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Evaluation of the Effects of Different Packaging Materials on the Quality Attributes of the Tomato Fruit

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Abstract: Post-harvest loss continues to be a significant problem in the food industry. Different packaging materials, designed to reduce fruit damage, are anticipated for various applications in the supply chain. Recently, stamped paper (SP) and expandable polystyrene (EPS) trays have been introduced as tomato retail packaging. Although the combination of paper trays and clear plastic are still not 100% biodegradable packaging, they are promising alternatives to the heavy utilisation of petrochemical-based polymers. This study investigated the effects of different packaging materials and storage conditions on the 'Nema-Netta' tomatoes' quality attributes. The treatments consisted of a stamped paper (SP) + polyvinyl chloride (PVC), expandable polystyrene (EPS) + polyvinyl chloride (PVC), stamped paper (SP)+ flow wrap, expandable polystyrene (EPS) + flow wrap, polypropylene (PP), and unpackaged tomatoes stored at cold and ambient conditions. Firmness, physiological weight loss (PWL), pH value, titratable acidity (TA) and total sugars were evaluated at seven-day intervals, over 28 days. Temperature and relative humidity at cold storage ranged between 8–12 °C, 78–80% RH and 22–26 °C, 68–72% RH at ambient storage conditions. The packaging and storage conditions significantly affected the PWL, firmness, pH, TA and total sugars. Samples in the EPS Tray combined with the PVC wrap at cold storage maintained the quality of the tomatoes better than the other packaging. The combination of packaging and cold storage created an ideal environment for maintaining the quality of tomatoes. The relative differences between EPS Tray + PVC (non-biodegradable) and SP Tray + PVC (biodegradable) were less than 5% in multiple tests.

Keywords: post-harvest; packaging materials; storage conditions; tomatoes

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1. Introduction

Tomatoes (*Solanum Lycopersicum*) are an important product in the global market. They supply most of the daily nutritional phytochemicals required for human health in abundant forms [1,2]. They can be consumed raw or as a processed product in many forms [3]. Changes in their colour, flavour and texture, as well as biochemical changes, take place throughout their lifespan due to their climacteric nature [4,5]. These changes are associated with various metabolic processes, including the accumulation of organic acids, organic compounds and sugars [6]. A rapidly growing population requires an appropriately fast production of food and other nutritional needs. Hence, improving the quality of tomato handling is a pending and interesting issue reflected in consumers' behaviour in the global market [4,7]. Quality has multiple traits and it is dependent on stakeholders [8]. Consumers rely primarily on tomatoes' external appearance (e.g., colour, size and form), their storage life and firmness, their organoleptic quality, such as texture, and their biochemical traits [4,9]. Despite the growing familiarity with the molecular regulations and metabolic pathways of the tomato fruit, understanding their quality changes is a global challenge [10]. Even under the best conditions, the lifespan of tomatoes is relatively short and they require careful handling and management [11].

The South African market for fresh tomato products is very important and must strive to preserve its commodities, including during probable high-temperature transpiration phases. Expandable polystyrene trays (EPS) are well insulated and have traditionally been used in Icelandic fish export in the British market [12] and as disposable fast-food containers in China, due to their low cost and lightweight [13]. EPS trays are white, manufactured from polystyrene, with a master batch and a nucleating agent, and consist of air pores [12,13]. The air pores reduce the strength and density of the packaging but increase the insulation performance as well as the volume [14] Another alternative type of wholesale fresh tomato packaging that has been receiving international recognition is stamped paper (SP) trays. SP trays are manufactured from fibrous materials from wood and recycled paper turned into pulp, which is then bleached and coated with Kraft paper. Paper trays are environmentally friendly, but they have poor strength and insulation, thus making them unfavourable for harsh weather conditions. Food security is a top priority, therefore it is important to know not only the environmental impact but also to understand the effects on the quality of the food. Since the use of EPS and paper trays is new in the South African tomato industry, more emphasis has been put on investigating the use of EPS and paper trays and covering them with polyvinyl chloride (PVC) and flow wrap. The objective of this study was to evaluate the effects of different packaging materials and storage conditions on the quality attributes of tomato fruits.

2. Materials and Methods

Fresh tomatoes (*Solanum Lycopersicum* cv. 'Nema-Netta' Mill) were harvested from ZZ2 farms in Limpopo, South Africa, at the pinkish-red maturity stage. The tomatoes were grown on open fields in the Mooketsi area (23.5992 S, 30.1424 E). The region receives an average annual rainfall of less than 600 mm, which peaks between January and February. The summers in Limpopo are warm, with mean daily temperatures between 18–22 °C, and the winters are relatively mild, with mean daily temperatures of between 8–14 °C. The tomatoes were harvested manually during the summer season on 23 January 2020 and transported to nearby packhouses and then transported to laboratories located in Pietermaritzburg. The selection of tomatoes at the pinkish-red maturity stage coincided with consumers' South African fresh market retail requirements.

2.1. Packaging Materials

SP Tray is made of a biodegradable solid bleached sulphate and cross-linked coated paperboard. It is formed by turning fibrous materials from wood and recycled paper into pulp, which is then bleached and coated with Kraft paper. An SP Tray has three layers: an inside Kraft liner, an outside Kraft liner and a corrugated fluting medium, which gives it strength and rigidity. It is lightweight, yet strong.

An EPS Tray is a thermoplastic film. It is manufactured from general-purpose polystyrene, master batch and a nucleating agent. Pentane is used as an expandable agent. The amount of styrene monomer present in the raw materials is below 500 ppm. The EPS Tray is a brittle and poor barrier against gases and water vapour.

PVC wrap film is manufactured from PVC resin, which is mainly plasticised with DEHA (Bis(2-Ethylhexyl) adipate) and stabilised by using ESBO (Epoxidized soybean oil) and CaZn (Calcium Zinc) heat stabilisers.

The flow wrap is a PP film. The make-up of the PP film contains an outer layer, a PP core acrylic-coated layer to prevent friction on the contact surface and an interior sealant layer. The flow wrap has perforated holes.

Polypropylene (PP) is a non-biodegradable addition to the propylene polymer and the resins used are mainly isotactic. PP has the lowest density of 0.89–0.91 $g \cdot cm^{-3}$ of all the commodity plastics. It is elastic, more transparent, more effective at bearing water vapour and has good chemical resistance (Figure 1).

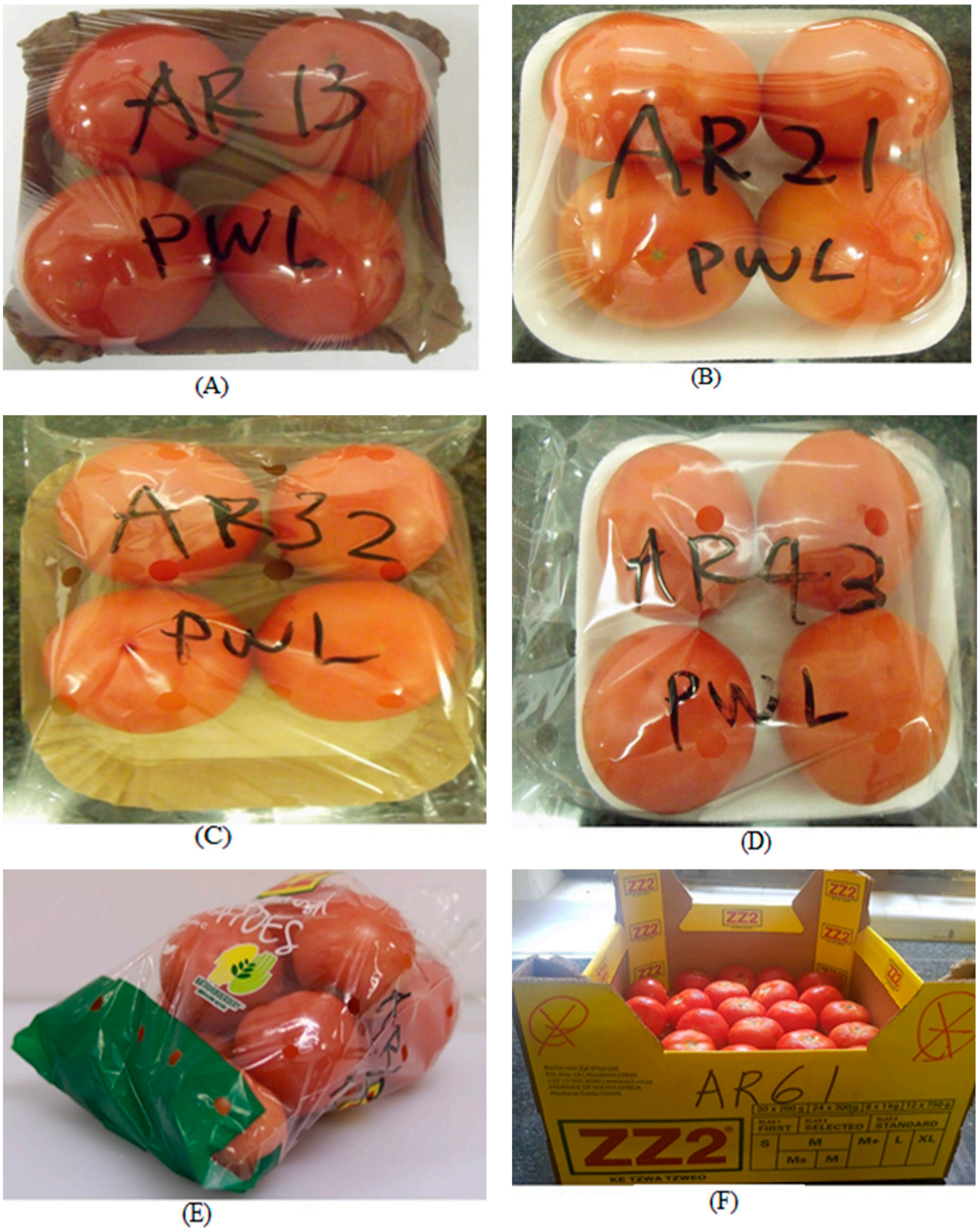

Figure 1. Round tomato packaging treatment: (**A**) SP Tray + PVC wrap, (**B**) EPS Tray + PVC wrap, (**C**) EPS Tray + Flow wrap, (**D**) SP Tray + Flow wrap, (**E**) 1 kg PP bag, and (**F**) Unpackaged (Control).

2.2. Storage Conditions

The tomatoes were divided and stored under ambient storage conditions, with recorded temperatures and relative humidity ranging between 22–26 °C, 68–72% RH and a cold storage facility that was set at 8–12 °C, 78–80% RH.

2.3. Firmness Analysis

As described by [15], the compression was measured by using a Texture Analyzer. It was equipped with a 55 mm diameter plate probe, with a speed setting of 10 mm·min^{-1}. Each tomato fruit was aligned vertically, from the stem end to the top apex on a smooth surface and pressed by the moving parallel probe until the fruit ruptured. The compressive load (N) at the breaking point defined the firmness.

2.4. Physiological Weight Loss

The physiological weight loss of the tomato samples was measured initially on Day 0 and labelled for consistent measurement every 7 days. The total weight loss was taken as the difference between the initial and the final weight during each storage interval. The percentage of weight method followed the description of the [16]. The formula for calculating the percentage weight loss is presented in Equation (1).

$$\% \text{ Weight loss} = \frac{W_0 - W_f}{W_o} \times 100 \quad (1)$$

where

W_o = the average weight of the tomato sample at Day 0
W_f = the average weight tomato of the tomato sample on the final day

2.5. Titratable Acidity

The total titratable acidity was determined as described in [17]. Randomly selected tomatoes from the sample packages were blended. An aliquot of juice was extracted, filtered through using a muslin cloth and transferred to a sterilized conical flask. The titratable acidity was determined by titrating 25 mL of the sample tomato juice with 0.1 mol·L^{-1} of sodium hydroxide (NaOH).

2.6. pH Value

The pH of the tomatoes was measured using a method described by [18]. An aliquot of juice was filtered through using a muslin cloth and a sample was transferred into a sterile beaker, into which a glass electrode pH meter was inserted.

2.7. Total Sugars

The total sugars were determined using a method by [19]. A tomato fruit sample was blended and 5 mL of the juice was extracted into centrifuge tubes, then 2 mL of deionized water was added and centrifuged at 10,000 rpm, maximum g-force of 81,800× g for 15 min at 4 °C. All solutions of the samples were filtered through a 0.45 µm nylon syringe filter and 2 mL was injected into LC-20AT High-Performance-Liquid-Chromatography (HPLC) vials. The HPLC system column was set at 85 °C, with ultra-pure water as the mobile phase flowing at 0.6 mL·min^{-1}. The chromatographic comparisons identified the sugar compounds with authentic standards of glucose and fructose (sucrose was negligible). Quantification was performed by using the standard internal method and the sugar content was expressed in mg per 100 g of fresh weight (mg·100^{-1} g^{-1} FW).

2.8. Statistical Data Analysis

Significance tests were conducted by the Analysis of Variance (ANOVA) in a completely randomized design arrangement by using the GenStat® 18th Edition. The performance level of the treatment's means was carried out by considering a statistical significance level of 5% and Duncan's multiple range comparison tests.

3. Results and Discussion

3.1. Physiological Weight Loss

The packaging treatments and storage conditions had a significant ($p < 0.001$) influence on the physiological weight loss (PWL) of tomatoes. The EPS Tray + PVC wrap under cold storage had the lowest PWL (%), with 0.23% on Day 7 and 1.74% on Day 28. Unpackaged (control) tomatoes had the highest PWL (%) of all the packaging treatments, averaging 1.30% on Day 7 to 8.98% on Day 28 in both storage conditions. Similar results have been reported by [20,21] where the weight loss in the uncontrolled ripening of unpackaged fruits caused a sudden increase in ethylene production and in the respiration rate. This degrades the nature of the fruit faster, while the packaging slows down these processes.

The results of the SP Tray + PVC revealed a rapid increase in weight loss within the first 7 days of packaging, averaging 2.93%, compared to the other packaging treatments. This increase was the highest rapid PWL (%) during the first 7 days of storage, compared to all the other packaging treatments, including the unpackaged tomatoes. Ref. [22] stated that the permeability properties of the packaging material generate a localised modified atmosphere inside the packaging, which can be positive or negative, depending on the response of the fruit to its new surrounding atmospheric conditions. The accumulation of water vapour inside the SP Tray + PVC wrap caused the packaging to swell, which resulted in a blossom-end rot in the tomato samples. The results show that, as the storage period progressed, PWL increased. Ref. [23] stated that high temperatures accelerate the rate of transpiration and enhance water loss. Subsequently, the fruit shrivels and softens. This explains the rapidly increasing trend of water loss in the unpackaged tomato treatments and samples at ambient storage. Ref. [24] stated that packaging can retard the rate of transpiration and can thus prevent excessive water loss. The PWL (%) ranged from 0.27% on Day 7 to 11.93% on Day 28 (Table 1), which is similar to the range reported by [23].

Table 1. The effects of the packaging and storage conditions on the physiological weight loss (%) of tomatoes over a 28-day storage period (*n* = 3).

Package Treatment	Storage Conditions	Storage Period (Days)				
		0	7	14	21	28
SP Tray + PVC wrap	Cold	0.00^{a}	$2.42 \pm 0.36^{b-k}$	$3.23 \pm 0.14^{f-m}$	$4.22 \pm 0.20^{j-q}$	$5.45 \pm 0.60^{n-r}$
	Ambient	0.00^{a}	$3.44 \pm 0.13^{g-m}$	$4.80 \pm 0.24^{l-r}$	$5.67 \pm 1.49^{o-s}$	8.64 ± 0.07^{tu}
EPS Tray + PVC wrap	Cold	0.00^{a}	0.23 ± 0.03^{a}	$0.77 \pm 0.04^{a-d}$	$1.28 \pm 0.08^{a-g}$	$1.78 \pm 0.11^{a-i}$
	Ambient	0.00^{a}	$1.17 \pm 0.67^{a-f}$	$3.20 \pm 1.13^{f-m}$	$3.58 \pm 0.32^{h-o}$	6.11 ± 1.19^{qrs}
SP Tray + Flow wrap	Cold	0.00^{a}	0.57 ± 0.06^{ab}	$1.79 \pm 0.20^{a-i}$	$2.84 \pm 0.39^{c-m}$	$3.92 \pm 0.50^{i-p}$
	Ambient	0.00^{a}	$0.88 \pm 0.08^{a-e}$	$2.90 \pm 0.20^{d-m}$	$4.56 \pm 0.28^{k-q}$	6.74 ± 0.38^{rst}
EPS Tray + Flow wrap	Cold	0.00^{a}	0.58 ± 0.11^{ab}	$1.83 \pm 0.43^{a-i}$	$3.03 \pm 0.64^{e-m}$	$4.29 \pm 0.91^{j-q}$
	Ambient	0.00^{a}	$1.44 \pm 0.95^{a-h}$	$3.11 \pm 0.31^{f-m}$	$4.97 \pm 0.44^{m-r}$	7.48 ± 0.89^{stu}
1 kg PP bag	Cold	0.00^{a}	0.62 ± 0.12^{ab}	$1.91 \pm 0.26^{a-i}$	$3.21 \pm 0.49^{f-m}$	$4.46 \pm 0.59^{k-q}$
	Ambient	0.00^{a}	$2.64 \pm 3.46^{b-l}$	$3.13 \pm 1.09^{f-m}$	8.70 ± 3.26^{tu}	9.34 ± 3.37^{u}
Unpackaged (Control)	Cold	0.00^{a}	0.69 ± 0.12^{abc}	$2.19 \pm 0.37^{a-j}$	$4.14 \pm 0.80^{j-q}$	$6.00 \pm 1.14^{p-s}$
	Ambient	0.00^{a}	$1.91 \pm 0.46^{a-i}$	$4.86 \pm 1.75^{m-r}$	8.51 ± 2.80^{tu}	11.93 ± 3.70^{v}

Values are means of three replications ± standard deviation. Means followed by the same letter(s) within a column are not significant. Duncan's multiple range test ($p < 0.05$). SP = stamped paper tray: EPS = expandable polystyrene: PVC = polyvinyl chloride: PP = polypropylene.

3.2. Firmness

The packaging treatments had a significant ($p < 0.05$) influence on the compressive load of the tomatoes. Tomatoes packed in the EPS Tray + Flow wrap and stored at cold storage had a higher compressive load (112.0 N) on Day 28, whilst the Unpackaged (control) tomatoes under ambient storage had the lowest compressive load (72.8 N) after 28 days. According to [25], tissue failure under compression loading is a result of the cell wall rupturing, caused by extreme stress. The significant changes are related to the presence of pectin in the amorphous matrix of the fruit, where the cellulose microfibrils of the cell wall are rooted, and in the middle lamella. For rupturing to occur, the lining of this pectin in the amorphous matrix significantly influences tissue failure. The ripening stage determines these factors [25] explaining the low compressive force in unpackaged fruits, which ripened faster. Ref. [26] reported that tomatoes stored in a controlled cooling system remained firmer than those stored under ambient conditions. The compression force varied significantly over the storage period. It decreased progressively as the storage time progressed between Day 0 and Day 28. According to [27] the firmness is expected to decline as the storage time increases, due to the maturity of the fruit. The firmness values of this experiment had a range of 155.5 to 72.8 N (Table 2). These values are below the range reported by [25]. The differences can be attributed to the difference in cultivars, the geographic location and the growing conditions of the Nema-Netta tomatoes.

Table 2. Compression (N) test of tomatoes influenced by the packaging and storage conditions over a 28-day storage period (n = 3).

Packaging Treatment	Storage Conditions	Storage Period (Days)				
		0	7	14	21	28
SP Tray + PVC wrap	Cold	155.5 ^{v}	133.6 ± 0.01 $^{n-t}$	123.7 ± 0.01 $^{j-q}$	116.8 ± 16.83 $^{f-n}$	107.3 ± 2.63 $^{c-i}$
	Ambient	155.5 ^{v}	129.5 ± 0.01 $^{m-t}$	116.0 ± 0.06 $^{f-m}$	105.8 ± 1.72 $^{c-h}$	101.1 ± 0.01 $^{c-g}$
EPS Tray + PVC wrap	Cold	155.5 ^{v}	143.9 ± 5.64 $^{s-v}$	128.1 ± 0.01 $^{m-t}$	119.0 ± 0.01 $^{g-p}$	112.0 ± 0.01 $^{e-l}$
	Ambient	155.5	126.3 ± 24.83 $^{k-r}$	115.4 ± 0.01 $^{f-m}$	113.4 ± 9.92 $^{e-m}$	103.4 ± 1.60 $^{c-g}$
SP Tray + Flow wrap	Cold	155.5 ^{v}	135.6 ± 0.01^{0-t}	127.0 ± 0.01 $^{l-s}$	124.2 ± 0.01 $^{i-q}$	106.6 ± 0.01 $^{c-h}$
	Ambient	155.5 ^{uv}	129.5 ± 27.00 $^{m-t}$	123.6 ± 12.28 $^{j-q}$	96.2 ± 19.25 $^{b-e}$	92.8 ± 2.52 ^{bcd}
EPS Tray + Flow wrap	Cold	155.5 ^{v}	145.9 ± 0.01 ^{tuv}	133.8 ± 0.01 $^{n-t}$	128.6 ± 1.73 $^{l-s}$	99.8 ± 19.60 $^{c-f}$
	Ambient	155.5 ^{uv}	136.1 ± 0.01 $^{p-t}$	126.1 ± 0.01 $^{k-r}$	116.6 ± 0.01 $^{f-m}$	103.4 ± 12.61 $^{c-g}$
1 kg PP bag	Cold	155.5 ^{uv}	129.9 ± 8.87 $^{m-t}$	129.5 ± 0.01 $^{m-t}$	112.9 ± 4.41 $^{e-m}$	108.6 ± 0.01 $^{d-j}$
	Ambient	155.5 ^{uv}	116.2 ± 0.01 $^{f-m}$	113.9 ± 15.00 $^{f-m}$	81.6 ± 13.75 ^{ab}	93.7 ± 0.64 ^{bcd}
Unpackaged (Control)	Cold	155.5 ^{uv}	138.8 ± 3.46 $^{q-u}$	124.7 ± 6.01 $^{j-q}$	110.9 ± 5.06 $^{e-l}$	105.5 ± 13.20 $^{c-g}$
	Ambient	155.5 ^{uv}	134.8 ± 0.01^{0-t}	107.5 ± 0.01 $^{c-j}$	90.5 ± 22.04 ^{bc}	72.8 ± 21.53 ^{a}

Values are means of three replications ± standard deviation. Means followed by the same letter(s) within a column are not significant. Duncan's multiple range test (p < 0.05). SP = stamped paper tray: EPS = expandable polystyrene: PVC = polyvinyl chloride: PP = polypropylene.

3.3. pH Value

The results show that the packaging and storage condition had a highly significant (p < 0.001) influence on the pH values of the tomatoes. Unpackaged (control) tomatoes had the highest increase in pH value from 4.20 to 4.60 under ambient storage, while the EPS Tray + PVC wrap under cold storage had the lowest increase in pH value from 4.20 to 4.44. Similar results were reported by [28] where packaged tomato fruits had the lowest pH values, compared to unpackaged tomato fruits. According to [23] the lower pH values in packaged tomatoes can be attributed to the relatively reduced respiration rate which results from the changes brought about by the packaging environment. The difference shows that respiration occurs much faster in unpackaged tomatoes than in packaged treatments. Generally, the normal tomato ripening process causes the pH to rise as the fruit converts acids to sugars [29]. The higher pH values of tomatoes under ambient storage conditions could be attributed to the faster conversion rate of acids to sugar, due to the faster respiration rate experienced by tomatoes during ripening [29]. Ref. [18] reported that higher temperature conditions cause a faster respiration rate which results in a loss of acidity. The pH values show a significant increase as the storage time progressed, from 4.20 to 4.46 between Day 0 and Day 28, respectively. Similar observations have been reported by [30,31] where the pH continually increased with the storage time. Ref. [32] explained that the pH value of tomatoes increases with the storage time due to ripening and respiration. The pH values ranged from 4.20 to 4.60 over the 28-day storage period, as presented in Table 3. Ref. [33] found a similar pH range, from 4.15 to 4.55 over eight days of storage.

3.4. Titratable Acidity

The different packaging had a significant (p < 0.001) influence on the titratable acidity (TA) of the tomatoes. The EPS Tray + PVC wrap at cold storage had the lowest reduction in TA from 0.51% to 0.38%, while the Unpackaged (control) tomatoes at ambient storage had the highest reduction from 0.51% to 0.23% within 28 days. Ref. [32] reported that the packaging significantly affects the TA and that the TA decreases in the fruit, while the pH increases as the fruit storage time progress toward senescence. Tomato samples packaged and stored under cold storage conditions had higher TA values, with an average of 0.42%, than the TA values averaging 0.36% of tomato samples stored under ambient storage conditions. The results also show that, as the storage period progressed, the TA declined, with the highest TA values recorded on Day 0 (0.51%) and the lowest TA values recorded on Day 28 (0.30%). Similar results were reported by [34] where the titratable acidity decreases with time. Ref. [35] reported that a reduction of the TA as the storage time progresses can be attributed to the use of titratable acids by the respiration processes and the metabolism of tomatoes. The Titratable Acidity (TA) values ranged from 0.51 to 0.24% (Table 4), which is similar to those of the field-grown tomatoes reported by [36].

Table 3. pH values of the tomatoes affected by the packaging and storage conditions during storage (n = 3).

Packaging Treatment	Storage Conditions	Storage Period (Days) 0	7	14	21	28
SP Tray + PVC wrap	Cold	4.20 ^{a}	4.51 ± 0.02 $^{d–j}$	4.42 ± 0.06 $^{b–f}$	4.48 ± 0.01 $^{d–j}$	4.47 ± 0.03 $^{c–j}$
	Ambient	4.20 ^{a}	4.55 ± 0.01 $^{f–k}$	4.45 ± 0.05 $^{b–i}$	4.54 ± 0.05 $^{e–k}$	4.58 ± 0.02 $^{i–k}$
EPS tray + PVC wrap	Cold	4.20 ^{a}	4.47 ± 0.23 $^{c–i}$	4.34 ± 0.01 ^{b}	4.44 ± 0.07 $^{b–g}$	4.44 ± 0.03 $^{b–f}$
	Ambient	4.20 ^{a}	4.53 ± 0.03 $^{e–j}$	4.47 ± 0.03 $^{c–j}$	4.57 ± 0.06 $^{g–k}$	4.54 ± 0.01 $^{e–k}$
SP Tray + Flow wrap	Cold	4.20 ^{a}	4.42 ± 0.02 $^{b–f}$	4.34 ± 0.01 ^{b}	4.35 ± 0.05 ^{bc}	4.50 ± 0.01 $^{d–j}$
	Ambient	4.20 ^{a}	4.46 ± 0.05 $^{b–i}$	4.46 ± 0.05 $^{b–i}$	4.48 ± 0.02 $^{d–j}$	4.48 ± 0.04 $^{d–j}$
EPS Tray + Flow wrap	Cold	4.20 ^{a}	4.48 ± 0.16 $^{d–j}$	4.43 ± 0.02 $^{b–f}$	4.44 ± 0.01 $^{b–g}$	4.49 ± 0.06 $^{d–j}$
	Ambient	4.20 ^{a}	4.57 ± 0.11 $^{h–k}$	4.46 ± 0.03 $^{b–i}$	4.57 ± 0.03 $^{g–k}$	4.52 ± 0.06 $^{e–j}$
1 kg PP bag	Cold	4.20 ^{a}	4.44 ± 0.06 $^{b–h}$	4.44 ± 0.04 $^{b–f}$	4.50 ± 0.02 $^{d–j}$	4.49 ± 0.04 $^{d–j}$
	Ambient	4.20 ^{a}	4.53 ± 0.03 $^{e–j}$	4.46 ± 0.05 $^{b–i}$	4.53 ± 0.09 $^{e–j}$	4.55 ± 0.03 $^{f–k}$
Unpackaged (control)	Cold	4.20 ^{a}	4.50 ± 0.06 $^{d–j}$	4.47 ± 0.18 $^{c–j}$	4.53 ± 0.01 $^{e–j}$	4.58 ± 0.02 $^{i–k}$
	Ambient	4.20 ^{a}	4.60 ± 0.01 ^{jk}	4.50 ± 0.03 $^{d–j}$	4.66 ± 0.19 ^{k}	4.60 ± 0.06 ^{jk}

Values are means of three replications ± standard deviation. Means followed by the same letter(s) within a column are not significant. Duncan's multiple range test (p < 0.05). SP = stamped paper tray: EPS = expandable polystyrene: PVC = polyvinyl chloride: PP = polypropylene.

Table 4. Titratable acidity (%) of the tomatoes is influenced by the packaging and storage conditions (n = 3).

Packaging Treatment	Storage Condition	Storage Period (Days) 0	7	14	21	28
SP Tray + PVC wrap	Cold	0.51 ^{r}	0.50 ± 0.08 ^{r}	0.43 ± 0.03 $^{k–n}$	0.38 ± 0.01 $^{g–j}$	0.26 ± 0.11 $^{a–c}$
	Ambient	0.51 ^{r}	0.46 ± 0.01 $^{n–q}$	0.39 ± 0.02 $^{h–k}$	0.35 ± 0.04 $^{e–g}$	0.24 ± 0.05 ^{a}
EPS Tray + PVC wrap	Cold	0.51 ^{r}	0.45 ± 0.02 $^{m–p}$	0.40 ± 0.01 $^{i–l}$	0.36 ± 0.01 $^{e–i}$	0.38 ± 0.02 $^{g–j}$
	Ambient	0.51 ^{r}	0.43 ± 0.01 $^{k–n}$	0.35 ± 0.02 $^{e–h}$	0.30 ± 0.02 ^{cd}	0.25 ± 0.02 ^{ab}
SP Tray + Flow wrap	Cold	0.51 ^{r}	0.49 ± 0.01 $^{p–r}$	0.48 ± 0.01 $^{o–r}$	0.37 ± 0.01 $^{e–i}$	0.35 ± 0.03 $^{e–g}$
	Ambient	0.51 ^{r}	0.47 ± 0.01 $^{n–r}$	0.36 ± 0.02 $^{e–i}$	0.30 ± 0.02 ^{cd}	0.24 ± 0.00 ^{a}
EPS Tray + Flow wrap	Cold	0.51 ^{r}	0.46 ± 0.01 $^{n–q}$	0.43 ± 0.01 $^{k–n}$	0.38 ± 0.01 $^{g–j}$	0.33 ± 0.02 ^{de}
	Ambient	0.51 ^{r}	0.41 ± 0.03 $^{j–m}$	0.37 ± 0.01 $^{f–j}$	0.29 ± 0.01 ^{cd}	0.27 ± 0.02 $^{a–c}$
1 kg PP bag	Cold	0.51 ^{r}	0.45 ± 0.00 $^{n–p}$	0.37 ± 0.01 $^{e–i}$	0.35 ± 0.01 $^{e–g}$	0.33 ± 0.03 $^{d–f}$
	Ambient	0.51 ^{r}	0.45 ± 0.01 $^{m–p}$	0.38 ± 0.00 $^{g–j}$	0.28 ± 0.01 ^{bc}	0.28 ± 0.02 $^{a–c}$
Unpackaged (Control)	Cold	0.51 ^{r}	0.47 ± 0.03 $^{o–r}$	0.43 ± 0.01 $^{l–n}$	0.40 ± 0.02 $^{i–l}$	0.34 ± 0.02 $^{e–g}$
	Ambient	0.51 ^{r}	0.44 ± 0.00 $^{m–o}$	0.40 ± 0.04 $^{i–l}$	0.28 ± 0.02 $^{a–c}$	0.25 ±0.02 ^{ab}

Values are means of three replications ± standard deviation. Means followed by the same letter(s) within a column are not significant. Duncan's multiple range test (p < 0.05). SP = stamped paper tray: EPS = expandable polystyrene: PVC = polyvinyl chloride; PP = polypropylene.

3.5. Total Sugars

The packaging had a significant (p < 0.001) effect on the changes in the total sugar concentration of the tomatoes. The unpackaged tomatoes (Control) showed a rapid decline in total sugars, compared to the packaged tomatoes. Ref. [21] reported similar results on the effects of different packaging systems, where the total sugars gradually decreased as the ripening progressed during the tomato fruit lifespan. The EPS Tray + PVC wrap had the minimum loss in total sugars (6.90 g$\cdot$100^{-1} g FW), followed by the SP Tray + Flow wrap (6.56 mg$\cdot$100^{-1} g FW), the EPS Tray + Flow wrap (6.25 mg$\cdot$100^{-1} g FW) and the SP Tray + PVC wrap (6.40 mg$\cdot$100^{-1} g FW). The Old PP plastic (6.23 mg$\cdot$100^{-1} g FW) did poorly and was only exceeded by the unpackaged tomatoes (5.76 mg$\cdot$100^{-1} g of FW). The packaging potentially creates a modified atmosphere around the tomatoes, which helps to regulate the gaseous exchange influxes [37]. With the fruit respiring inside the packaging, the O_2 concentration levels decrease, while the CO_2 increases [23]. The interplay of these gases lessens the utilization of respiratory substrates, such as sugars; hence, the quality of the fruit is maintained [29]. Similarly, as reported by [22] the permeable properties of the packaging materials play an essential role. One of the disadvantages of typical biodegradable materials is their high permeability rate [38], which can explain the difference in sugars between the SP Tray and the EPS Tray packaging materials.

Total sugars of tomato samples stored under ambient storage conditions (5.98 mg·100^{-1} g FW) declined more quickly compared to those stored under cold storage conditions (6.72 mg·100^{-1} g FW). Similar results were reported by [39] where there was more than a 30% decrease in the total sugar concentration of tomatoes stored at ambient storage conditions, compared to those stored at cold storage conditions. Ref. [19] reported that total sugars are a significant source of metabolic energy within the fruit. The higher loss of sugars under ambient storage conditions can be associated with a high respiration rate and metabolic processes, which trigger the rapid hydrolysis of sugars. Similarly, ref. [29] also reported that higher temperatures advocate the more rapid utilization of sugars as a substrate for ripening and metabolic processes. Cooler temperatures help to delay these processes, which results in the lower utilization of sugars.

The results show a decline in the total sugar concentration over the storage period, from 8.95 mg·100^{-1} g on Day 0 to 4.77 mg·100^{-1} g of fresh weight (FW) on Day 28. Ref. [40] also reported a decline in the total sugar concentration with the advancement of a 30-day storage period. According to [21] the total sugars reach a peak concentration at the pinkish-yellow to red ripening stages. Thereafter, they begin to decrease as the fruit matures and changes to become entirely red. The results show that the highest total sugar concentration was at the initial stage of packaging, where the tomatoes were at their pinkish-yellow to red ripening stage. Ref. [41] reported that sugars generally increase with the maturity of tomatoes. The fructose and glucose dominate, while the sucrose decreases up to 90% of its initial concentration and declines when the tomatoes start to deteriorate. This explains the decline in total sugars during storage as they ripen to full red. Similar trends were reported in the papaya fruit by [29] where the fruit showed a slight increase in total sugars at the beginning and a decrease towards the end of its lifespan. Ref. [42] also reported that sugar phosphates are intermediate pathways of central metabolism; as the fruit begins to deteriorate there is a high turnover rate of sugar concentration. As the tomatoes mature to become entirely red, more starch is lost due to respiration, which causes carbon influxes. The total sugar concentration values ranged from 8.95 to 3.43 mg·100^{-1} g of fresh weight (Table 5). These results are in agreement with the range reported by [40].

Table 5. The total sugars (mg·100^{-1} g FW) of tomatoes are influenced by the packaging and storage conditions over the 28-day storage period (*n* = 3).

Packaging Treatment	Storage Condition	Storage Period (Days)				
		0	7	14	21	28
SP Tray + PVC wrap	Cold	8.95^{v}	$7.69 \pm 0.09^{\text{u}}$	$6.58 \pm 0.30^{\text{o–r}}$	$5.96 \pm 0.06^{\text{k–n}}$	$5.06 \pm 0.16^{\text{gh}}$
	Ambient	8.95^{v}	$6.22 \pm 0.05^{\text{m–p}}$	$6.02 \pm 0.44^{\text{k–n}}$	$5.19 \pm 0.03^{\text{g–j}}$	$5.00 \pm 0.05^{\text{gh}}$
EPS Tray + PVC wrap	Cold	8.95^{v}	$7.564 \pm 0.08^{\text{u}}$	$6.67 \pm 0.19^{\text{pqr}}$	$6.57 \pm 0.06^{\text{o–r}}$	$6.11 \pm 0.06^{\text{l–o}}$
	Ambient	8.95^{v}	$6.40 \pm 0.06^{\text{n–q}}$	$6.01 \pm 0.35^{\text{k–m}}$	$6.04 \pm 0.18^{\text{lmn}}$	$5.76 \pm 0.28^{\text{klm}}$
SP Tray + Flow wrap	Cold	8.95^{v}	$6.02 \pm 0.44^{\text{k–n}}$	$5.88 \pm 0.35^{\text{klm}}$	$5.79 \pm 0.53^{\text{klm}}$	$5.64 \pm 0.01^{\text{i–l}}$
	Ambient	8.95^{v}	$5.64 \pm 0.23^{\text{i–l}}$	$5.63 \pm 0.29^{\text{jkl}}$	$5.52 \pm 0.32^{\text{h–k}}$	$4.43 \pm 0.33^{\text{cde}}$
EPS Tray + Flow wrap	Cold	8.95^{v}	$7.33 \pm 0.07^{\text{tu}}$	$6.95 \pm 0.26^{\text{rst}}$	$6.87 \pm 0.39^{\text{q–t}}$	$5.22 \pm 0.58^{\text{g–j}}$
	Ambient	8.95^{v}	$6.05 \pm 0.13^{\text{lmn}}$	$4.98 \pm 0.06^{\text{fg}}$	$4.41 \pm 0.04^{\text{cde}}$	$4.26 \pm 0.32^{\text{bcd}}$
1 kg PP bag	Cold	8.95^{v}	$6.94 \pm 0.21^{\text{rst}}$	$6.19 \pm 0.03^{\text{m–p}}$	$5.16 \pm 0.13^{\text{ghi}}$	$3.96 \pm 0.07^{\text{bc}}$
	Ambient	8.95^{v}	$4.86 \pm 0.69^{\text{efg}}$	$4.79 \pm 0.05^{\text{efg}}$	$4.38 \pm 0.02^{\text{cde}}$	$3.87 \pm 0.11^{\text{b}}$
Unpackaged (Control)	Cold	8.95^{v}	$7.26 \pm 0.22^{\text{stu}}$	$6.82 \pm 0.30^{\text{qrs}}$	$5.07 \pm 0.11^{\text{gh}}$	$4.56 \pm 0.00^{\text{def}}$
	Ambient	8.95^{v}	$6.26 \pm 0.72^{\text{m–p}}$	$6.01 \pm 0.08^{\text{k–n}}$	$4.55 \pm 0.79^{\text{def}}$	$3.43 \pm 0.13^{\text{a}}$

Values are means of three replications ± standard deviation. Means followed by the same letter(s) within a column are not significant. Duncan's multiple range test ($p < 0.05$). SP = stamped paper tray: EPS = expandable polystyrene: PVC = polyvinyl chloride: PP = polypropylene.

4. Conclusions

Different packaging and storage conditions significantly influenced the quality attributes of the round 'Nema-Netta' tomato fruits. A shortened shelf-life and substantial quality changes were observed in all unpackaged tomatoes, while packaged tomatoes showed a reduced quality deterioration. Packaged tomatoes stored at cold storage conditions of (8–12 °C, 78–80%RH) maintained firmer fruits, a low PWL, a low increase in pH and decreasing TA, and the lowest decline of total sugars. The best treatment combination was the EPS Tray + PVC wrap under cold storage. This combination resulted in a low PWL of 1.78%, compared to unpackaged tomatoes, with the highest reduction in L* of 23.0%, a hue angle of 24.8% and a PWL of 11.9% between Day 0 and Day 28. The tomato samples in the EPS + PVC wrap resulted in the lowest changes in the firmness of 28%, compared to the highest firmness of 53.2% in unpackaged tomatoes under ambient storage conditions after the 28-day storage period. The highest increase in pH values of 10%, together with the highest decline in TA of 0.51%, was obtained in unpackaged samples under ambient storage conditions, whilst samples packaged in the EPS Tray + PVC wrap under cold storage conditions resulted in the lowest increase in pH values of 5.7% and a decline in TA of 25% after 28 days. The highest decrease in total sugars of 61.7% was obtained in the unpackaged tomato samples stored under ambient conditions, whilst samples packaged in the EPS Tray + PVC wrap under cold storage conditions resulted in the lowest decline in total sugars of 31.7% after 28 days. From the results of this experiment, it can be concluded that the EPS Tray + PVC wrap at cold storage conditions was the ideal packaging treatment beneficial for preserving the quality attributes of tomatoes by retarding the physiological and biochemical processes and therefore extending their shelf-life. The difference between the EPS Tray + PVC wrap and SP Tray + PVC wrap was less than 5% in multiple tests.

5. Recommendations

The observations of this study prove that differences in the construction of the packaging and cover result in the interplay of gaseous exchange (CO_2 and O_2) and water vapour, with minimal quality changes and losses. Packaging treatments with PVC wrap (the EPS and SP Tray + PVC wrap) were the most beneficial packages under cold storage conditions. Other factors are the permeable properties, thermal conductivity, absorption bands and water vapour transmission (WVTR) of the packaging which need to be explored. The literature has cited that non-biodegradable materials are less permeable than biodegradable cardboard or paper-based packages. Exploring WVTR would fortify the comparison of the EPS Tray and SP Tray packages. The respiration rate can be increased slightly by the movement of particles through porous spaces of the packaging. The study also requires extensive experimentation of polyphenols, ascorbic acid and individual phenols, as well as studies on the material properties, to provide more conclusive results.

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