of 1.5 scans/s over the mass range (m/z) of 40–550 after acquisition of the total ion chromatogram for stock standard solutions in scan mode, which were identified by their retention time (RT) and mass spectra. Selected ion monitoring (SIM) mode was used for the quantitative purpose.

Determination of the Processing Factor (PF); the processing factor is the proportional amount by which pesticide residues change when food is processed. The processing factor in this study was determined according to the study done by Boulaid et al. [19].

The processing factor was calculated based on the following formula:

$$\text{Processing factor} = \frac{\text{Concentration of pesticide residues in samples after processing.}}{\text{Concentration of pesticide residues in samples before processing.}}$$

Finally, after obtaining the processing factor, the percent reduction was calculated by using the following formula:

$$\% \text{ reduction} = (1 - PF) \times 100.$$

3.2.10. Statistical analysis

All data are expressed as mean ± standard division. One-way ANOVA was applied to the statistical setup of all obtained observations. A significant difference between each means was estimated at a 5% probability level ($p \leq 0.01$ and 0.05) using the Duncan analysis test. The GenStat software, 17th Ed. (VSN International Ltd., Hemel Hempstead, UK) was applied for statistical analysis.

3. Results and discussion

The nutritional value of tomatoes fruits is mainly determined by their chemical composition, which in turn depends on environmental and agricultural factors. Tomatoes fruits are mainly composed of water, soluble solids, and insoluble solids. Ripe tomato fruits were chemically analyzed to determine their approximate chemical composition and the results obtained are shown in Table (1).

The results shown in Table (1) indicated that total solids content of tomato fruits was 6.2 %. This result agreed with several studies that showed the total solid content of tomatoes fruits usually varies between 5.5 - 9.5% [20]. The chemical analysis data given in Table (1) showed that total sugars, reducing sugars and non-reducing sugars of tomato fruits were 3.50, 3.09 and 0.41 %, respectively. These data showed that total sugars represent about 88% of TSS. It has been reported that sugars content of tomatoes fruits accounts for 50-75% of total solids of the fruit. In addition to the importance of sugars, organic acids are the other major components that account for total solids in tomato and contribute to the acidity of the tomato, influencing the taste of the fruits and play an important role in the safety of tomato products [20]. The results in Table (1) showed that total acidity and pH value of tomato fruits were 0.61% and 4.78, respectively. The total acidity is primarily caused by citric acid content of the fruits and the optimum pH value for ripe tomatoes fruits has been reported to be around 4.25 [20]. In addition to the above-mentioned important solids in tomato, the results also showed that protein and lipids contents of tomato fruit were 0.28 % and 0.62 %, respectively, while ash content was 0.57 %. In general, several factors included cultivation area, environmental and climate conditions, agricultural treatments, fruit variety, maturity at harvest.

Table (1): The Proximate Chemical Composition of tomato.

Components	**Proximate Amount**
Moisture (%)	93.80±1.52
Total Solids (%)	6.2±0.12
Total Soluble Solids, TSS (%)	5.19±0.24
Total Sugars (%)	3.50±0.02
Reduced Sugars (%)	3.09±0.07
Non-Reduced Sugars (%)	0.41±0.01
Total Titratable Acidity (%)	0.61±0.02
pH Value	4.78±0.06
Protein (%)	0.28±0.08
Lipid (%)	0.62±0.02
Ash (%)	0.57±0.09

Means ± Standard deviation.

3.1. Determination of pesticide residues in various treatments

Commercial home preparations such as washing, peeling, blanching, and cooking remove major portions of the residue levels of pesticides that are currently permitted on the raw agricultural crops and freshly eaten plant foods. Removal of pesticide residues by commercial home preparations depends on several factors, such as, character of the surface of plant foods, chemical and physical properties of applied pesticides, the length of time that the pesticide has been in contact with the plant foods, formulation and rate of application and the weather conditions [5,6,21]. The effect of various treatments preparations on residue levels of pesticide detected on tomato is shown in Table (2).

Table (2): Effect of various treatments on detected pesticide residue levels on tomatoes fruits .

Pesticide	Conc. ppm							
	C	T1	T2	T3	T4	T5	T6	T7
Ethoprophos	11.64	0	0	6.03	5.8١	10.23	6.12	7.61
Atrazine	14.62	4.54	3.63	3.75	3.56	12.43	4.93	4.07
Terbufos	42.46	6.73	6.51	6.93	7.94	39.58	5.62	7.85
Diazinon	8.877	0	0	5.65	0	8.84	8.47	8.23
Pirimicarb	3.88	2.55	2.51	1.79	2.58	3.68	2.08	3.32
Perimorphs- methyl	3.62	0	0	0	0	3.57	3.55	3.59
Malathion	12.37	0	0	0	0	10.47	11.23	11.4
Chlorpyrifos	7.951	4.58	4.57	5.35	5.24	7.23	6.48	6.95
Cyprodinil	4.89	1.06	0.87	2.85	2.69	3.52	2.44	4.57
Penconazole	6.99	0	0	0	0	4.85	0	0
Chlorfenvinphos	7.04	0	0	0	0	4.56	0	0
Profenofos	13.46	0	0	0	0	5.45	0	0
Kresoxim- methyl	7.43	0	0	0	0	6.64	0	0
Chlorfenapyr	8.46	0	0	0.02	0.0٣	8.42	0	0
Diniconazole	2.87	0	0	0	0	2.78	0	0
Ethion	8.77	6.23	6.18	6.64	6.45	7.85	6.23	7.84
Bifenthrin	2.24	0	0	0	0	2.14	0	0
Fenpropathrin	19.09	0	0	2.34	2.33	18.98	4.32	6.64

C: Control samples without any treatment, T1: tomatoes fruits immersed in a 4% vinegar solution for 10 min. T2: tomatoes fruits immersed in a 4% vinegar solution with sonication for 10 min. T3: tomatoes fruits soaked in a 3% salt solution for 10 min. T4: tomatoes fruits soaked in a 3% salt solution with sonication for 10 min. T5: tomatoes juice after sonication. T6: tomatoes puree. T7: sun-dried tomato sample.

Results in Tables (3 and 4) present the processing factor (PF) and % reduction after treated tomatoes fruits with various treatments. PF values of ≤1 indicate a reduction in residues in a processed commodity, whereas values of ≥1 indicate concentration effects from the processing procedures [22]. It is important to note that the effectiveness of the 4% vinegar treatment in reducing pesticide residues can vary depending on the specific pesticide, its chemical properties, and its affinity to vinegar. Additionally, other factors such as the initial concentration of the pesticide and the duration of the treatment can also influence the reduction levels. Overall, 4% vinegar treatment for 10 min is a practical and effective method for reducing pesticide residues on tomatoes and their product, ensuring food safety, and preserving nutritional value while minimizing environmental impact.

The provided data in Tables (3 and 4) appears to represent the processing factor (PF) and the corresponding reduction percentages of various pesticides in tomatoes fruits after treatment with 4% vinegar for 10 minutes with sonication. The results indicate the impact of a 10-minute treatment with 4% vinegar and sonication on pesticide reduction in tomatoes fruits. Ethoprophos, Diazinon, Pirimiphos-methyl, Malathion, Penconazole, Chlorfenvinphos, Profenofos, Kresoxim methyl, Chlorfenapyr, Diniconazole, Bifenthrin and Fenpropathrin exhibit complete elimination (100% reduction), emphasizing the effectiveness of the treatment. Atrazine and terbufos show significant reductions of 75.13% and 84.56%, respectively, while other pesticides like pirimicarb and chlorpyrifos display moderate reductions (34.52 % and 42.09 %). Notably, Pirimiphos-methyl, malathion, and several others are eliminated (100% reduction), underscoring the treatment's potency. However, ethion demonstrates a lower reduction (29.87%), suggesting less efficacy against this specific pesticide. Overall, the findings highlight the potential of 4% vinegar with sonication for reducing pesticide residues in tomatoes fruits , with varying degrees of success for different pesticides.

Table (3): Processing factor of pesticide residues (PR) after various treatments (T1-T7).

Treatments	T1	T2	T3	T4	T5	T6	T7
Ethoprophos	0	0	0.52	0.5	0.88	0.52	0.65
Atrazine	0.31	0.26	0.26	0.24	0.85	0.34	0.28
Terbufos	0.16	0.15	0.16	0.19	0.93	0.13	0.18
Diazinon	0	0	0.63	0	0.99	0.95	0.92
Pirimicarb	0.66	0.65	0.47	0.66	0.94	0.53	0.85
Perimorphs methyl	0.01	0	0	0	0.98	0.97	0.98
Malathion	0	0	0	0	0.84	0.9	0.92
Chlorpyrifos	0.58	0.58	0.67	0.66	0.91	0.81	0.87
Cyprodinil	0.22	0.19	0.56	0.55	0.71	0.5	0.93
Penconazole	0	0	0	0	0.69	0	0.31
Clorfenvinphos	0	0	0	0	0.65	0	0.45
Profenofos	0	0	0	0	0.4	0	0.25
Kresoxim methyl	0	0	0	0	0.89	0	0.63
Chlorfenapyr	0	0	0	0	0.99	0	0.41
Diniconazole	0	0	0	0	0.96	0	0
Ethion	0.71	0.7	0.76	0.73	0.89	0.71	0.89
Bifenthrin	0	0	0	0	0.94	0	0
Fenpropathrin	0	0	0.12	0.12	0.99	0.23	0.35

C: Control samples without any treatment, T1: tomatoes fruits immersed in a 4% vinegar solution for 10 min. T2: tomatoes fruits immersed in a 4% vinegar solution with sonication for 10 min. T3: tomatoes fruits soaked in a 3% salt solution for 10 min. T4: tomatoes fruits soaked in a 3% salt solution with sonication for 10 min. T5: tomatoes juice after sonication. T6: tomatoes puree. T7: sun-dried tomato sample.

Table (4): % reduction of pesticide residues (PR) after various treatments (T1-T7).

Treatments	T1	T2	T3	T4	T5	T6	T7
Ethoprophos	100	100	47.96	50.26	12.42	47.6	34.83
Atrazine	68.76	74.33	74.41	75.64	15.15	66.31	72.21
Terbufos	84.07	84.56	83.7	81.3	6.86	86.77	81.53
Diazinon	100	100	36.54	100	0.78	4.91	7.64
Pirimicarb	33.87	34.52	52.92	33.95	6.07	46.83	15.28
Pirimiphos methyl	98.64	100	100	100	2.38	3.03	2
Malathion	99.6	100	100	100	15.59	9.51	8.01
Chlorpyrifos	42.12	42.09	33	34.3	9.46	18.83	13
Cyprodinil	77.74	81.31	43.56	45.32	28.61	50.47	7.39
Penconazole	100	100	100	100	31.03	100	68.64
Clorfenvinphos	100	100	100	100	35.48	100	55.41
Profenofos	100	100	100	100	59.6	100	74.85
Kresoxim methyl	100	100	100	100	11	100	37.22
Chlorfenapyr	100	100	99.9	99.89	0.91	100	58.86
Diniconazole	100	100	100	100	4.2	100	100
Ethion	28.9	29.87	24.36	26.74	10.87	29.28	11.02
Bifenthrin	100	100	100	100	6.1	100	100
Fenpropathrin	100	100	87.8	87.78	0.77	77.4	65.27

C: Control samples without any treatment, T1: tomatoes fruits immersed in a 4% vinegar solution for 10 min. T2: tomatoes fruits immersed in a 4% vinegar solution with sonication for 10 min. T3: tomatoes fruits soaked in a 3% salt solution for 10 min. T4: tomatoes fruits soaked in a 3% salt solution with sonication for 10 min. T5: tomatoes juice after sonication. T6: tomatoes puree. T7: sun-dried tomato sample.

Comparing between (T1) and (T2) present in Figure (2), no differences could be observed in the reduction of the vast majority of pesticides that were estimated in tomatoes fruits. However, for certain pesticides like Atrazine, Pirimiphos-methyl, Cyprodinil and Ethion the treatment with 4% vinegar and sonication showed different reduction levels compared to the treatment without sonication. In general, the addition of sonication resulted in higher reduction levels for these pesticides. For example, Atrazine showed a reduction level of 75.13% with sonication compared to 68.8% without sonication. Similarly, Cyprodinil displayed a reduction level of 82.12% with sonication compared to 78.26% without sonication. On the other hand, the pesticide Ethion showed a reduction level of 29.87% with the treatment of 4% vinegar and sonication, while the reduction level without sonication was 23.88%. In this case, the addition of sonication slightly improved the reduction of Ethion residues. The results are in agreement with the previously reported results [23–25].

Overall, the data suggests that the treatment of 4% vinegar with sonication can lead to higher pesticide reduction levels for certain pesticides compared to the treatment without sonication. We conclude that the status of pesticide residues affects their removal from tomatoes fruits. This is mainly attributed to the difference in the physicochemical properties of the pesticides.

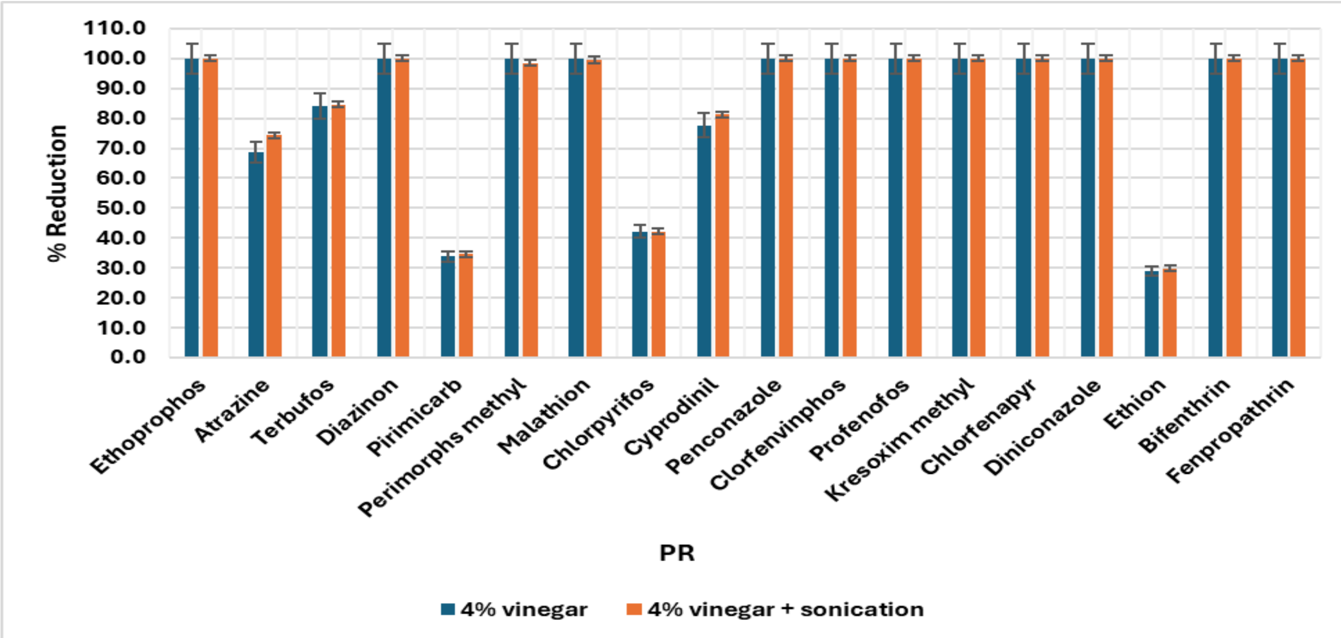

Figure (2): Effect of sonication on the reduction level of pesticide residue in tomato.

The efficacy of 3% NaCl solution treatment (T3) in reducing pesticide residues in tomato has been a subject of research in recent times [24,26,27]**.** The results in tables (3 and 4) reveal the impact of a 3% NaCl treatment for 10 minutes on pesticide reduction in tomatoes fruits. Notably, Atrazine and Fenpropathrin show significant reductions of 74.35% and 87.73%, respectively, indicating the treatment's effectiveness. Terbufos also exhibits a high reduction of 83.68%, while several pesticides, including Pirimiphos-methyl, Malathion, Penconazole, Chlorfenvinphos, Profenofos, Kresoxim methyl, Diniconazole, and Bifenthrin are eliminated (100% reduction). Chlorpyrifos and Cyprodinil demonstrate moderate reductions of 32.69% and 41.77%, respectively, suggesting partial efficacy. Ethoprophos, Diazinon, Pirimicarb, and Ethion show varying degrees of moderate reduction (48.18%, 36.28%, 53.73%, and 24.27%, respectively). Overall, the NaCl treatment proves promising in reducing or eliminating multiple pesticides in tomatoes fruits , with scope for further optimization for specific compounds with lower reduction percentages.

The data shows that 4% vinegar and 4% vinegar + sonication are the most effective treatments for most of the pesticides, except for Pirimicarb, Chlorpyrifos, and Ethion, which have low reduction percentages. These pesticides are more lipophilic and less soluble in water, so they are harder to remove by washing [6]. The addition of sonication slightly improves the reduction for Atrazine and Cyprodinil, but not for the other pesticides. Treatments of 3% NaCl and 3% NaCl + sonication are less effective than vinegar, especially for Diazinon, which has a high reduction percentage with vinegar but a low one with NaCl. This may be because Diazinon is more acidic and more soluble in vinegar than in NaCl [5]. The other pesticides have similar or slightly higher reduction percentages with NaCl than with vinegar, except for Cyprodinil, which has a lower reduction percentage with NaCl. Sonication does not seem to have a significant effect on the reduction with NaCl.

Juicing after sonication is the least effective treatment for all pesticides, except for Profenofos, which has a high reduction percentage with juicing. This may be because juicing removes the outer layer of the tomato, where most of the pesticides are concentrated, and exposes the inner layer, where the pesticides have penetrated. Sonication may also damage the tomato tissue and facilitate the migration of pesticides from the outer to the inner layer [6]**.**

From Figure (3), it appears that the combination of vinegar or salt with sonication generally leads to a higher reduction in pesticide residues compared to using vinegar or salt alone. The effectiveness of each treatment varies with the type of pesticide, but there is a clear trend that sonication enhances the reduction of residues. The most effective method for reducing the levels of pesticides in the tomatoes fruit was 4% vinegar + sonication. This method reduced the levels of most of the pesticides. The 3% NaCl and 3% NaCl + sonication treatments were also effective in reducing the levels of pesticides in tomatoes fruit. However, they were not as effective as the 4% vinegar + sonication method.

These results are consistent with other publications that have shown that vinegar is an effective pesticide removal agent [28]. Study published by [29] found that vinegar was effective in removing chlorpyrifos from apples. Overall, the results of this study suggest that vinegar is a promising method for removing pesticides from fruits and vegetables. However, more research is needed to determine the best way to use vinegar for this purpose. Another study by Balkan and Yılmaz [21] compared the efficacy of different washing solutions, such as water, vinegar, salt, baking soda, and lemon juice, for removing pesticide residues in tomatoes fruits . It found that vinegar was the most effective solution, followed by lemon juice and baking soda, and that water was the least effective. It suggested that vinegar could be used as a natural and safe method for reducing pesticide residues in tomatoes fruits .

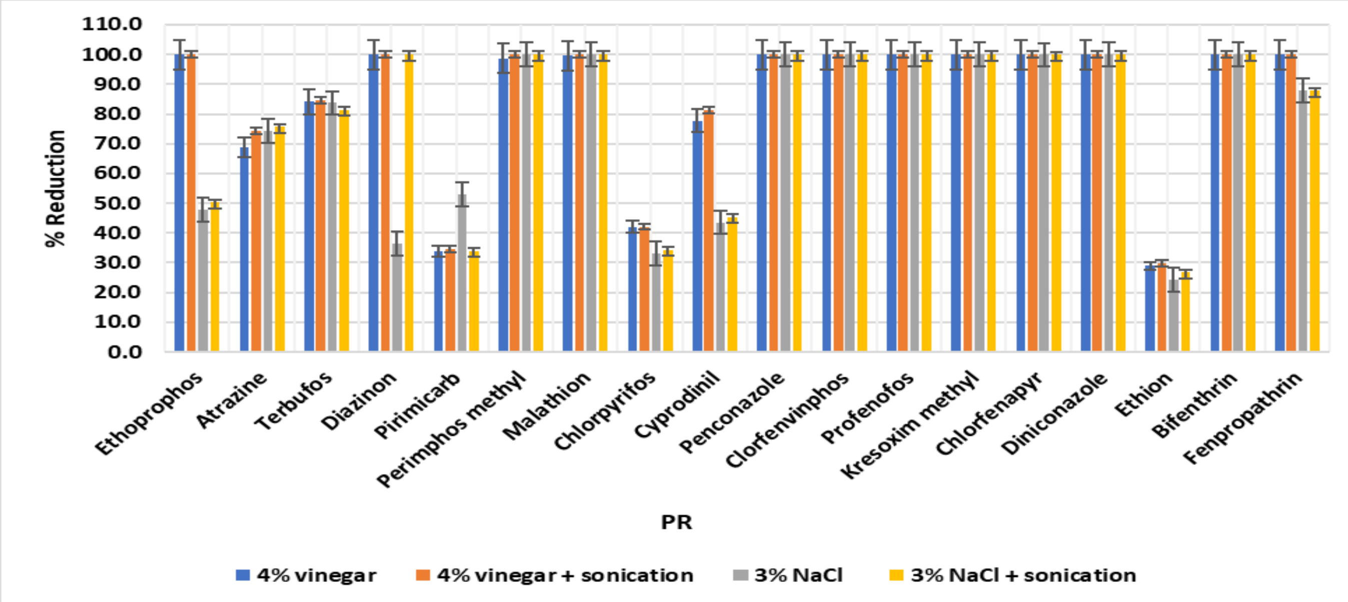

Figure (3): Comparing vinegar and salt with or without sonication on the reduction level of pesticide residue in tomatoes fruit.

Sun drying, with its historical significance and simplicity, holds promise as an environmentally friendly approach. However, its efficacy in reducing or modifying pesticide residues in tomatoes fruits remains a subject of substantial scientific interest. This study explores the impact of sun drying as a treatment for tomatoes fruits and its potential influence on pesticide residues. Understanding the effectiveness of sun drying in reducing or altering pesticide residues is crucial not only for food safety but also for sustainable agricultural practices. Results in tables (3 and 4) show the intricate relationship between sun drying and pesticide residues in tomatoes fruits .

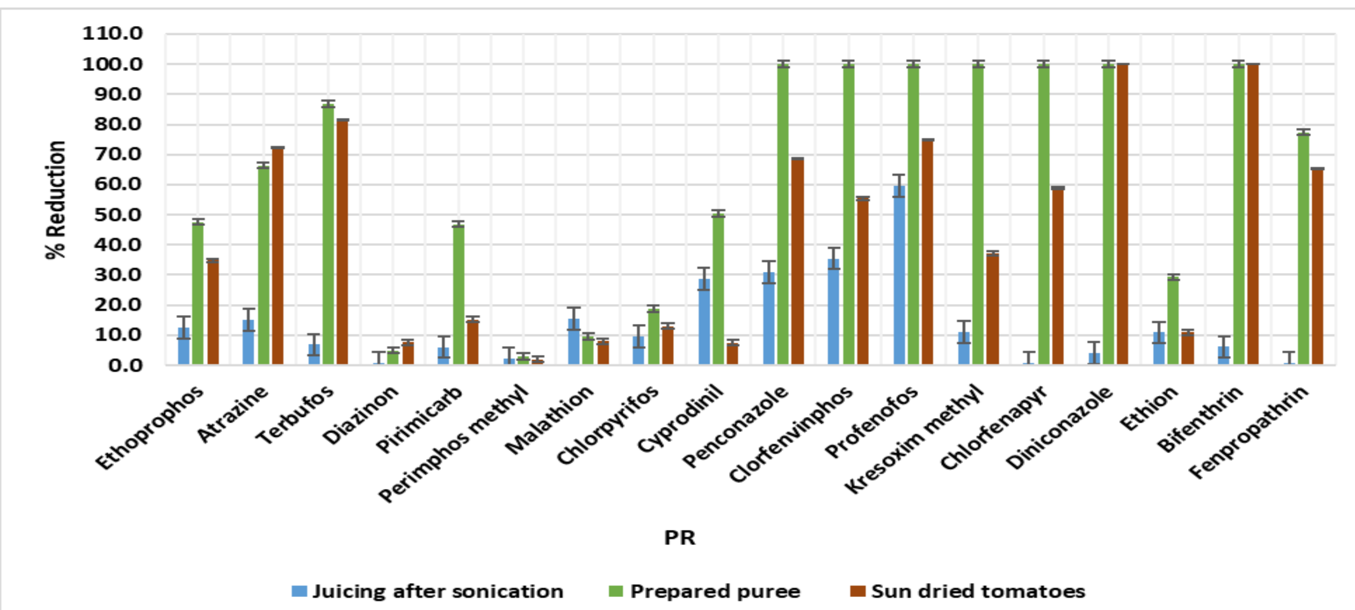

Figure (4): Comparing juicing, prepared puree and sun dried on the reduction level of pesticide residue in tomato.

According to some recent studies, different household processing techniques can affect the reduction level of pesticide residue in tomato [6,21,25]. Washing can reduce non-systemic pesticide residues on tomato surfaces by 52-92%, depending on the type of pesticide [5]. Peeling can further remove 34-97% of the remaining pesticide residues, especially chlorothalonil. Juicing can reduce 68-100% of chlorothalonil and 16-46% of thiophanate-methyl, but increase 14-37% of oxadixyl due to concentration effect [30;31].

Prepared puree can eliminate chlorothalonil completely and reduce 84-88% of thiophanate-methyl but increase 37-77% of oxadixyl due to boiling and concentration effect. Sun drying can increase the levels of some pesticide residues due to loss of water [5]. Prepared puree and sun-dried tomatoes fruits have varied results, depending on the pesticide. Prepared puree is effective for some pesticides, such as Penconazole, but not for others, such as Diazinon. Sun dried tomatoes fruits are generally less effective than both vinegar and NaCl treatments, but more effective than juicing after sonication. These methods may alter the physical and chemical properties of the tomato and the pesticides, affecting their solubility, volatility, and degradation.

3.2. Determination of quality attribute parameters in various tomatoes fruits treatments:

Total soluble solids (TSS) are a measurement of the concentration of dissolved solids, primarily sugars, in a solution [32]. The TSS content can be an important parameter for evaluating the quality and taste of tomato-based products. Data in table (5) presents the % of TSS in different tomato treatments.

Table (5): Effect of treatments on tomatoe fruits quality attributes.

Treatments	T.S.S(%)	pH	Vit. C mg/100gm	Total carotenoids (mg/100g)	Lycopene (mg/100 g)	β- carotene (mg/100 g)	Total Phenolics mg (GAE) per 100 g	Total Flavonoids mg (QE) per 100 g
C	5.17±0.03 c	4.8±0.02 a	17.94±0.03 a	35.04±0.91d	30.4±0.04 cd	1.54±0.01c	36.8±0.14 fg	7.5±0.99 cd
T1	5.20±0.06 c	4.7±0.01 ab	12.21±0.01 b	35.21±1.01d	30.2±0.01 cd	1.51±0.01cd	36.6±0.04 g	7.2±0.01 bcd
T2	5.10±0.01 c	4.6±0.03 b	11.42±0.04 bc	35.18±2.11d	30.5±0.02 cd	1.58±0.01b	37.1±0.05 de	7.7±0.13 ab
T3	5.29±0.01 c	4.7±0.06 ab	12.00±0.03 bc	35.22±2.81d	30.3±0.03 cd	1.52±0.01cde	36.9±0.07 ef	7.4±0.03 bc
T4	5.49±0.01c	4.7±0.01 ab	10.71±0.07 cd	35.16±1.98d	30.6±0.01 cd	1.61±0.03ab	37.4±0.03 d	7.9±0.15 ab
T5	5.60±0.01c	4.4±0.01 c	15.60±0.02 a	40.16±2.77c	30.9±0.04 c	1.62±0.01a	39.2±0.28 c	8.1±0.04 ab
T6	15.27±0.03b	4.2±0.04 d	2.04±0.01 e	68.06±2.50b	22.4±0.04 a	1.06±0.02f	45.5±0.13 a	8.6±0.03 a
T7	37.50±0.06 a	4.0±0.01 e	ND	104.08±3.82a	21.1±0.02 ab	1.08±0.02f	41.7±0.11 b	8.2±0.01 ab

Means ± Standard deviation, different letters at mean represent statistically significant differences among treatments ($P<0.05$).

The results demonstrated that tomatoes puree and sun-dried tomatoes had the highest TSS content among all the treatments 15.27 % and 37.50 %, respectively. The evaporation and drying process removes water from the tomatoes fruits , leading to a significant concentration of sugars and other soluble solids. The other treatments did not significantly alter the TSS content compared to the control. In the same trend the pH measurement showed no significance between all treatments.

Vitamin C (L-ascorbic acid) is one of the most important antioxidants in fruits and vegetables, exerting a crucial role in the detoxification of reactive oxygen species generated in the human body [33]. Therefore, vitamin concentration is one criterion of quality in tomato fruit. Review of literature showed that vitamin C content of tomato fruits greatly depends on the cultivar, growing conditions and ripening stage [34–37]. The data in Table (5) presents the ascorbic acid (vitamin C) concentration in various tomato treatments. From the table, we can observe that the concentration (mg/100gm) differs depending on the treatment. The control and juicing treatments have a slightly higher value. On the other hand, value for the prepared puree treatment is the lowest among all the treatments, because the thermal processing involved in preparing the puree has resulted in ascorbic acid degradation or loss. Overall, the data clearly indicates that different treatments and processing methods can have a significant impact on the ascorbic acid content in tomatoes fruits . Factors such as treatment duration, additives, processing techniques, and exposure to heat or air can influence the degradation or loss of ascorbic acid. It is important to consider these factors to preserve the ascorbic acid content in tomato-based products, as it is a valuable nutrient with various health benefits.

Carotenoids are well known as functional compounds involved in reducing the risk of development of several types of diseases such as diabetes, gastrointestinal and cardiovascular diseases. The healthy benefits of carotenoids have been attributed to their function as natural antioxidants [2,38,39]. Data in Table (5) and figure (5) presents the concentration of total carotenoids in various tomato treatments.

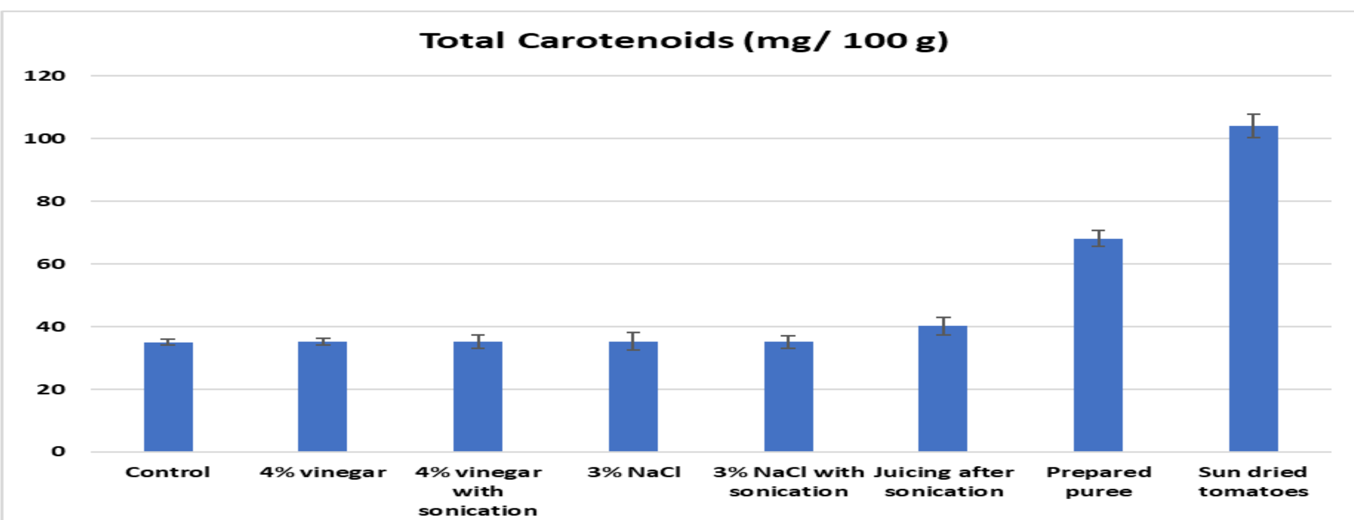

Figure (5): The concentration (mg/100g) of total carotenoids as affected by various treatments.

As shown in Table (5) and Figure (5) considerable changes were observed in tomato samples according to various treatments. Similar values were noticed in the control, 4% vinegar, 3% NaCl immersion with or without sonication. In contrast, the total carotenoids of tomato juice and prepared puree samples were determined by 40.16 mg/100g and 68.06 mg/100g, respectively while the concentration was 104.08 mg/100 g in sun dried tomato samples. The results are in agreement with the others obtained by [40–42]. Figure (5) also reveals that sun-dried tomatoes fruits have the highest content of carotenoids, significantly more than other preparations. This could be because sun-drying reduces the water content.

Lycopene is a potent antioxidant that has been associated with several on the release or extraction of lycopene from the sample. Data in Table (5) and Figure (6) present the lycopene concentration (mg / 100g) in various tomato treatments.

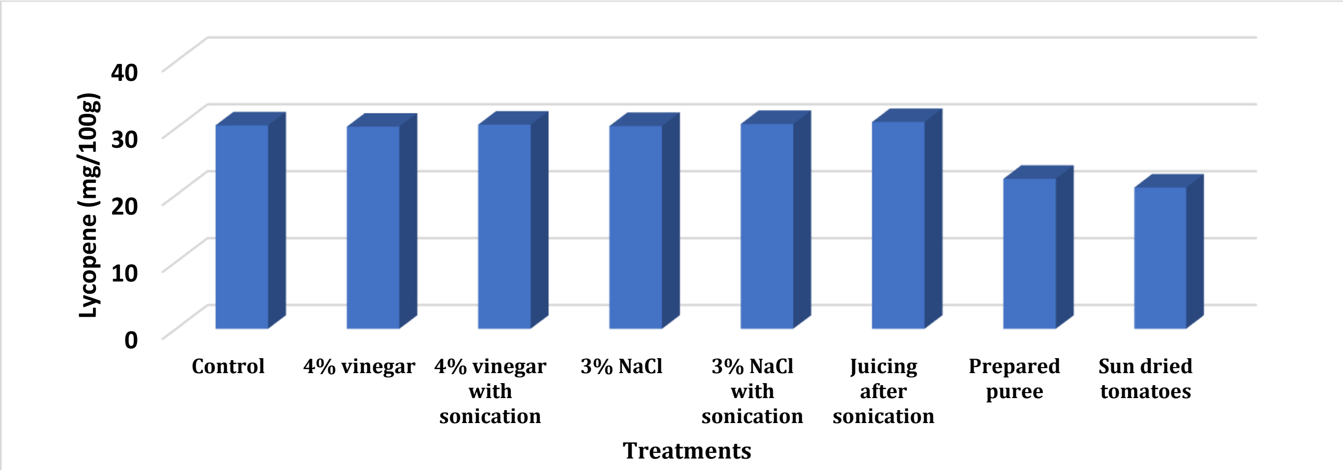

Figure (6): The concentration (mg/100g) of lycopene as affected by various treatments.

There is a significant difference ($p<0.05$) in the concentration of lycopene in control tomatoes fruits (30.4±0.04) compared to prepared puree (22.4±0.04) and sun-dried tomatoes fruits (21.1±0.02). Additionally, there is no significant difference ($p>0.05$) in the concentration of lycopene in tomatoes fruits that have been treated with 4% vinegar (30.2±0.01), 4% vinegar with sonication (30.5±0.02), or 3% NaCl (30.3±0.03). This suggests that these treatments do not have a significant effect on the concentration of lycopene in tomatoes fruits .

The data in Table (5) provides a clear comparison of β-carotene concentrations in different treatments, highlighting the impact of various processing methods on the nutrient content. The highest concentration of β-carotene is found in the treatment involving juicing after sonication with a value of 1.62±0.01 mg/100 g. The lowest concentrations are seen in the prepared puree and sun-dried tomatoes fruits treatments with values of 1.06±0.02 mg/100 g and 1.08±0.02 mg/100 g, respectively.

Phenolic compounds are known for their antioxidant properties and potential benefits [43–45]. The results of the impact of the different treatment processes on the total phenolic compounds (TPC) detected in the tomato are shown in Table (5). Total phenolic content ranged between 36.6 mg/100g (GAE) and 45.5 mg/100g (GAE). Prepared puree and sun-dried treatments have the highest total phenolic content, 45.5 and 41.7 mg/100g (GAE), respectively. The increase in total phenolic content in the prepared puree and the sun-dried tomatoes fruits may be due to the concentration of phenolic compounds during the preparation process. These preparation methods may release or extract phenolic compounds from the plant material, leading to a higher concentration in the final product. Results are in agreement with previous reports [46-48].

Flavonoids are a subgroup of phenolic compounds known for their antioxidant and anti-inflammatory properties. The data shows that treatments of juicing after sonication, prepared puree, and sun-dried tomatoes fruits resulted in higher total flavonoid levels compared to the control and other treatments. This suggests that the application of sonication and specific processing methods can enhance the flavonoid content in tomatoes fruits , potentially increasing their nutritional value and health benefits. The prepared puree has the highest total flavonoid content, with an increase of 14.7% compared to the control. The sun-dried tomatoes fruits and the juicing after sonication also have significantly higher total flavonoid contents than the control, with increases of 9.3% and 8.0%, respectively. The increase in total flavonoid content in the prepared puree and the sun-dried tomatoes fruits may be due to the concentration of compounds during the preparation process. These preparation methods may release or extract flavonoid compounds from the plant material, leading to a higher concentration in the final product.

3.3. Determination of Antioxidant Activity by DPPH method in various Treatments

The DPPH method is a colorimetric technique used to determine the antioxidant activity in various foods and beverages. The method relies on the reduction of 2,2′-diphenyl-1-picrylhydrazyl (DPPH), a stable free radical. When antioxidants react with DPPH, they become paired off in the presence of a hydrogen donor (such as a free radical scavenging antioxidant), resulting in reduced DPPH [49,50]. The absorbance decreases, and this reduction is quantified as the antioxidant activity [51].

3.3.1. Determination of % inhibition in various Treatments:

Data in Table (6) presents the % inhibition in various tomato treatments. The results demonstrate that the different treatments have a notable impact on the antioxidant activity in tomato samples. Treatments such as prepared puree showed the highest levels of antioxidant activity across all concentrations tested, indicating that this processing method significantly enhances the antioxidant properties of tomatoes fruits. Additionally, treatments involving sonication, juicing after sonication, and sun-dried tomatoes fruits also exhibited increased antioxidant activity compared to the control and other treatments. These findings suggest that specific processing techniques can influence the antioxidant capacity of tomatoes fruits , potentially providing additional health benefits to consumers [52–55].

Table (6): % inhibition in various Treatments

Treatments	% inhibition / Conc. (µg)		
	100	200	300
Control	7.18	12.19	20.05
4% vinegar	0.42	2.74	13.3
4% vinegar with sonication	1.26	8.44	17.1
3% NaCl	3.06	10.87	21.01
3% NaCl with sonication	1.16	10.66	24.28
Juicing after sonication	6.33	14.87	26.5
Prepared puree	27.45	47.72	72.96
Sun dried tomatoes fruits	8.5	16.98	33.64

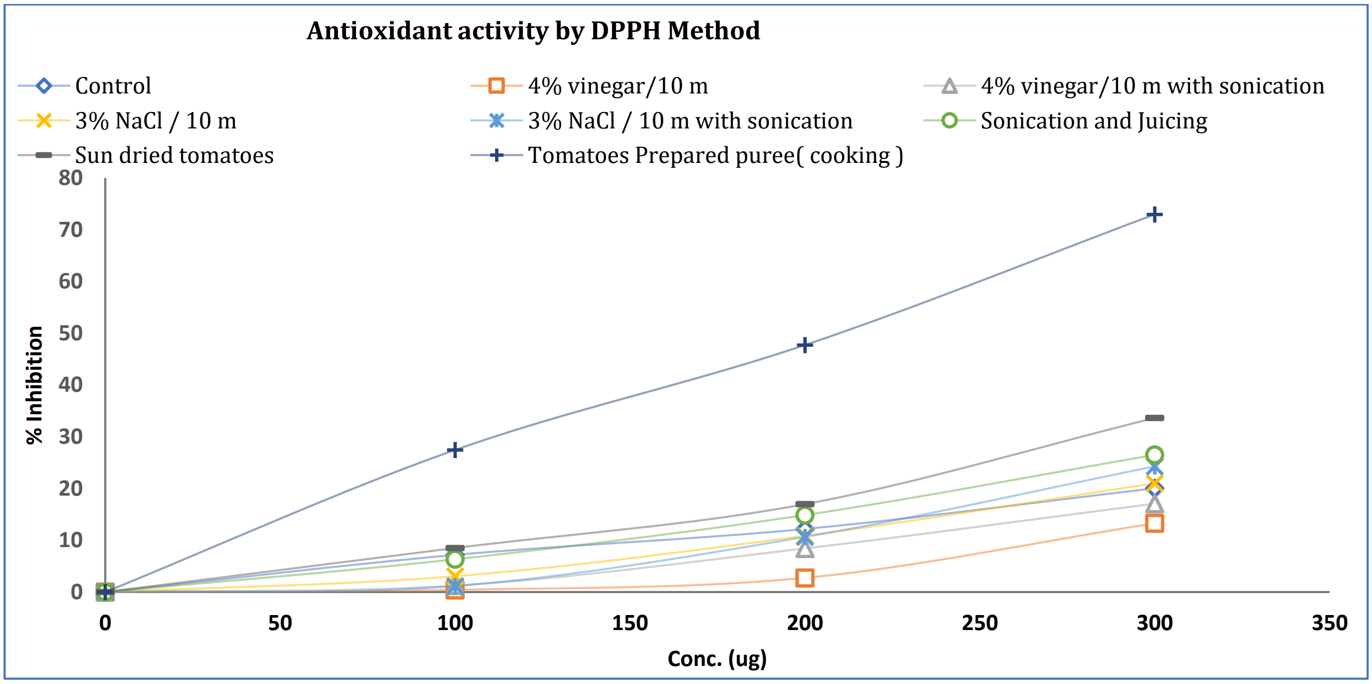

Figure (7): Effect of different processing treatments on the % inhibition.

3.3.2. Calculation of IC50 and ARP in tomatoe fruits as affected by various Treatments:

IC_{50} refers to the effective concentration of a substance required to produce 50% of its maximum response or effect. Lower IC_{50} values indicate a greater effect. The antiradical power (ARP) is a measure of the ability of a substance to scavenge free radicals and prevent oxidative damage. The antiradical power (ARP) is expressed as the percentage of DPPH radical inhibition by the tomato extract. The higher the ARP, the higher the antioxidant capacity of the tomato sample. Data in Table (7) shows the IC_{50} and ARP values of various tomatoes treatments.

Table (7): IC_{50} (mg) and ARP of tomatoe fruits as affected by different Treatments

Treatment	IC_{50}	ARP
Control	0.77 ±0.1 ^{b}	1.30 ^{g}
4% vinegar	0.44 ±0.02^{f}	2.25 ^{c}
4% vinegar with sonication	0.59 ±0.07 ^{d}	1.71 ^{e}
3% NaCl	0.80 ±0.03 ^{a}	1.25 ^{h}
3% NaCl with sonication	0.42 ±0.06 ^{g}	2.37 ^{b}
Juicing after sonication	0. 61 ±0.04 ^{c}	1.65 ^{f}
Prepared puree	0.20 ±0.02 ^{h}	4.88 ^{a}
Sun dried tomatoes fruits	0.49 ±0.02 ^{e}	2.05 ^{d}

Means ± Standard deviation, different letters at mean represent statistically significant differences among treatments ($P<0.05$).

Based on the table, the treatments can be ranked from the most potent to the least potent as follows: Prepared puree (0.20 ±0.02 mg and 4.88), 3% NaCl with sonication (0.42 ±0.06 mg and 2.37), 4% vinegar (0.44 ±0.02 mg and 2.25), Sun dried tomatoes fruits (0.49 ±0.02 mg and 2.05), 4% vinegar with sonication (0.59 ±0.07 mg and 1.71), Juicing after sonication (0.61 ±0.04 mg and 1.65) ,Control (0.77 ±0.1 mg and 1.30), 3% NaCl (0.80 ±0.03 mg and 1.25). The table shows that prepared puree is the most effective inhibitor, while 3% NaCl is the least effective. It also indicates that sonication, a process of applying sound waves, enhances the inhibitory effect of vinegar and NaCl, but not of juicing. Sun dried tomatoes fruits have a moderate inhibitory effect, while the control has a low effect.

The results in Table (7) indicate that the different treatments have a significant impact on the antioxidant activity in tomato samples, as expressed by the IC_{50} values. Treatments such as prepared puree, 3% NaCl with sonication, 4% vinegar and sun-dried tomatoes fruits treatments showed lower IC_{50} values, suggesting higher antioxidant activity compared to the control and other treatments. These findings highlight the importance of processing methods and treatments in influencing the antioxidant properties of tomatoes fruits [47]. The results also show that the prepared puree and the sun-dried tomatoes fruits had the highest ARP values among all the samples. This could be explained by the fact that these treatments involve concentrate the component, which can increase the antioxidants in tomatoes fruits [38,39,56]. Moreover, the prepared puree may have lost some of the phenolic compounds during the peeling and sieving processes [57]. In conclusion, the results demonstrate that different treatments can affect the antiradical activity of tomatoes fruits in different ways. The treatments that increased the ARP of the tomato samples were puree, sun dried sonication with vinegar, and salt. These findings have implications for the valorization of tomato waste as a source of antioxidants and the development of novel functional foods from tomatoes fruits.

4. Conclusions

This study contributes valuable insights into the practical application of household solutions in reducing pesticide residue on commonly consumed produce like tomatoes fruits . The outcomes provide a foundation for refining decontamination strategies and ensuring food safety, emphasizing the importance of accessible and effective methods for reducing pesticide exposure in agricultural produce. Further studies should be carried out using more samples and for more pesticides by changing the concentrations of solutions and changing the time of applying treatments. Preliminary findings suggest that both the 4% vinegar solution and the 3% salt solution exhibit promising capabilities in reducing pesticide residue on tomato surfaces. However, the extent of residue reduction varied between the two treatments. The results also indicated a differential impact on chemical content, highlighting the need for further investigation into the potential consequences on food safety beyond pesticide degradation. From the previous results, it appears that treating tomatoes fruits with vinegar or salt with or without sonication, as well as heat treatment and sun drying; All these treatments lead to a good reduction in pesticide residues with varying impact on quality characteristics, but we can say that treatment with vinegar and sonication is the most effective method in reducing pesticide residues. To address the impact of different treatments on the quality attribute (for example total phenols and flavonoids and antioxidant activity) in tomato samples, several approaches can be considered: Conduct further research to understand the mechanisms behind the observed effects of the treatments on flavonoid content and antioxidant activity. Optimize processing techniques such as sonication, juicing, and drying methods to maximize the nutritional value and health benefits of tomatoes fruits. Explore the potential synergistic effects of combining different treatments to enhance the flavonoid content and antioxidant activity in tomatoes fruits. Investigate the bioavailability and bio accessibility of flavonoids and antioxidants in processed tomato products to assess their potential health benefits upon consumption. Collaborate with food scientists and nutritionists to develop innovative tomato-based products with enhanced nutritional profiles and antioxidant properties.

Author Contributions

Conceptualization, M.H.H Roby and S.A. Abdel-Tawab; Methodology, M.O.H. Ahmed, M.H.H. Roby, and L.A.R. Ahmed; Validation M.H.H. Roby and S.A. Abdel-Tawab; Formal analysis, M.O.H. Ahmed and M.H.H. Roby; Investigation, M.H.H. Roby, S.A. Abdel-Tawab, and L.A.R. Ahmed; Data curation, M.H.H. Roby, S.A. Abdel-Tawab and L.A.R. Ahmed; Writing—original draft preparation, M.H.H. Roby, M.O.H. Ahmed, S.A. Abdel-Tawab and L.A.R. Ahmed; Writing—review and editing, M.O.H. Ahmed, M.H.H. Roby; Visualization, E.M.M.A., E.A.H.A and L.A.I.H. Supervision, M.H.H. Roby, S.A. Abdel-Tawab, and L.A.R. Ahmed. Project administration, M.H.H. Roby, S.A. Abdel-Tawab, and L.A.R. Ahmed; Funding acquisition, M.H.H. Roby, S.A. Abdel-Tawab, and L.A.R. Ahmed. All authors have read and agreed to the published version of the manuscript.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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