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Effect of Storage Conditions on Rate of Color Degradation of Paprika based Products

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Abstract

The purpose of this study was to determine the effect of storage conditions on rate of color degradation of paprika based products. The study was conducted on 7 paprika, 3 chili pepper and 2 chili powder products commercially produced at Olam Spices and Vegetable Ingredients. All products were collected from the manufacturing location at Las Cruces, NM and stored in ziploc bags for up to 6 months at 4 different storage conditions, namely: 35°C/80% RH, room temperature ~ 22°C/45% RH, refrigerated temperature at 7°C and frozen temperature at -8°C. Representative samples were collected at Time 0, 2, 4, 6, 8, 12, 16, 20 and 24 weeks from each storage condition and analyzed for moisture and water activity (Aw), extractable color (ASTA) and surface color (Hunter L, a, b). Results showed that samples with ethoxyquin demonstrated a significantly lower extractable color loss than samples without ethoxyquin. Further, samples that had been irradiated demonstrated a significantly higher surface color loss than samples that had not been irradiated. Samples at high temperature – humidity storage degraded significantly rapidly compared to samples stored in room conditions. Refrigerated and freezer stored samples showed minimal extractable and visual color loss. This study provides significant information on storage stability of paprika based products during long term storage.

Keywords: Extractable color; Irradiation; Paprika

Abbreviations: ASTA: American Spice Trade Association; PACI : Paprika Color Index

Introduction

Dehydrated paprika *(Capsicum annuum)* based ground spice products can be divided into 3 major categories, namely: ground paprika, chili peppers and chili powders. These products are used in food applications throughout the world as natural food colorants or seasoning agents, due to their attractive color, unique sweet taste, flavor and pungency. Dehydrated paprika is mainly used for their extractable color (ASTA) and contains high ASTA paprika blended with ethoxyquin as an antioxidant to maintain desired ASTA levels. Chili peppers are mainly used for taste and flavor and mild to moderate heat and usually contain dehydrated paprika blended with ground cayenne red peppers or hot seed for providing heat and pungency. Chili powders are mainly used for direct applications on food, color and mild to moderate heat and usually contain chili peppers with added salt and blended with different dehydrated spices depending on the formulation.

The quality parameters of the stored dehydrated capsicum based products that are important to spice formulators are, in addition to microbiological status and absence of insect infestation, the retention of characteristic color, characteristic aroma, and content of capsaicinoids (pungency) [1,2]. Many factors such as cultivar, temperature of drying, oxygen/air atmosphere, temperature, and moisture content during storage affect the retention of color [3]. Typically products are stored and used between 6 months to 1 year from the date of manufacturing. Paprika being a seasonal raw material is dehydrated, ground and used in formulations typically in a 1 year cycle.

The red color intensity is considered the most important physical attribute for paprika. The red varieties of paprika are very rich sources of carotenoids, particularly capsanthin and capsorubin containing one and two keto groups, respectively. Qualitative and quantitative distribution of carotenoids in red paprika reveal that the red carotenoids (capsanthin, capsorubin, and cryptocapsin) are formed from the appropriate 5,6-epoxycarotenoids (antheraxanthin, violaxanthin, and cryptoxanthin 5,6-epoxide) [4]. In the traditional paprika dehydration processes, due to a prolonged exposure to heat, light, and oxygen, a 20–53% loss of the initial carotenoids and thereby the color of paprika has been reported [5]. Non-enzymatic browning is another cause of paprika color degradation. It has been found that the water activity and temperature had a significant effect on the non-enzymatic browning rate of dried red peppers during their storage [6]. Paprika is high in content of reducing sugars and amino acids so it is a good medium for Maillard reactions during its processing and storage of its products [7,8].

Ethoxyquin is used in the spice industry as an antioxidant to prevent carotenoid loss during postharvest handling and has been used since Lease and Lease and Chen and Gutmanis proved its effectiveness for color retention in stored dehydrated paprika [9,10]. The council of European communities developed directives regarding authorization of food additives throughout the community and ethoxyquin was not listed as an approved additive [11]. FDA has reported no scientific or medical evidence that ethoxyquin used at approved levels is injurious to human or animal health [12]. Paprika products in the US generally use ethoxyquin for maintaining color stability during storage.

Irradiation treatments have been used to reduce the microbiological load of dehydrated paprika and the effect of irradiation on color loss of paprika is unclear. Studies on red paprika with irradiation doses between 0 to 12.5 kGy showed no significant differences between the color properties of irradiated and non-irradiated samples [13]. However, another study suggested that higher irradiation doses and a

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longer storage period, resulted in a significant ($p<0.01$) reduction of all the carotenoids, except capsorubin [14].

Most studies conducted on dehydrated paprika based products have been conducted on different species of paprika and measuring the effect of heating parameters, microbial reduction treatments, storage conditions or added antioxidants on the color characteristics of paprika products. This study is significant because we have used products from a commercial facility and analyzed the effect of storage conditions on color and other parameters on these samples. This study would provide significant information on the color loss information on commercial paprika samples during long term storage. This information could be useful for specifying storage conditions and shelf life which can also be used for shipping products across different continents.

Materials and Methods

Sample preparation and storage

Twelve different product samples from 3 main product categories: 7 paprika, 3 peppers and 2 powders; were collected from our Las Cruces manufacturing plant and evaluated in this study. Approximately 6 lb of each product sample was collected in polyethylene bags and sent to Olam's Innovation and Quality center at Fresno, California. Before beginning the shelf life study, each 6 lb sample bag was opened and the product was divided into 4 polyethylene ziploc bags (~1.5 lb in each bag) for each product sample. Each individual ziploc bag was labeled and placed into another larger polyethylene bag, to provide dual layer protection simulating an inner and outer package used for commercial products. The larger bags were tied and placed in 4 different storage conditions (1 bag in each condition) for each product sample type. Ultimately ~ 1.5 lb of each product sample was stored in each storage condition. The storage conditions for this study included freezer temperature (-8°C and 45% RH), refrigerator temperature (7°C and 55% RH), room temperature (22°C and 45% RH) and elevated temperature (35°C and 80% RH).

Sample details

The main ingredients and treatment details for all the paprika, chili pepper and chili powder samples are listed in Table 1. The 7 paprika samples contained blends of different dehydrated paprika with different particle sizes and color, to meet our specifications. All 7 paprika products contained silicon dioxide as a flowing agent and all paprika samples except samples 2 and 6 contained ethoxyquin to preserve the red color. We specifically selected 2 samples of paprika without ethoxyquin, at different ASTA levels, to study the effect of ethoxyquin on preserving ASTA color. Paprika sample 3 was subjected to irradiation treatment of 12 – 15 kGy for microbial reduction purpose. The U.S. Food and Drug Administration irradiation dose limits for spices and seasonings is 30 kGy [15]. The 3 chili pepper samples contained a combination of paprika and ground red pepper (for heat) in different proportions, to meet our specifications. All chili pepper samples contained silicon dioxide as a flowing agent and ethoxyquin for color preservation. Chili pepper 2 was also subjected to irradiation treatment of 12 – 15 kGy for microbial reduction purpose. The 2 chili powder samples contained paprika, ground red pepper and spices (for flavor) in different proportions, to meet our specifications. Chili powder 1 contained ethoxyquin for color preservation whereas chili powder 2 did not contain ethoxyquin. None of the chili powder samples were irradiated for microbial reduction.

Sample ID	Ingredients	Ethoxyquin	Irradiation
Paprika 1	Paprika, SiO_2	Yes	No
Paprika 2	Paprika, SiO_2	No	No
Paprika 3	Paprika, SiO_2	Yes	Yes
Paprika 4	Paprika, SiO_2	Yes	No
Paprika 5	Paprika, SiO_2	Yes	No
Paprika 6	Paprika, SiO_2	No	No
Paprika 7	Paprika, SiO_2	Yes	No
Pepper 1	Paprika, ground red pepper, SiO_2	Yes	No
Pepper 2	Paprika, ground red pepper, SiO_2	Yes	Yes
Pepper 3	Paprika, ground red pepper, SiO_2	Yes	No
Powder 1	Paprika, ground red pepper, spice blend, SiO_2	Yes	No
Powder 2	Paprika, ground red pepper, spice blend, SiO_2	No	No

Table 1: Ingredients in paprika, chili pepper and chili powder blends used in shelf life study.

Testing protocol

All the products were tested for 4 parameters – moisture, water activity, extractable color (ASTA) and surface color (HUNTER) at each time point. Initially, the samples were tested for all the four parameters before they were placed in the respective storage conditions and the results were recorded as Day '0' data, considered as the initial data for the study. During the shelf life study, ~ 40 g sample each was collected for each of the 12 product samples from all 4 storage conditions and analyzed for the above parameters; throughout the study for 24 weeks. Hence, overall at each time point during the study, a total of 48 samples were analyzed, in duplicate, for all 4 testing parameters. For the first 8 weeks the samples were analyzed every 2 weeks and thereafter they were analyzed every 4 weeks up to 24 weeks. All the results were reported as the average of the duplicate readings.

Moisture

Moisture content for the samples was measured following ASTA 2.1 using vacuum oven method [16]. The samples were weighed (2.0 g - 3.0 g) and placed in the oven (Thermo Fisher Scientific Lindberg / Blue M Vacuum Ovens VO914, Thermo Fisher Scientific Inc., Asheville, NC, www.thermoscientific.com) which was pre-heated to 70°C and vacuum of 2 - 4 in Hg units. The samples were dried for 6 h and then were cooled to ambient temperature in a desiccator. The samples were then weighed to calculate the % moisture. The average of duplicate readings was used for each sample in each condition at each time point. The average of duplicate readings was used for each sample in each condition at each time point.

$$\% \, Moisture = [(initial\, wt. - final\, wt.)/initial\, wt.]\, X\, 100$$

Water activity (Aw)

The water activity for the samples was measured following ASTA 6.0 method using Aqua lab 4TE (Aqua lab by Decagon – Decagon Devices Inc., Pullman, WA, (www.decagon.com) [17]. The samples were measured before and during storage similar to other analyses mentioned earlier. The average of duplicate readings was used for each sample in each condition at each time point.

Extractable color

Extractable color was determined following ASTA 20.1, which is widely used by the spice industry for evaluation of color [18]. ~0.1 g was weighed and placed in an amber colored 100 ml volumetric flask and the volume was made up with acetone. The samples were left in the dark at room temperature for 16 h for color extraction and absorbance was measured using a spectrophotometer (Shimadzu Spectrophotometer UV – 1800, Kyoto, Japan, at 460 nm wavelength using the solvent acetone as blank. The results were reported in ASTA units following the procedure. The samples were analyzed before and during storage at regular time intervals as mentioned earlier. The average of duplicate readings was used for each sample in each condition at each time point.

$$ASTA\ Extractable\ Color = Absorbance\ at\ 460\ nm\ X\ 16.4/Sample\ weight\ (\mathrm{g})$$

Surface color or visual color

Surface color was determined using HunterLab (HunterLab – LabScan XE, Hunter Associates Laboratory Inc., Reston, VA, www.hunterlab.com), which includes lightness and chroma saturation. The samples were measured before and during storage, similar to extractable color as mentioned earlier. The Hunter L, a, b color space is a 3 dimensional rectangular color space based on the opponent - colors theory [19]. For the L value which is "L "(Lightness) axis, 0 value is black and 100 is regarded as white.

Similarly for "a" (red-green) axis, positive values are red, negative values are green and 0 is neutral. And for "b" (blue-yellow) axis, positive values are yellow, negative values are blue and 0 is neutral. Change in color over time was calculated as Delta E (Δ E), where "Δ E" was the total color difference and was used to compare any change in color over time. The average of duplicate readings was used for each sample in each condition at each time point.

$$\Delta E = \sqrt{\left(L_f - L_i\right)^2 + \left(a_f - a_i\right)^2 + (b_f - b_i)^2}$$

Where L_i, a_i and b_i were the initial (Day "0" values – before storage) hunter readings for L, a and b

L_f, a_f and b_f were the readings obtained each time the samples were analyzed.

Several other color parameters such as L X a values for color intensity, hue angle ($\tan^{-1}$ b/a) and PACI (paprika color index ie. (1000 * a*)/(L* + hue angle h) were also calculated and used in In our study we used L and a values instead of L* and a*.

Statistical analysis

The elevated and room temperature storage data was analyzed per product category (paprika, chili pepper, chili powder) in Microsoft Excel using Welch's two sample t-test with unequal variances to analyze difference of the population means between week 0 and week 24 data, to determine significant differences at 95% confidence interval ($p<0.05$, 2-tailed). The data was further analyzed for calculating correlation coefficients (Pearson's r) between various analytical parameters. Finally, the data was also analyzed to calculate rate constants for extractable color (ASTA) and Hunter values (L X a) for elevated and room temperature conditions, using first order reaction kinetics equation.

Results and Discussion

Refrigerated and freezer conditions

The results of our study indicated that there was minimal change observed in extractable color (ASTA) and Hunter L, a, b values in all the samples, when stored under refrigerated and freezer conditions for 6 months. Only paprika sample 6 (no ethoxyquin and high ASTA) showed ~ 30% loss in extractable color in refrigerated conditions. All other samples had <5% loss in extractable color and surface color (L × a) in refrigerated and freezer storage conditions. Overall, there was a slight decrease in moisture content and no major change in water activity in all samples stored in refrigerated and freezer conditions. The relative humidity (% RH) of refrigerator and freezer were 55% and 45% respectively and hence there was minimal absorption or desorption of water vapor in these conditions, resulting in stable moisture and water activity results.

Researchers suggest that a sharp change in the rate of color loss is observed at 15°C: the value Q_{10} (°C) changes from 1.62 to 2.82 when the temperature rises above 15°C [20]. Other researchers also suggest that evolution of carotenoid content indicated that autoxidative reactions are minimal and that coloring capacity is maintained when paprika samples are stored under controlled storage (4°C and 70% RH) [21]. Studies have shown that the enzyme extracted carotenoid pigments from orange peel, sweet potato and carrot samples were first freeze dried and stored at different temperatures. These samples suffered minimal pigment loss at 4°C and maximum loss was observed at 40°C and freeze drying lowered pigment loss for all samples under all conditions [22]. Hence, all of our results and discussion in this section will mainly focus on changes in analytical parameters in elevated and room temperature storage.

Elevated and room temperature conditions

In general, there was an increase in moisture and water activity in all samples upon storage in elevated conditions (35°C, 80% RH). At room temperature (~22°C, 45% RH), all samples generally showed a decrease in moisture and water activity, mainly attributed to desorption of moisture from the products. Our main focus in the rest of the results section will be mainly on extractable color loss (ASTA) and surface color loss (Hunter).

Hunter color parameters L, a, and b values were used to calculate L X a and Paprika Color Index (PACI) results which are referred in some of the results discussed in this section. Studies conducted on heating of different paprika samples for different times between 100° - 150°C suggest that the Hunter a value is related to carotenoid content decreasing with heat degradation of carotenoids; the decrease in L value is a function of the logarithm of percent increase in browning compounds [23]. It is also suggested that both *a* and *L* values decrease with time of heating (increasing changes of color), and hence the authors suggest that it may be appropriate to use a X L value to indicate color quality that provides an expanded scale. A new color index for paprika (PACI) is proposed based on the CIELAB coordinates L* (lightness), a* (red-blue), and h (hue angle), and it is calculated as "1000a*/(L*+h)". This new index shows a high correlation with the logarithm of extractable color (r=0.9662) and is able to distinguish between sample groups of different ASTA units [24]. In our study, we calculated PACI by using L and a values instead of L* and a* values and compared correlations with Ln (ASTA) for different samples. We found that for elevated storage conditions, the average correlation coefficient ("r") between PACI and Ln (ASTA) values for the 7 paprika samples was 0.98, for the 3 chili pepper samples was 0.99 and for the 2 chili powders was 0.99, which were very similar to the values reported by other researchers.

Welch's t-test for mean comparison at 0 and 24 weeks

The Welch's two sample t-test results assuming unequal variances, 2 – tailed (Table 2) indicated that for the 7 paprika samples combined, there was significant difference ($p<0.05$) between week 0 and week 24 data for extractable color (ASTA) and Hunter L X a values when data was analyzed combining observations for elevated and room

	ASTA			L X a		
Sample Type	**EL + RT**	**EL**	**RT**	**EL + RT**	**EL**	**RT**
Paprika	*	*	NS	*	*	NS
Pepper	NS	NS	NS	NS	NS	NS
Powder	*	NS	NS	NS	NS	NS

t-Test: Two-sample assuming unequal variances
$p<0.05$, Two-tail
*=significant, there are significant differences between week 0 and week 24
NS=non-significant, there are no significant differences between week 0 and 24
Where, EL + RT=combined data from elevated and room temperature storage, EL=elevated storage
conditions only, RT=room temperature storage only

Table 2: Welch's two sample t-test data analysis for differences in mean values for ASTA and L X a between week 0 and week 24 data.

temperature conditions and also for elevated conditions analyzed individually. There was no significant difference in ASTA and L X a value between week 0 and week 24 at room temperature storage. Researchers have shown that the color change of red pepper powder was greatly dependent on temperature and Aw and that as temperature and Aw increased, red color of pepper powder increasingly faded out to become brown and tarnish black, which is mainly attributed to the degradation of carotenoid pigments and development of browning compounds [25].

There was also no significant difference between week 0 and week 24 data for ASTA and L X a value for the 3 pepper samples combined, at elevated and room temperature storage. For the 2 powder samples combined, there was significant difference in week 0 and week 24 data when data was analyzed by combining observations in elevated and room temperature storage, but no significant difference when data in both conditions was analyzed separately. We believe a lot of the non-significance in the elevated conditions for the chili pepper and chili powder samples for ASTA and L X a has to do with the low sample size, attributing to low degrees of freedom (df).

Correlation between analytical parameters

The elevated and room temperature data was further analyzed to observe for correlation coefficients (Pearson's r) between various analytical treatments for paprika, chili peppers and chili powders (Tables 3a-3c). Across the 7 paprika, 3 chili pepper and 2 chili powder samples, combining all of the elevated and room temperature conditions data over 24 weeks, a significant positive correlation ($r>0.8$) was noted between moisture and water activity. The Pearson r values for paprika for correlation between moisture and water activity were 0.921 for paprika, 0.846 for chili pepper and 0.917 for chili powder samples. Also, a significant negative correlation ($r<-0.8$) was noted between ASTA and hue angle values. The Pearson r values for these parameters were -0.947 for paprika, -0.982 for chili pepper and -0.945 for chili powder samples. These correlations are highlighted by * in columns in the Table 3. Also, for individual sample categories, we noticed a few other significant ($r>0.8$) positive and negative correlations.

Rate constants calculations for elevated and room temperature conditions

ASTA and L X a value data for elevated and room temperature storage conditions was analyzed to calculate rate constants of degradation using first-order kinetics, using the equation:

$$\ln[C_t/C_0] = -kt$$

Where, C_0 = initial value of ASTA or L X a

C_t = value of ASTA or L X a at time "t"

t = time in weeks

k = rate constant in week^{-1}

The k-values were calculated over 24 weeks storage at elevated and room temperature conditions and a ratio was calculated by dividing the k-value under elevated conditions with the k value under room temperature conditions. These results are shown in Table 4.

Based on Table 4, higher ratios would indicate that the rate of degradation is high in elevated conditions and rate of degradation is low in room temperature conditions. Lower ratios would indicate that the rate of degradation is high in both storage conditions. Based on this analysis, we found the samples without ethoxyquin (paprika 2, paprika 6 and powder 2) to have low ratios for extractable color (ASTA) analysis, since the extractable color (ASTA) degradation is high in these samples even in room temperature storage. Also, powder 1 has a lower ratio, because this powder despite containing ethoxyquin had very low moisture content and it has been shown that ASTA degradation tends to be higher at lower moisture content. It has been shown that for ground paprika samples stored under ambient temperature (19 –24°C) and humidity (24–42%) storage for 4 months, samples with 6 or 9% pre-storage moisture content showed higher ASTA color loss compared to samples with 15 or 18% pre-storage moisture content [26]. Researchers have also further shown that a 3% increase in moisture content, caused a decrease in hue angle with more clean red color and a decrease in L values, resulting in a darker color [27].

Table 3a: Paprika

Paprika Samples						
	ASTA	**Moisture**	**Aw**	**L X a**	**Delta E**	**Hue Angle**
ASTA	**X**	-0.469	-0.323	0.087	-0.393	(-) 0.947 *
Moisture		**X**	0.921*	-0.086	0.683	0.558
Aw			**X**	-0.925	0.730	0.423
L X a				**X**	-0.683	-0.230
Delta E					**X**	0.332
Hue Angle						**X**

Table 3b: Chili Pepper

Chili Pepper Samples						
	ASTA	**Moisture**	**Aw**	**L X a**	**Delta E**	**Hue Angle**
ASTA	**X**	-0.825	-0.569	-0.436	-0.634	(-) 0.982 *
Moisture		**X**	0.846*	-0.067	0.853	0.825
Aw			**X**	-0.0393	0.911	0.561
L X a				**X**	-0.352	0.397
Delta E					**X**	0.678
Hue Angle						**X**

Table 3c: Chili Powder

Chili Powder Samples						
	ASTA	**Moisture**	**Aw**	**L X a**	**Delta E**	**Hue Angle**
ASTA	**X**	-0.867	-0.900	0.848	-0.632	(-) 0.945 *
Moisture		**X**	0.917 *	-0.993	0.469	0.844
Aw			**X**	-0.890	0.665	0.791
L X a				**X**	-0.397	-0.852
Delta E					**X**	0.457
Hue Angle						**X**

*indicates significant ($r>0.8$) positive or negative correlation between parameters across all 3 product categories

Table 3: Correlation coefficients (Pearson r) between analytical parameters combining elevated and room temperature data for various product categories.

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Rate constants for ASTA and L X a values in elevated and room temperature conditions						
	ASTA EL - k	**ASTA RT - k**		**L X a EL - k**	**L X a RT - k**	
Sample ID	**value**	**value**	**Ratio**	**value**	**value**	**Ratio**
Paprika 1	0.0103	0.0031	3.31	0.0180	0.0009	19.77
Paprika 2-no ethoxyquin	**0.0209**	**0.0085**	**2.47**	0.0232	0.0014	16.10
Paprika 3-irradiation	0.0186	0.0044	4.19	**0.0324**	**0.0035**	**9.18**
Paprika 4	0.0100	0.0018	5.49	0.0187	0.0011	16.44
Paprika 5	0.0182	0.0049	3.75	0.0169	-0.0003	-65.63
Paprika 6-no ethoxyquin	**0.0307**	**0.0263**	**1.17**	0.0225	0.0018	12.73
Paprika 7	0.0112	0.0038	2.96	0.0219	0.0015	15.05
Pepper 1	0.0144	0.0049	2.94	0.0162	0.0005	33.63
Pepper 2-irradiation	0.0174	0.0036	4.79	**0.0302**	**0.0034**	**8.98**
Pepper 3	0.0136	0.0043	3.21	0.0217	0.0006	38.37
Powder 1	**0.0399**	**0.0237**	**1.69**	0.0119	0.0003	44.49
Powder 2-no ethoxyquin	**0.0356**	**0.0280**	**1.27**	0.0165	0.0007	22.86

Important k-value discussed in results section are highlighted in **"bold font"**

Table 4: Rate constants for ASTA and L X a value in elevated and room temperature conditions for different product types.

Furthermore, for the Hunter L X a value analysis, we found the irradiated samples (paprika 3 and pepper 2) to have lower ratios, because these samples would degrade at a higher rate in both elevated and room storage conditions. These particular findings are highlighted in **"bold font"** in the table.

The rate constants also allow us to predict the rate of degradation of extractable color (ASTA) values and Hunter L X a values in samples at room temperature compared to elevated conditions. The paprika samples for ASTA values, the samples containing ethoxyquin will degrade 3.94 times slower at room temperature than at elevated conditions, compared to 1.82 times slower at room temperature than at elevated conditions for non ethoxyquin containing samples. Researchers have shown that after 4 months storage at ambient temperature, the control treatment lost 63% of the initial extractable color, the d-tocopherol treated samples lost 32%, and the ethoxyquin treated paprika sample lost 6% color from their original value. The pepper samples for ASTA values would degrade 3.65 times slower at room temperature than at elevated conditions and powder samples at 1.48 times slower at room temperature than at elevated conditions. This proves that added ethoxyquin provides significant color protection to paprika based products at elevated and room temperature storage, similar to data shared by other researchers. The effect of ethoxyquin on preservation of ASTA color in same sample (with same starting ASTA) but with and without ethoxyquin is shown in Figure 1. The figure clearly indicates that in the sample set containing no ethoxyquin (blue line – elevated or green line – room temperature) the loss of ASTA values are significantly higher than in the same sample set containing ethoxyquin (red line – elevated or purple line – room temperature).

In the case of Hunter L X a value, for paprika samples, the irradiated sample would degrade 9.18 times slower at room temperature than at elevated temperature. The non-irradiated samples would degrade ~ 16.02 times slower at room temperature compared to elevated temperature. For pepper samples, for L X a value, the irradiated sample would degrade at 8.98 time slower rate at room temperature than elevated temperature. The non-irradiated samples would degrade at 36 time slower rate at room temperature compared to elevated temperature. This proves that irradiation treatment negatively affects the surface color (Hunter values) and increases the rate of degradation of paprika based products and that irradiation treatment provides energy to activate the color degradation reaction at a faster rate in both elevated and room temperature storage conditions. Researchers

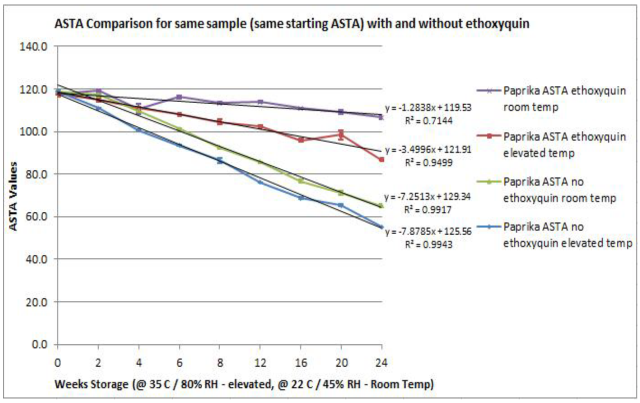

Figure 1: Extractable color (ASTA) comparison for same sample with and without ethoxyquin inelevated and room temperature conditions.

have similarly reported carotenoid degradation including capsanthin and other yellow pigments with irradiation treatment at 10 kGy dose. Interestingly, irradiation treatment did not have a major effect on extractable (ASTA) color.

These ratios provide us with excellent information for future studies in this area and would help in saving considerable time conducting shelf life studies for new products for the industry. We could potentially conduct a quick shelf life study in elevated conditions and based on sample type, we could use these degradation rate constants to predict the shelf life at room temperature and other storage conditions, without having to complete the entire study at the lower storage temperatures.

Conclusion

This study shows that there was minimal extractable color (ASTA) and visual (Hunter) color loss in all 12 samples when stored at refrigerated and frozen conditions. There is a significant color loss for most samples for both color parameters when stored in elevated conditions. There was also a good correlation achieved between moisture and water activity and ASTA and hue angle measurements for all 12 samples under elevated and room temperature storage. Finally, there is a low rate constant ratio between elevated and room temperature conditions for ASTA measurements in samples not containing ethoxyquin, indicating a high loss of ASTA value even at room temperature conditions. There was also a low rate constant ratio between elevated and room temperature conditions for L X a measurements in samples that had been subjected to irradiation treatment, indicating a higher loss L X a values even at room temperature conditions.

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