RESEARCH ARTICLE

Hot peppers: vii. Efficacy of chemical preservatives on the quality and stability in red hot peppers (Capsicum chinensis L.)

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ABSTRACT

The Caribbean is the producer of some of the most pungent red hot peppers (Capsicum chinensis L.); however, the quality is affected by pre- and post-processing methods. This reduces several physiochemical quality parameters such as color stability and pungency in particular. A series of experiments were conducted to develop a Caribbean hot pepper visual color standard and the relative pungency of the fresh and processed products. In addition, studies were conducted to assess the effects of preserving agents and various pre-processing methods on color and pungency changes. The study has demonstrated that, from the wide selection of Caribbean hot peppers, there are potential varieties which have met the standards set by the American Spice Trade Association (ASTA) for red color pigmentation and pungency. Carvalho hot which is the second most pungent pepper cultivar (1.07mg capsaicinoids and 16,000,000 Scoville Heat Units) displayed no significant variation in Hue angle (13°-30°) and is similar to commercially graded paprika. The ASTA values for that pepper in acetic acid (377 ASTA units) and macerated state are similar to the bright red state (366 ASTA units) in the fresh mature hot fruit. The study found that Carvalho hot peppers can be used for industrial processing as mash, flakes, or powder without loss of color or pungency compared to all the other tested cultivars.

Key words: Capsaicinoids, capsanthin, colorimeter, freeze‑dried, pungency

INTRODUCTION

The Caribbean is recognized as the producers of some of the world’s most pungent red hot peppers (Capsicum chinensis L.). However, food processing enterprises are unable to capitalize on market demands due to variability and consistency in fruit quality in terms of pungency and color.¹⁵,³⁹ The culinary and ethnomedicinal value of red hot pepper increases the demand in the international market whether as fresh or dried, whole or ground powder, or as hot sauces and flavoring agents.²⁷ Fresh hot pepper fruits are rich in pigments, such as, chlorophylls, anthocyanins, and carotenoids and when dried could be transformed into red chili powder.⁴⁰ The carotenoids [Figure 1] give the red–orange color of peppers and may be any of the followings: capsanthin, capsorubin, zeaxanthin, lutein, cryptocapsin, and α- and β-carotene.²³,²⁸

Hot pepper quality is affected by thermal processing which reduces the physiochemical qualities of the final product particularly color and to a lesser extent pungency.⁴⁰ The pigment content increases as the fruit ripens.
Red hot peppers are traded as whole chilies, powder, or flakes based on color expressed in American Spice Trade Association (ASTA) color value. Developed by OAMSTA, however, such value-added products also experience similar quality issues with regard to color retention. Processed pepper as hot sauces and pepper mash encounter similar problems in addition to the subsequent loss of pungency due to microbial growth.

One method to alleviate the degradation in color is fermentation in peppers as in the “Tobasco” sauces. Observed chemical characteristics change during the aging process of pepper mash as the pectic substances are degraded.

The major issues in processing of red hot peppers are loss of color and pungency and microbial spoilage. This study was conducted to assess the red color stability and the retention of the pungency of selected Caribbean hot pepper processed products destined for the export trade.

### MATERIALS AND METHODS

A series of experiments were conducted in 4 separate studies during the period 2013–2018 at the Waterloo Research Center, University of Trinidad and Tobago. All varieties of hot peppers used in the study were cultivated in pots using soil as the growing medium. The crop was “fertigated” daily (2.0 kg/ha/200 L of water) with the recommended rates of N.P.K. nutrient mix (9:18:36) using a drip irrigation system as described previously by Bridgemohan et al. The peppers were harvested in the mature ripe stages, weighed and size sorted, and recorded for each tree. All trials were laid out as randomized block design with a minimum of 20 plants per treatment. The fruits were sanitized with 250 ppm sodium hypochlorite solution and air-dried before any treatment was applied as described previously by Minguez-Mosquera et al. and Mohamed and Bridgemohan.

- **Study 1: Developing a Caribbean hot pepper visual color standards**

Four varieties of hot peppers which are representative of the wide color spectrum of Caribbean hot peppers were selected to calibrate the color scheme and to set the standards for the quantification of colors for all other pepper fruits. The distinct colors and cultivars are described and correlated to the United States Food and Drug Administration (FDA) and the European Union (EU) food grade colors [Table 1].

The variations in capsanthin pigment were measured using the International Commission on Illumination (CIE) Lab color scale. The colors of the fresh and processed pepper
were determined using a Chroma Meter according to the Hunter’s Lab scale. The equipment used an internal Xenon light source and was calibrated against a white plate. The capsicum extractable color in the fresh hot peppers was determined according to ASTA analytical methods.[4,8]

**Study 2: Effects of preserving agents on color changes in fresh hot peppers**
The changes in color during preservation in acetic acid and ethanol were observed over an extended period. 100 g of mature fresh fruits of 11 hot pepper varieties which represent some of the world’s hottest peppers were sliced and placed in a glass bottle and topped with 100 ml of the solvents. Samples were stored in the laboratory at 20–22°C with normal room lights, for over 1000 days. Color changes were recorded every 6 months during the period and the final color change reported. The study was designed with 11 varieties in 2 solvents over 5 color changing intervals.

**Study 3: Effect of pre-processing methods on color retention in hot pepper products**
The 3 physical methods of the preparation of hot peppers used in this study were cutting/slicing, grinding, and chopping which were processed at room temperature, oven heated, or freeze-dried. The two cultivars of hot pepper (Chili and Carvalho hot) from Study 1 were selected as the former already has superior potential as a dry whole or powdered product and possessed the distinct red coloration required by the spice and condiment industries. It was an opportunity to explore the potential of this extremely pungent pepper for processing into flakes or powder. Heat drying was conducted in a convection air oven at 60°C for a minimum of 72 h or until initial constant weights were obtained. These were kept whole or later crushed into powder using a high-speed blender (Waring Commercial Heavy Duty Model: NSF- DO 54218). The freeze-dried flakes were undertaken with a Labconco® Freeze Dryer® (FreeZone 2.5 L Model: 117[A65312906]), and color retention was recorded at the fresh state at tri-monthly intervals (100 days) until 1000 days during storage.

**Study 4: Effects of preserving agents and capping on color retention**
Freshly harvested hot peppers cv. Carvalho were sanitized with 250 ppm sodium hypochlorite, air dried and blended with a food processor into a mash. Two (2) kg samples of the puree or mash were topped with 1 L of 2 different solutions which included acetic, citric acid, and ethanol. The preservative sodium benzoate (5 g) was added to both acetic and citric acids whereas the control had none.

The effect of a sealant or capping was conducted using 500 ml of vegetable oil and 100 g NaCl. The materials were placed on top of the mash with a wax paper layer separating in between to ensure no cross-contamination or mixing occurred. This was placed securely to ensure no air spaces in the mash. The experimental design was a completely randomized, with 3 sealant caps (oil, salt, and control) and 5 preserving treatment (acetic acid, citric acid, alcohol, and control with or without sodium benzoate). The jars were placed in a dark cupboard in an air conditioned laboratory and observed weekly. The color retention was conducted 300 days after the bottling process.

**Color standards**
In all studies, the surface color was determined using Hunter Lab (Hunter Lab – Lab Scan XE, Hunter Associates Laboratory Inc., Reston, VA, www. hunterlab.com), which includes lightness and chroma saturation.[22] Color measurements were based on the three-color coordinates, and the color space is in the form of cube with 3 axes [Table 2 and Plate 1]. The Hue angle (ho) for each

| Table 1: Pericarp color for various Caribbean fresh hot peppers |
|-------------------------------|------------------|
| Pepper cultivars | Pericarp color |
| Carvalho hot | Red |
| Chili and Scotch bonnet | Green |
| Scotch bonnet | Yellow |
| Congo | Brown |

| Table 2: Surface color determination based on Hunter Lab |
|-------------------|--------------|
| Code | Value | Color description |
| L* | 100 | Perfect reflecting diffuse |
| 0 | Black |
| a* | +a* | Red |
| -a* | Green |
| b* | +b* | Yellow |
| -b* | Blue |

Plate 1: CIELAB color scale
sample was also calculated as arctan b*/a*. All color values represent the average of three measurements. Color change of stored products was monitored during 6–36 months of storage.

Fruit color was obtained using a portable tristimulus Minolta Chroma Meter (Model CR-200, Minolta Corp, Ramesy, NJ). The meter was calibrated with a white standard (Minolta calibration plate CR-A43) and fruit chromaticity was measured in “L,” “a,” “b” coordinates. Color components “L” represents the value (lightness) of colors and is larger for lighter colors. Measurements were taken at three locations chosen at random on the top, middle and blossom end of the fruits.

**Total extractable and oleoresin extractable color**

The capsicum total extractable color and the oleoresin extractable color in the fresh hot peppers were conducted in accordance with ASTA analytical methods 21.3. Based on absorbance, 460 nm is used for quantifying the color of paprika and oleoresin spices. 100 mg of pepper powder of the four different colors was dissolved with 100 ml of acetone and left to stand for 2 min for the oleoresin extractable and 16 h for the total extractable and incubated at 25°C in the dark. The absorbance for both test samples was determined at 460 nm in UV-Vis dual beam spectrophotometer (Labomed, Inc., USA), and color expressed as ASTA units and Paprika Color Index.

**Pungency**

The capsaicin and dihydrocapsaicin were analyzed using the U3000 - high-performance liquid chromatography (HPLC) and the ODS-2 Beckmann column (250 mm × 4.6 mm; 5 µm). The solvent was filtered using reverse osmosis water and methanol (HPLC grade - BDH) at 60% methanol/ H₂O (0–2 min), 60–99% methanol/H₂O (2–6 min), 99% methanol/H₂O (6–8 min), and 99–60% methanol/ H₂O (8–10 min). The standard solutions were prepared from a stock solution of capsaicin and dihydrocapsaicin using six serial dilutions (0.50–0.5 µg/g) which exhibited a linear response for both the compounds. Each solution was injected 3 times and standard solutions were run on the HPLC, and the standard curves were generated by plotting peak area against concentration. The external calibration curves were found at r² = 0.9982 for capsaicin and r² = 0.9996 for dihydrocapsaicin, and the values of r² were highly significant confirming the good linearity of the method.

**Freeze drying**

The freeze dry flakes were processed using a Labconco Freeze Dryer. The Freeze Dryer parameters were 0.120 mbar vacuum pressure, ambient temperature, and a condenser temperature between −46 and −52°C. The pre-freezing sample time was at least 48 h, and freeze-drying time was approximately 3 days for complete dryness. The color retention was recorded at the fresh state and at tri-monthly intervals (100 days) until 1000 days.

**Vacuum sealing**

Vacuum packing was used to remove air from the package pepper samples (vacuum chamber pouch 5 cm × 30 cm) before sealing and to reduce atmospheric oxygen, thus inhibiting microbial growth and preventing the evaporation of volatile components. The Vacmaster VP210 Chamber machine was operated at PR = 0.0–−0.1 MPa (negative pressure), vacuum time at 23 s, sealing time at 1.8 s, and a cooling time at 3.2 s. The four selected colored peppers after vacuum sealed were stored in the chiller (4°C), freezer (−5°C), and the laboratory counter (25°C) and observed for color change and spoilage up to 60 days after treatment.

**Data analysis**

All experiments were laid out as completely randomized designs with three replicates as a minimum of 10 treatments per replicate. All data were subjected to generalize linear modeling using Minitab Statistical Software, and where necessary, variables were first subjected to log transformation and then analyzed. For all comparisons, significance was defined at P≤0.05.

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### Table 3: Computation formula for capsicum total and oleoresin extractable color expressed as ASTA units and the paprika color index

<table>
<thead>
<tr>
<th>Color analytical method</th>
<th>Calculation (ASTA 20.1)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total extractable</td>
<td>ASTA units = (\frac{\text{Absorbance at 460 nm}}{\text{Sample weight (g)}} \times 16.4)</td>
</tr>
<tr>
<td>Oleoresin extractable</td>
<td>ASTA units = (\frac{\text{Absorbance at 460 nm}}{\text{Sample weight (g)}} \times 16.4)</td>
</tr>
<tr>
<td>Paprika color index</td>
<td>(\text{PACI- paprika colour index} = \left(\frac{1000 \times a^<em>}{L + h^</em>}\right) \times \left[\ln(\text{ASTA units})\right])</td>
</tr>
</tbody>
</table>
RESULTS AND DISCUSSION

Caribbean hot pepper visual color standards
The visual color standards were based on the description of the four selected peppers with the appropriate FDA and EU codes [Table 4]. The qualitative descriptors of the four pepper colors spanned a wide spectrum from mature green, chocolate (brown), and yellow (orange), with shades of dark, light, and bright. Both the FDA and EU color codes were used to align the standards for the quantification of colors for all other peppers in subsequent studies [Plate 1].

The fresh hot pepper standards using the whole red fruits showed that the “L” value range displayed the wide spectrum of reflective diffusim. Thus, cv. Congo with “L” value of 29.43 depicted a brown pericarp, Freshly harvested hot peppers cv. Carvalho hot attained a value of 42.77. However, significant (P ≤ 0.05) differences existed for cv. Scotch Bonnet with mature green fruits showing “L” values of 51.29 and ripe yellow fruits with 62.91 [Tables 5 and 6]. That is, the low brown value was closer to the black, and the higher yellow value was closer to the whiter spectrum. The highest a* value (38.46) demonstrated the most redness Freshly harvested hot peppers cv. Carvalho. Similarly, the negative a* (−18.11) clearly described the green coloration (Chili and green Scotch bonnet), but the positive b* (56.23) confirmed the degree of the yellow pericarp coloration for ripe cv. Scotch bonnet [Table 6].

The Hue angle determined the color purity. The cv. Carvalho Hot had a hue angle of 34.4° with a red color intensity of 1644.9. Meanwhile, the ripe cv. Scotch bonnet had hue angle of 71° making it a close to deep yellow, while the cv. Chili with Hue angle of 120° as almost to pure green [Table 6]. Commercial paprika has a Hue angle of 0–45° and is usually described as red to orange.[11]

The total extractable color based on the absorbance (460 nm) ranged from 665.8 (green) to 1382.92 (brown) ASTA units [Table 7]. It showed that the carotenoid pigments for red coloration were higher than of commercial paprika (2151 ASTA units).[16] The color index for paprika (PACI) which is based on the CIELAB coordinates L*, a*and b* and h showed that surface color is not well correlated with extractable color but can be used to distinguish between sample groups of different ASTA units. The regression analysis (C5 = 221 + 0.0118 C4) was not significant and the Pearson correlation = 0.144, and P value = 0.85.

Although paprika has a dominant shade of cooler red, the quality indicator is the degree of yellowness (1653.12 ASTA units) in the red pepper [Table 7]. The typical ASTA color value for paprika is 2000 ASTA units and the IC color is 80,000 IC units.[20] In this study, the color red in cv. Carvalho hot was in excess of the ASTA standards. The color code standards developed for Caribbean red hot peppers are summarized hereunder.

Study 2: Effect of preserving agents in color changes in fresh hot peppers
The color changes of 11 cultivars some of the world’s hottest peppers stored in solutions of acetic acid and ethanol over an extending period of 6–36 months were evaluated [Table 8]. Both cvs. Trinidad Scorpion and Bhut Jolokia retained their reflecting diffuser capacity (L*) in both acetic acid and ethanol for red color, while the color in Scotch bonnet and Congo deteriorated in both solutions compared to their fresh state. The cvs. Habanero and 7-Pot peppers reflecting diffuser capacity were reduced when placed in ethanol as opposed to acetic acid.

All the peppers were bleached of their red pigmentation (a*) in both acetic acid and ethanol after 100 days and their value from the standard (a* = 38.4) compared to acetic acid (0.77) and ethanol (14.61). The red color of Carvalho hot (10.77) and 7-Pot (12.08) was reduced by 60% compared to the fresh samples and those treated with acetic acid. Ethanol had a
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There was a positive b value for yellow pigmentation (56.23) in the standard. The Scotch bonnet coloration was reduced to 8.42 and 14.36 for both acetic acid and ethanol, respectively. Scorpion and Bhut Jolokia both with red pericarps were able to maintain some degree (30%) of their original fresh state color in acetic acid [Plate 2].

Acetic acid or ethanoic acid (60 g/mol) is a monobasic weak acid that is found mainly in vinegar and used in the preservation for several fruits and vegetables, including pepper in hot sauces. Supposedly, it can assist in the retention of the color, flavor, and pungency of the pepper. Ethanol which is the simplest member of the alcohol family is used as organic solvents and is less acidic than ethanoic acid. It was expected that ethanol would exhibit a more bleaching effect on the pigments as observed by Mohammed et al.

Color may also be specified in connection with the grade, providing that 90% of peppers show the amount of the specified color. The Hue angle was determined for 9 red peppers in both acetic acid and ethanol. Of the red color peppers, only two peppers in acetic acid, namely Carvalho Hot (44.1°) and 7-Pot (32.20), maintained Hue angles similar to the fresh state (34.4°) close to the commercial paprika, taking into consideration that paprika coloration is due almost exclusively to the carotenoid fraction and perhaps small amounts of polyphenols. All others were completely bleached of their coloration in the alcohol [Table 8].

Pepper color retention after 60 days when vacuumed sealed is temperature dependent [Table 9]. Color retention of vacuum sealed pepper is notably effective (100%) when stored at freezing temperature of −16°C compared to fruits stored at

<table>
<thead>
<tr>
<th>Pericarp color</th>
<th>L*</th>
<th>a*</th>
<th>b*</th>
<th>Color intensity¹</th>
<th>Hue angle²</th>
</tr>
</thead>
<tbody>
<tr>
<td>Red</td>
<td>42.77</td>
<td>38.46</td>
<td>26.42</td>
<td>1644.9</td>
<td>34.4</td>
</tr>
<tr>
<td>Green</td>
<td>51.29</td>
<td>−18.11</td>
<td>32.54</td>
<td>−928.8</td>
<td>120.2</td>
</tr>
<tr>
<td>Yellow</td>
<td>62.91</td>
<td>18.57</td>
<td>56.23</td>
<td>1168.2</td>
<td>71.7</td>
</tr>
<tr>
<td>Brown</td>
<td>29.43</td>
<td>9.15</td>
<td>2.25</td>
<td>269.2</td>
<td>13.8</td>
</tr>
</tbody>
</table>

¹Color intensity: L x a*. ²Hue angle: (tan⁻¹ b*/a*)

<table>
<thead>
<tr>
<th>Pepper color</th>
<th>Oleoresin extractable color</th>
<th>Total extractable color</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Absorbance (460 nm)</td>
<td>ASTA units</td>
</tr>
<tr>
<td>Yellow</td>
<td>0.07</td>
<td>11.80</td>
</tr>
<tr>
<td>Green</td>
<td>0.02</td>
<td>4.75</td>
</tr>
<tr>
<td>Red</td>
<td>0.50</td>
<td>82.49</td>
</tr>
<tr>
<td>Brown</td>
<td>0.60</td>
<td>98.72</td>
</tr>
</tbody>
</table>

ASTA: American Spice Trade Association, PACI: Color index for paprika

Plate 2: Color standards of Caribbean hot peppers.
refrigerated temperatures (7–8°C). While the chlorophyll pigment in the green peppers did not retain color neither at refrigeration nor bench top or ambient temperatures [Table 10], only red peppers were able to retain color at bench top temperatures when vacuum sealed after 60 days.

The HPLC determination of pungency revealed that the capsaicinoids content of both Trinidad scorpion (2.08 mg) and Carvalho hot (1.07 mg) are considered as highly pungent, and the computed Scoville heat units (SHUs) were 32 and 16 million SHUs, respectively [Table 10].

### Study 3: Effect of pre-processing on color retention in hot pepper products

Both Chili and Carvalho hot peppers were selected for testing at the fresh green, ripe, and dried stages and also in the processed forms of flakes or powder. The results [Table 11] indicated that there were no changes in color from 100 to 1000 days after processing. However, there were observable visual changes from the fresh mature fruits to the processed states [Table 11]. The chili in the fresh and whole (aged) dry state maintained $L^* = 43–44$, but this was significantly decreased in the dry ($L^* = 29$) state.

### Table 9: Carvalho peppers oleoresin extractable color (2 min) and total extractable color (16 h)

<table>
<thead>
<tr>
<th>Sample</th>
<th>Oleoresin extractable color (@ 2 min)</th>
<th>Total extractable color (@ 16 h)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Absorbance (460 nm)</td>
<td>ASTA units</td>
</tr>
<tr>
<td>Ground paprika</td>
<td>0.146</td>
<td>23.944</td>
</tr>
<tr>
<td>Whole air-dried</td>
<td>0.037</td>
<td>6.068</td>
</tr>
<tr>
<td>Sliced air-dried</td>
<td>0.051</td>
<td>8.364</td>
</tr>
<tr>
<td>Freeze dried</td>
<td>0.109</td>
<td>17.876</td>
</tr>
<tr>
<td>Milled air-dried</td>
<td>0.116</td>
<td>19.024</td>
</tr>
<tr>
<td>x</td>
<td>0.0918</td>
<td>15.06</td>
</tr>
<tr>
<td>SE</td>
<td>0.0206</td>
<td>3.38</td>
</tr>
</tbody>
</table>

**ASTA:** American Spice Trade Association

### Table 10: CIEB for 12 Caribbean hot peppers in various solutions after 100 days

<table>
<thead>
<tr>
<th>Hot pepper varieties</th>
<th>Pericarp color (Capsaicinoid) mg</th>
<th>SHU$^1$</th>
<th>Acetic acid</th>
<th>Solution</th>
<th>Ethanol</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>L* a* b* Hue angle</td>
<td>PACI L* a* b* Hue angle</td>
<td>PACI$^2$</td>
</tr>
<tr>
<td>7- Pots</td>
<td>Red</td>
<td>1.09</td>
<td>16.3</td>
<td>35.0 12.0 7.6 32.2 377.1</td>
<td>40.5 5.3 17.0 72.5 204.64</td>
</tr>
<tr>
<td>Cayenne</td>
<td></td>
<td>37.5</td>
<td>7.2</td>
<td>73.8</td>
<td>129.5</td>
</tr>
<tr>
<td>Large bird pepper</td>
<td></td>
<td>0.14</td>
<td>2.1</td>
<td>32.3 13.4 3.9 16.3 432.8</td>
<td>34.6 16.1 7.4 24.7 491.39</td>
</tr>
<tr>
<td>Jalapeno</td>
<td></td>
<td>0.16</td>
<td>2.5</td>
<td>40.6 7.9 13.7 60.1 254.8</td>
<td>41.7 0.4 9.2 87.01 98.51</td>
</tr>
<tr>
<td>Habanero</td>
<td></td>
<td>0.35</td>
<td>5.3</td>
<td>33.8 14.6 6.3 23.4 455.0</td>
<td>39.8 0.9 7.0 81.9 106.83</td>
</tr>
<tr>
<td>Chilli</td>
<td></td>
<td>0.16</td>
<td>2.5</td>
<td>40.1 1.8 9.2 78.6 124.7</td>
<td>41.2 0.5 8.6 86.2 100.06</td>
</tr>
<tr>
<td>Carvalho hot</td>
<td></td>
<td>1.07</td>
<td>16.0</td>
<td>33.8 10.7 10.47 44.1 362.1</td>
<td>32.9 7.4 11.1 56.3 282.35</td>
</tr>
<tr>
<td>Trinidad Scorpion</td>
<td></td>
<td>2.08</td>
<td>31.2</td>
<td>43.2 1.8 14.0 82.5 125.1</td>
<td>42.7 0.7 8.4 84.9 102.50</td>
</tr>
<tr>
<td>Bhut Jolokia</td>
<td></td>
<td>0.51</td>
<td>7.7</td>
<td>46.9 0.7 11.7 86.2 102.6</td>
<td>44.9 0.7 11.8 86.2 103.59</td>
</tr>
<tr>
<td>Scotch bonnet Yellow</td>
<td></td>
<td>0.23</td>
<td>3.5</td>
<td>48.0 0.8 8.4 84.5 101.2</td>
<td>50.1 2.1 14.3 81.3 124.88</td>
</tr>
<tr>
<td>Congo Brown</td>
<td></td>
<td>38.0</td>
<td>8.2</td>
<td>75.5 131.0</td>
<td>36.9 1.2 5.6 77.1 112.00</td>
</tr>
<tr>
<td>x</td>
<td></td>
<td>0.643</td>
<td>0.62</td>
<td>39.0 7.75 9.75 377.12 37.45 4.51 9.75 71.68 183.5</td>
<td></td>
</tr>
<tr>
<td>se</td>
<td></td>
<td>0.219</td>
<td>1.60</td>
<td>1.68 0.93 7.89 2.96 6.00 1.26 0.926 6.00 37.9</td>
<td></td>
</tr>
</tbody>
</table>

$^1$SHU: Scoville Heat Units in ’000’000, $^2$PACI: Paprika color index
Carvalho hot in all the states maintained L* values similar to the fresh red state (42) but lost some of its lightness in the processed (30) mash. Chili kept its greenness (a* = −16.93) for long period (21 days) at chilled temperatures but became brown (a* = 5.4–16) after 400 days due to the drying. Carvalho maintained and retained a high level of redness (a* reduced from 38 to 25) over the 1200 days’ experimental period. However, in the mash form, this was significantly reduced (a* = 8.30) and appeared more brownish. All forms of the processed samples displayed the lower end of the yellow spectrum (b* = 4.9–15.2) [Table 11].

The ASTA paprika varied, color varied between 2154 and 2438 units, and the ICU International color varies between 86,186 and 97,538. The commercial paprika used in this study fell within this range. Total extractable color after 16 h indicated that Carvalho hot maintained its color both as freeze-dried and milled air-dried [Table 9].

In general, there were no significant changes in L*, a*, and b* from the fresh to freeze dry processed stage, and oven drying had a lighter color (L*), but blending into mash caused pigment degradation, resulting in a reduction in a* and b* values. However, the mash created over 50% loss in color.

### Table 11: Chilli and Carvalho pepper in flakes and powder

<table>
<thead>
<tr>
<th>Pepper</th>
<th>Thermal</th>
<th>Physical</th>
<th>Product</th>
<th>L*</th>
<th>a*</th>
<th>b*</th>
<th>Hue angle</th>
<th>PACI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chilli peppers</td>
<td>None</td>
<td>None</td>
<td>Fresh (green)</td>
<td>43.15</td>
<td>−16.93</td>
<td>27.34</td>
<td>58.23</td>
<td>450.5</td>
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<td></td>
<td>Heat</td>
<td>Cutting</td>
<td>Air-dried sliced</td>
<td>27.90</td>
<td>16.43</td>
<td>20.61</td>
<td>51.43</td>
<td>640.3</td>
</tr>
<tr>
<td></td>
<td>Heat</td>
<td>None</td>
<td>Whole (aged) dry</td>
<td>44.97</td>
<td>5.46</td>
<td>5.59</td>
<td>45.67</td>
<td>167.0</td>
</tr>
<tr>
<td></td>
<td>Heat</td>
<td>Grinding</td>
<td>Ground powder</td>
<td>46.98</td>
<td>15.09</td>
<td>17.18</td>
<td>48.70</td>
<td>369.9</td>
</tr>
<tr>
<td></td>
<td>freeze</td>
<td>Chopping</td>
<td>Freeze-dried flakes</td>
<td>44.22</td>
<td>15.35</td>
<td>7.76</td>
<td>44.93</td>
<td>488.2</td>
</tr>
<tr>
<td>Carvalho hot</td>
<td>Heat</td>
<td>Grinding</td>
<td>Ground powder</td>
<td>36.62</td>
<td>27.79</td>
<td>12.20</td>
<td>23.70</td>
<td>782.5</td>
</tr>
<tr>
<td></td>
<td>Heat</td>
<td>None</td>
<td>Whole (aged) dry</td>
<td>28.00</td>
<td>21.29</td>
<td>4.93</td>
<td>13.03</td>
<td>773.3</td>
</tr>
<tr>
<td></td>
<td>Heat</td>
<td>None</td>
<td>Air-dried sliced</td>
<td>36.62</td>
<td>27.79</td>
<td>12.20</td>
<td>23.70</td>
<td>782.5</td>
</tr>
<tr>
<td></td>
<td>Freeze</td>
<td>Chopping</td>
<td>Freeze-dried flakes</td>
<td>46.53</td>
<td>25.35</td>
<td>15.22</td>
<td>30.98</td>
<td>575.7</td>
</tr>
<tr>
<td></td>
<td>Heat</td>
<td>Grinding</td>
<td>Ground powder</td>
<td>44.22</td>
<td>25.35</td>
<td>6.76</td>
<td>14.93</td>
<td>588.2</td>
</tr>
<tr>
<td></td>
<td>X (SE+)</td>
<td></td>
<td></td>
<td>39.92</td>
<td>16.30</td>
<td>12.98</td>
<td>23.9</td>
<td>472</td>
</tr>
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</table>

### Table 12: Effects of preserving agents and capping on color retention

<table>
<thead>
<tr>
<th>Sealant cap</th>
<th>Preserving agent</th>
<th>L*</th>
<th>a*</th>
<th>b*</th>
<th>hue</th>
<th>PACI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oil</td>
<td>Acetic acid</td>
<td>31.83</td>
<td>11.79</td>
<td>6.54</td>
<td>29.01</td>
<td>399.42</td>
</tr>
<tr>
<td></td>
<td>Alcohol</td>
<td>33.46</td>
<td>10.03</td>
<td>6.10</td>
<td>31.30</td>
<td>331.06</td>
</tr>
<tr>
<td></td>
<td>Citric acid</td>
<td>36.16</td>
<td>7.69</td>
<td>13.48</td>
<td>60.29</td>
<td>272.96</td>
</tr>
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<td></td>
<td>Control</td>
<td>36.24</td>
<td>6.59</td>
<td>13.29</td>
<td>63.62</td>
<td>245.46</td>
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<td>Sodium benzoate</td>
<td>31.35</td>
<td>9.08</td>
<td>6.21</td>
<td>34.36</td>
<td>324.00</td>
</tr>
<tr>
<td>Salt</td>
<td>Acetic acid</td>
<td>33.43</td>
<td>5.63</td>
<td>6.16</td>
<td>47.57</td>
<td>215.98</td>
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<tr>
<td></td>
<td>Alcohol</td>
<td>31.09</td>
<td>8.44</td>
<td>5.82</td>
<td>34.58</td>
<td>306.05</td>
</tr>
<tr>
<td></td>
<td>Citric acid</td>
<td>31.50</td>
<td>10.36</td>
<td>6.49</td>
<td>32.06</td>
<td>360.95</td>
</tr>
<tr>
<td></td>
<td>Control</td>
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<td>6.31</td>
<td>6.35</td>
<td>45.18</td>
<td>238.32</td>
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<td>7.12</td>
<td>5.84</td>
<td>39.35</td>
<td>269.33</td>
</tr>
<tr>
<td>zero</td>
<td>Acetic acid</td>
<td>35.95</td>
<td>5.76</td>
<td>13.33</td>
<td>66.63</td>
<td>226.85</td>
</tr>
<tr>
<td></td>
<td>Alcohol</td>
<td>32.65</td>
<td>9.58</td>
<td>6.34</td>
<td>33.49</td>
<td>326.91</td>
</tr>
<tr>
<td></td>
<td>Citric acid</td>
<td>32.01</td>
<td>16.92</td>
<td>9.63</td>
<td>29.64</td>
<td>558.23</td>
</tr>
<tr>
<td></td>
<td>Control</td>
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<td>11.40</td>
<td>6.37</td>
<td>29.19</td>
<td>392.59</td>
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<tr>
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<td>Sodium benzoate</td>
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<td>8.85</td>
<td>5.15</td>
<td>30.19</td>
<td>335.89</td>
</tr>
<tr>
<td>X (SE)</td>
<td></td>
<td>33.2</td>
<td>7.8</td>
<td>8.7</td>
<td>29.01</td>
<td>399.42</td>
</tr>
</tbody>
</table>
and similarly, any processing or slicing resulted in significant color loss [Plate 3].

**Study 4: Effects of preserving agents and capping on color retention**

In this study, the fresh color pigmentation was recorded and the final color changes conducted after 1 year [Table 12]. It was observed that, regardless of the sealant, “L” value differences remained consistent [Table 12]. However, sodium benzoate-treated samples had approximately 25% reduction in “L” compared to the freshly harvested fruits. The oil cap in both the citric acid and control (L*=36) retained similar color intensity to the fresh state. Further, in all treatments, the level of redness as indicated by a* was reduced by > 75% and bordered on more brownish appearance with less red pigmentation probably due to oxidative reactions. On the b* axis, all the treatments were between 5 and 13 and were at a lower degree of yellow coloration hue associated with this axis.

There was an interaction between sealant and preserving solution in that oil x acetic acid and oil x sodium benzoate maintained Hue angles of 29° and 34°, respectively. Similarly, salt x citric acid and zero x sodium benzoate had Hue angles of 32° and 30°, respectively. Oil cap x acetic acid maintained the same coloration as the control for the entire duration of the study, unlike the control which did not as spoilage occurred much earlier. This treatment had no chemical additives/preservatives and did not exhibit any color change or pigment deterioration, i.e., no observable levels of microbial contamination or fermentation compared to salt and zero cap. This suggested that oil cap was more tightly fixed on the pure/mash resisted air contact suppressing the growth of that may resulted in aerobic microorganism [Plate 4 and 5].

Cho et al.[19] reported that fermentation did not affect the capsaicinoids in pepper mash stored in plastic and oak wood barrel. Significant color changes can occur in the fresh peppers during processing and storage, and color retention is an important criterion for pepper products and pungency. Consumers prefer the dark-colored pepper products because of the aging process induced by fermentation which intrically would result in a sauce with a desirable pH according to Bozurt and Erkmen.[13]

In commercial pepper sauce production, pasteurization of the mash and addition of 12–15% salt have promoted color enhancement.[13] In addition to heat treatment, it is accepted that lactic acid and oxygen are other important factors that would contribute to the attainment of color development.[13] Many factors affect pepper color change during storage, and the most important is oxidative degradation of carotenoids, caused by exposure to heat, light, and oxygen.[13,18,45]

Previous studies have shown that the main quality contributing factors to color and pungency are influenced by agronomic, insects and microorganisms, and postharvest practices. Mohammed et al.[32] Seyoum and Woldetsadik[41] demonstrated that post-processing and storage can result in major deterioration. Vacuum packaging can maintain quality for a relatively longer period and result in reduced
oxygen levels in sealed packages. The removal of air due to vacuum sealing caused the package to collapse around the product creating an anaerobic environment which eventually prevented the growth of mainly aerobic spoilage microorganisms responsible for off odor and texture changes.\cite{18,37}

**CONCLUSIONS**

This study has demonstrated that, from the wide selection of Caribbean hot peppers, there are potential varieties which have met the standards set by ASTA for red color and pungency. Carvalho hot which is the second most pungent pepper cultivar (1.07 mg capsaicinoids and 16 m SHU) has no significant variation in Hue angle (13–30°) and is similar to commercially graded paprika [Figure 2]. The ASTA values for it in acetic acid (377 ASTA units) and ground state are similar to the bright red state (366 ASTA units) in the fresh mature hot fruit. The pepper fruit can be used for industrial processing as mash, flakes, or powder without loss of color or pungency, thereby pinpointing a new avenue for investment.

Figure 2: Capsaicin and dihydrocapsaicin (µg/g) contents of the various hot peppers: (a) Trinidad scorpion, (b) chilli, (c) cherry, (d) Scotch Bonnet, (e) Carvalho hot, (f) Carvalho hot, (g) Kiri Kiri, (h) bird, (i) Bhut Jolokia, and (j) Seven pot peppers landrace using the high-performance liquid chromatography method.
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