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Phenolic-chemical constituents, physical and color characteristics of pomegranates *(Punica granatum L.)* native to Jordan at full ripening stage: A comparative study

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Abstract - *The Punica granatum L. is interesting for different functional properties and high volumes of production. This work aims to compare the phenolic- chemical and physical parameters of two important commercial varieties of pomegranate. The fruits were collected from Abu Ziyad and Kafer Sawm valleys at the ripening stage. Chemical, spectrophotometric and colorimetric analyses were carried out. The properties evaluated shown significant differences (p≤0,5). The pomegranates from Kafer Sawm had a larger diameter (98,6 mm), sphericity (0,98), and arils juice yield (60,94%) with the low thickness of the rind (2,71mm). Its flavor presented more acidity (1,3%), less sweetness (15,8% Brix), and more redness. The concentration of phenolic compounds (TPC 454 mg GAE / 100 g), antioxidant activity (61,7%) and vitamin C content (10,15 mg / 100g) were also higher in Kafer Sawm samples. Its intense red hue, expressed in the "a" and "C" coordinates, is positively related to anthocyanin content. Where the redness records high values of the redness coordinate "a" (39,03 to 41,55) and Chroma "C" (42,22 to 42,72) and the anthocyanins content achieve about 402,5 mg as Cyannidine 3 glucoside / 100g). The content of total polyphenols (TPC) decreased when the maturity index increased. Exist inherence of color between arils and rinds, demonstrated by the anthocyanin content due to the osmotic-diffusional migration of the soluble compounds. The pomegranates from Kafer Sawm had a higher content of phenolic compounds and can be considered a better antioxidant source with higher functional abilities*.

Keywords: *Anthocyanins, antioxidant capacity, CIELab, flavonoids, total phenols.*

I. INTRODUCTION

Jordan, officially named "The Hashemite Kingdom of Jordan," is an Asian country located in the Middle East region influenced by the currents that come from the Mediterranean Sea; it presents a characteristic climate of the Mediterranean zone's countries. More than 90% of Jordan territories belong to arid and semiarid climates [1]. The absence of agricultural areas has turned Jordan into a net importer of foods; however, it is a net exporter for a reduced group of vegetables and fruits. Abu Ziyad valley is one of the perennial stream side valleys that flow from the east to west. "Abu Ziyad" valley begins at the west of "Der Abu Said" city and discharge to Jordan river with a length of about 8 km (Fig.1).

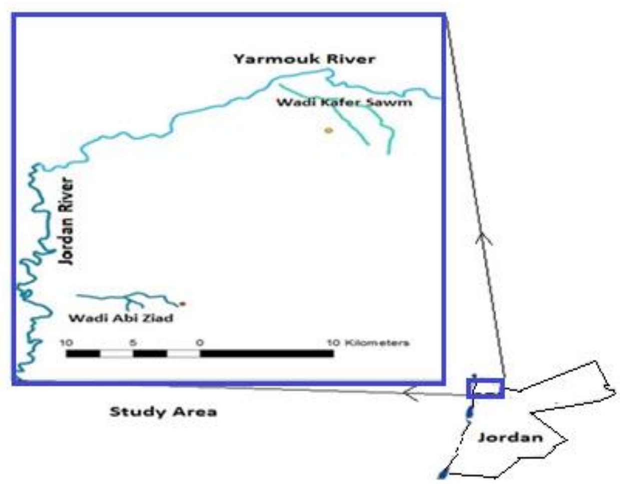

Fig.1: Location of Abu Ziyad and Kafer Sawm valleys in the Jordan map.

The valley of Kafer Sawm is located northwest of Jordan and discharges to Yarmouk River, representing the natural part of northern Jordan borders with Syria (Fig.1). It has an elevation of 300-400 m above sea level. Abu Ziyad valley (Fig.1) mostly form part of the rift valley depression where it has an elevation ranges between 0 to 100 m below sea level. Wadi Abu Ziyad's main temperatures are normally higher than that of Kafer Sawm valley because of the elevation difference. Both areas belong to a semiarid climate, with an average annual rainfall ranging from 350 – 300 millimeters for Abu Ziyad and 400-500 millimeters for Kafer Sawm Valley. One of the valleys' main crops is the pomegranate fruit, with high commercial, agricultural, and social importance for local communities.

Pomegranate is a fruit native to the Middle East. Its growing consumption popularity is due to its high functional properties, defining as "functional" those qualities that make a portion of food have a potentially positive effect on health beyond basic nutrition [2,3].

The pomegranate, in addition to being one of the fruits with the highest local demand for the human health reasons aforementioned, also would represent a potential economic value to the market due to the rise in crop production and consumption as the fresh, processed product (juice, jams, concentrate, etc.), or new forms of processing called "minimally processed" [4]. The production of this fruit has been increasing significantly in recent years. In this sense, the Jordanian Ministry of Agriculture reports a continued increase in pomegranate production in 2016, 2017, and 2018 from 12000, 16000 to 21000 tons respectively, with projection to a probable rise in the coming years [5].

Some Clinical investigations are testing treatments using arils, rind, seeds, or a mixture of these fruit fractions, corroborating pomegranate's properties as a medicinal plant. Nowadays, this fruit is being used to treat arteriosclerosis, and it is the subject of continuous research for its possible anti-carcinogenic, anti-microbial, and antiviral properties [6]. It is also known that some pomegranate compounds such as punicalagin and ellagic, gallic, oleanolic, ursolic, and uallic acid have anti-diabetic action. Some of its biological effects on the human body include regulating gene expression and the activity of various enzymes, depending on factors such as the type of phenolic compound, absorption, and metabolism [7].

Ascorbic acid is a compound of pomegranate with great antioxidant power that the human body cannot synthesize; for this reason, this is taken from vegetables and fruits. This acts as an active antioxidant in oxidation and reduction reactions, associating ascorbic acid content to the antioxidant capacity of fruits and vegetables [8].

Phenolic compounds of the pomegranate are responsible for these functional properties and recognized health benefits, among which are: Total Phenolic compounds (TPC), Anthocyanins, Condensed Tannins (Proanthocyanidins), Flavonoids. The percentage of Antioxidant capacity measures the potential antioxidant benefits.

The *Total Phenolic (TPC)* are antioxidant organic compounds, with variable molecular structures, which contain at least one phenol group, and an aromatic ring linked to a hydroxyl group.

The *Anthocyanins* are water-soluble pigments that belong to the flavonoids, being part of the polyphenols group. They are glycosides of anthocyanins. More precisely, it is an aglycone (anthocyanidin molecule) linked to a sugar by means of a glycosidic bond. They are responsible for the coloration of leaves, flowers, and fruits.

The *Condensed Tannins* or *Proanthocyanidins* are polymeric molecules of flavonoids, with non-nitrogenous structures, soluble in water and insoluble in alcohol or organic solvents. They produce characteristic odor in plants acting as a defense against herbivores and produce a slight degree of astringency and bitterness.

Color is the result of chemical, biochemical, physical, and even microbial processes during the growth, maturity-ripening stage, and post-harvest handling of the fruit. It is considered a quality attribute that contributes to consumer acceptability, which joined sweetness, acidity, aroma, and size.

As far as is known, there is no literature available about the comparative study of the characteristics of the pomegranates of the ”Abu Ziyad" and "Kafer Sawm" valleys presented in this work. Hence, our study's objectives are focused on identifying and comparing the main quality attributes, which determine consumer acceptance, evaluated by phenolic-chemical parameters and physical; briefly analyzing its aptitudes for fresh and processed consumption. Furthermore, the color characteristics of the pomegranate have not been extensively analyzed in this type of study. For this reason, it is taken into account within the physical parameters studied in this investigation.

II. MATERIALS AND METHODS

The fruit samples belong to the Abu Ziyad and Kafer Sawm valleys, located in Jordan, Alkura District / Irbid Governorate. The fruits were harvested at the full ripening stage because the most optimal consumption conditions appear at this stage: sweetness, softness, aril color, and juice yield. The samples' selection was made at random, considering general quality criteria such as size, color, and discarding defective samples due to burns, cuts, cracks, or bruises. They were subsequently stored at 4ºC during transport and storage until the time of analysis. The rind, arils, and juice of arils were removed manually, carrying out each test by triplicate.

Physical characterization.

The samples were individually weighed by a precision electronic 0,001g scale (Metler model AE100, range 0,01-500g). Vernier digital precision 0,001 caliper determined the equatorial diameter, latitudinal length and rind thick. The moisture content was determined by constant drying at 60ºC and reduced pressure (under vacuum conditions). The variant of adding sand to obtain a larger surface area for moisture release from the arils AOAC method 20.013 [9].

The real density was calculated from the relationship between weight and volume obtained using the displaced volume of toluene as the reference liquid.

The sphericity (ε) of the fruit was quantified by the method followed by Pérez (2004) [2]. Values of sphericity (ε) close to one indicate that pomegranate samples reach a likable spherical shape. This physical property is measured, taking into account three different diameters (a, b, c). Where c is the longest length diameter, and ε is calculated using the eq. $\varepsilon=(a.b.c)^{1/2}/c$ (1).

Determination of the color of fraction rind and arils juice.

A Minolta model CR-410 colorimeter measured the color of the rind samples. Measurements were made at four different points on the rind samples. According to the CIELab system (name established by the International Commission of L'eclairage), the color was assigned, which uses cartesian coordinates" L, a, b" to calculate the color in a space. Space where the parameter "a" moves between green and red, determining +a degree of redness and -a the degree of greenness. The parameter "b" moves between blue and yellow where the -b coordinate indicates the degree of blueness and +b the degree of yellowness. The luminosity "L" represents the degree of clarity of the sample, moving between L = 0 (black, maximum darkness) and L = 100 (white, maximum clarity). Chroma" C" describes the intensity or purity of the color (maximum saturation level) and the dullness of the color (minimum saturation level), showed in Fig.2. Chroma" C" is calculated by the eq.: $C=(a2+b2)1/2$ (2)

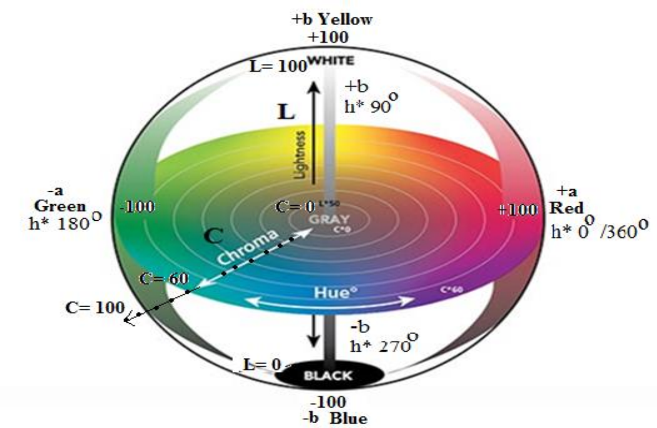

Fig. 2: CIELab and CIELCh systems illustrated simultaneously on Cartesian and polar space. Modified after: https://www.xrite.com/blog/tolerancing-part-3

The polar coordinates CIELCh uses chroma"C" also considered in the CIELab system, and calculated by Eq. 1. Further, CIELCh includes the hue angle h* or color shadiness, which describes the predominant color which an observer perceives. This is calculated by the following equation: $h^*=\arctan(b/a)$ (3).
Where 0º=red-purple, 90º=yellow, 180º=bluish-green and 270oblue [10]. The distribution of the coordinates CIELab and CIELCh are illustrated in Fig.2.

The color of the arils juice was determined by spectrophotometry (mass spectrometry (LC-MS/MS)), using the method provided by Eaton et al. (1995) [11] for liquid samples. This method quantifies the color coordinates in the X, Y, and Z space using equations 4, 5, and 6, using the transmittance measurements at selected wavelengths [12].
$X=0,03269.\sum Tx$ (4), $Y=0,03333.\sum Ty$ (5), $Z=0,03938.\sum Tz$ (6)
The coordinates X, Y, Z, were transformed to "L, a,b" coordinates by the equations:

$L=116.(Y/Yn)^{1/3}-16$ (7), $a=500.[(X/Xn)^{1/3}-(Y/Yn)^{1/3}]$ (8), $b=200.[(Y/Yn)^{1/3}-(Z/Zn)^{1/3}]$ (9)
These expressions, Xn, Yn, and Zn, represent the Illuminati "C" tristimulus, which has values of Xn=98,0681; Yn=100 and Zn=118,2313 [12].
The parameter of the difference of color (ΔE) is calculated using the CIELab coordinates by the equation:
$\Delta E = (\Delta L^2 + \Delta a^2 + \Delta b^2)^{1/2}$ (10)

Statistical analysis.

Three replicates were taken from each sample, and the results were used for statistical analysis. The values were reported as mean ± SD for all variables presented. The regression analysis and Pearson's correlation coefficients were calculated by the SPSS program to relate the color coordinates (a, C) and anthocyanins content. Values of differences $p < 0,5$ were considered significant.

Chemical –phenolic characterization.

Samples of arils juice were characterized in the following parameters:

Total titratable acidity (TTA) was expressed as % citric acid, and the official method AOAC 942.15 [13] was followed. It was carried out by acid-base titration with 0,1N sodium hydroxide. Simultaneously, potentiometric titration and pH determination were carried out using an Ingold U402-57 / 120 electrode with a sensitivity of 0,01. Total titratable acidity was calculated using the equation shown below, where VNaOH is the volume expressed in milliliters and the sample mass m in grams.
$\%TTA=V_{NaOH} .N_{NaOH}.192.100/(3m.1000)$ (11)

The total soluble solids (TSS) of arils juice were measured using a refractometer ABBE Carl Zeiss model 89553. Results were reported as Brix degrees at 25ºC.

The maturity index (MI) is the result of the relation degrees Brix and TTA calculate for the following equation:
$MI= \%Brix/ (TTA)$. (12)

The Ascorbic acid (vitamin C) content was determined following the official AOAC 967.21 method [14]. It was carried out by volumetric titration with 2,6-Dichloroindophenol. The indicator was standardized with a standard solution of L-ascorbic acid 750ppm (ac. L-ascorbic with metaphosphoric acid H_3PO, conc. 5%). The results were reported as mg. Ascorbic acid / 100 grams of sample.

The concentration of total polyphenols (TPC) was determined by applying the Folin-Ciocalteu method [15], reporting the mg results. Gallic acid (GAE) / 100g sample. This method is based on the treatment of diluted samples of the arils juice with the Folin-Ciocalteu reagent and aliquots of 20% sodium carbonate solution, with subsequent measurement of the absorbances at 765 nm.

The total flavonoid content of the arils extract was quantified using the method proposed by Shams et al. (2011) [6], which is based on the chelation technique with AlCl3.

The samples diluted are treated with reagents of NaNO2 (5%), $AlCl_3$(10%), and NaOH (1M), subsequently was measured the absorbance at 510nm. The results are expressed as mg. Catechin / g. dry extract.

Anthocyanins' concentration was evaluated, quantifying the predominant anthocyanin in these pomegranate varieties, cyanidine 3-glucoside, which produce the ripe's reddish characteristic color fruit. For this purpose, the official method AOAC 2005.02 [16] was followed. The difference in the absorbance of the pigments at 520 nm is proportional to the pigment concentration. Each diluted sample was treated with pH 1,0 buffer sol. (potassium chloride, 0.025M) and pH 4,5 buffer sol. (sodium acetate, 0.4M) and the absorbance was determined at 520 and 700 nm wavelength. The results were expressed as mg cyanidine 3-glucoside / 100g sample, respectively.

The condensed tannins, also called Proanthocyanidin, are quantified using the Bate-Smith assay [17]. Using this technique, the sample is diluted and treated with reagents of HCl (37%) and ethanol (95%). Subsequently, it carried out to heating by water bath and resting in the dark, to finally measure its absorbance at 550nm. The results were reported as mg. catechin/gram of sample.

The antioxidant capacity was evaluated by the method described by Moon and Terao (1988) [18]. This method measures the spectrometric absorbance at 517 nm (A517nm), referred to as a standard at the same length wave. The equation for calculating the %antioxidant capacity (AA) is:

%AA=(1-[Asample 517nm/Astandard517nm]).100 (13)

III. RESULTS AND DISCUSSION

Physical characterization.

The two fresh pomegranate fruits were analyzed at the full ripening stage (140 days after fruit set or after full bloom). The fruit samples of Lot 1 (variety" pale arils") and Lot 2 (variety "intense red arils") belong to the zones of "Abu Ziyad" and "Kafer Sawm," respectively.

The t-student statistical method was used to check the significant differences P <0,05. The results found between the two varieties of pomegranate revealed that the properties showed significant differences. The physical analysis of the two varieties of fruit at the ripening stage is presented in Table 1.

Physical analysis recorded large diameters, characteristic of the fruits of the advanced stage of maturity; high values of the mass of arils, and more than 50% juice yield in both varieties. In this sense, the highest values of the physical properties were for samples of Lot 2, presenting averages D=98,60mm; %marils=65,42 y %Rjuice:60,94%. The sphericity values (ε) reported for Lot 2 were closer to one than Lot 1, indicating a more spherical shape for fruits of this variety.

Table 1: Averages the physical analysis of pomegranate varieties at the "full ripening" stage.

Parameters	Lot 1 (pale arils) "Abu Ziyad"	Lot 2 (red arils) "Kafer Sawm"
Equatorial diameter (mm)	90,41±0,72	98,60±3,44
Latitudinal length (mm)	82,03±0,81	96,76±2,10
Sphericity (ε)	0,91±0,72	0,98±0,61
Rind thickness (mm)	2,95±1,04	2,71±0,84
Pomegranate mass (g)	295,09±2.03	314,09±9,89
% Mass of arils	61,23±1,71	65,42±0,81
%Mass of rind	38,77±2,24	34,58±1,06
% Arils moisture	86,54±1,83	88,75±2,02
% Rind moisture	70,36±0,98	68,38±1,5
%Yield arils juice	55,67±2,5	60,94±1,02
% Seeds	9,21±0,47	10,12±0,96
ρpomegranate(g/cm3)	0,934±0,021	0,940-1,058
ρarils(g/cm3)	1,098±0,013	1,178±0,01

**Three replicates for each sample were represented as mean ± standard deviation*

The results of moisture content for the arils fraction, were higher for Lot 2 (% H = 88,75%, massarils=65,42%) than Lot 1 (% H = 86,54%, massarils=% 61,23). The increase of arils mass, moisture content, and consequently yield juice is probably due to the water-sugars transferred by the diffusional osmotic mechanism through the fruit membranes' interior to reach the maximum sweetness, juiciness, and growth of arils at the full ripening stage [19]. Furthermore, the moisture content of the rind and being affected by the variety of cultivar and maturity stage are also influenced by post-harvest stress factors such as degree of dehydration, storage, local customs, mechanical damage during handling, etc.

The lowest values of thick rind and highest % seeds recorded were for the samples of Lot 2 (thick rind=2,71 mm and % seed=10,12%), finding a clear inverse relationship between "thick rind" and "% seeds" in both lots. This correlation is corroborated for Pearson's coefficients close to one, in concordance with the results obtained for Pérez (2004) [2] and Gozlekei et al. (2011) [20] for oranges variety "Valencia Late " and "Turkish pomegranate," respectively.

Chemical- phenolic evaluation.

The sweetness is a clear parameter of "optimal quality," reaching maximum levels at the fruit's full ripening stage. This is expressed by the content of total soluble solids (TSS) measured in degrees Brix. The Maturity Index (MI) gradually increases across all maturity stages together with sweetness (TSS) until it achieves the maximum values at the ripe fruit stage. The pH and titrable acidity (TTA) are two relevant properties for the conservation of fresh fruits, lightly or minimally processed. Low values of pH and TTA contribute greatly to the stability of the product. The results of the chemical-phenolic analysis are presented in Table 2.

Table 2: Chemical-phenolic parameters of pomegranate varieties at "full ripening" stage.

Properties	Lot 1 (pale arils) "Abu Ziyad"	Lot 2 (red arils) "Kafer Sawm"
TSS	16,8±0,10	15,8±0,3
TTA	1,1±0,04	1,8±0,01
MI	15,27±1,10	12,24±0,87
pH	3,8±0,02	3,14±0,01
Condensed tannins (ppm catechine)	3324,76±0,48	4842,18±0,41
Anthocyanins(mg cyannidine-3-glucosyde)/100g	12,41±0,18	402,25±0,27
%AA	48,85±0,29	61,07±0,42
Ascorbic acid content (mg/100g)	9,08±0,44	15,15±0,50
TPC(mg Gallic acid./100 g)	251±2,30	453,87±2,1
Total flavonoids (mg Catechine/g)	0,40±0,49	0,94 ±0,11

**Results were the averages of three replicates and represented as mean ± standard deviation.*

In our study of two varieties of pomegranate, the levels of total soluble solids (TSS) and maturity index (MI) was highest for the "pale arils variety" of Lot 1 (16,8 oBrix MI=15,27). These results demonstrated that the ripe fruit's paleness color was not correlated with its high-value MI, existing absence of the red hue characteristics of the ripening stage. Instead of this, the high MI at the ripening stage was successfully identified by the increasing of the measurements TSS (sweetness), pH, and decreasing of acidity (TTA) (Fig.3). The decreasing TTA levels are explained by changes in the content of malic and citric acids, which have been identified as the main acids in pomegranate fruits, similar to the results reported for Labbe et al. (2016) [21]. The high values of MI for Lot 1 did not explain the "paleness" of its arils, probably justified by the type of cultivars and growing conditions; for this reason, in this study, MI is considered an "estimative quality indicator." The results lead to think that there is not necessarily a relationship between the color of the ripe fruit, generally identified by redness hue at maturity stage; sweetness, and MI. This conclusion is also corroborated by the results for Lot2, which showed low MI and TSS values for samples of arils with intense red color. Fawole et al. (2011) [19] and Martinez et al. (2006) [22]; conducted research about "Spanish Pomegranate" cultivars, classifying sweetness under the following criteria: MI = 5-7 sour, MI: 17-24 sour-sweet, MI = 31-98 sweet. According to this scale, the samples of the two lots would fall into the range of sour-sweet. Other authors as Chace et al. (1981) [23]; have reported that pomegranate fruits are suitable for fresh consumption market when they present TTA lower than 1,8% and MI ranged from 7 to 12; considering fruits very tasty and pleasant when they have an MI between 11 to 16. Under these last criteria, two lots would fall into the classification of "very pleasant taste for the consumer."

Fig.3: Maturity Index (MI), titrable acidity (TTA), soluble solids(TSS), and pH of pomegranate juice at full ripening.

In this research, the samples from Lot 2 reported highest values of *Ascorbic acid* (%Asc. ac.=15,15mg / 100g), *Antioxidant Activity* (%AA=61,07%) and the *Total Polyphenols* (TPC=453,87 mg. Ac. Gallic/100 g). These results suggest that high levels of ascorbic acid are associated with high levels of antioxidant capacity and TPC (Fig. 4a) and demonstrate that the pomegranate of Lot 2 (Kafer Sawm) is a potential source of antioxidants.

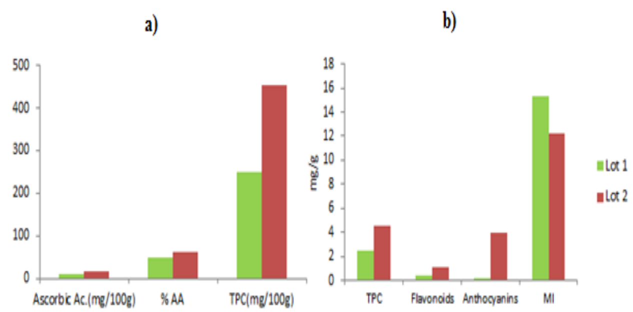

Fig.4: Ascorbic acid, %AA, MI, and TPC of pomegranate juice at full ripening.

Probably, this correlation occurs because functional similarities exist between them. Ascorbic acid acts as an active antioxidant in oxidation and reduction reactions. Associating ascorbic acid content to the antioxidant capacity of fruits, stimulating each other, and then creating metabolites that increase the TPC levels [8]. The decreasing of TPC content with the increasing MI (Fig. 4b) is probably due to oxidation a portion of the TPC by polyphenol oxidase enzyme at the fruit maturation stage [24]. Furthermore, the decreasing TPC levels, due to participation of TPC in the biosynthesis mechanism of flavylium anthocyanin ring at maturation stage, with the consequent reduction of TPC levels in concordance with Kulkarni and Aradhya (2005) [8].

Anthocyanin content contributes directly to the appearance of color, with the tendency to increase with Maturity index (MI) Radunic et al. (2015) [25]. The lowest values of anthocyanin and TPC contents were recorded for Lot 1 (variety “pale arils”), even when it showed highest MI (anthocyanins = 12,41 mg cyannidine 3 glucosyde / 100g ; TPC = 251,0 mg Gallic ac. / 100g ; and MI = 15,27). The results of “maturity index” and” anthocyanin content” presented an inverse correlation for Lot 1 and Lot 2 (Fig. 4b); even if, Radunic et al. (2015) [25] say that this correlation is direct. It concluded that the relationship between “anthocyanin content” and “MI” is specific for each variety of pomegranates. Additionally, this investigation found that exists a direct correlation between “anthocyanin content” and “TPC” (Fig. 4b); and between “the anthocyanins” and the color parameters “+a” and “C” -which expresses the redness hue of the arils-, shown in the Fig. 5c.

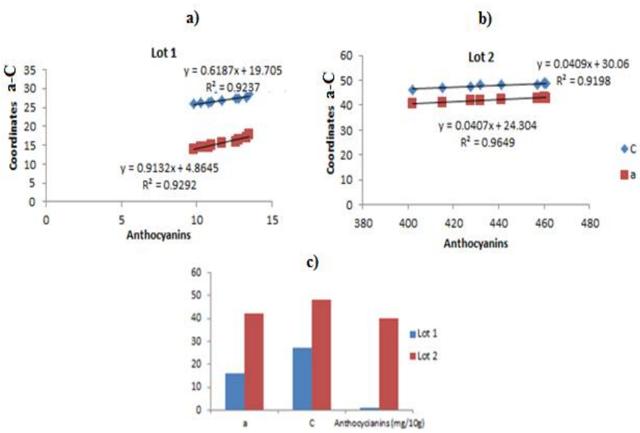

Fig.5: Correlation between color coordinates *C, a,* and Anthocyanins content of arils juice at full ripening.

The *Condensed Tannins* content produces a slight degree of astringency and bitterness in the fruits. In this sense, the samples of Lot 1, with the highest maturity index MI = 15,2, presented a low concentration of total tannins=3324,76 ppm. The contrary was the results of Lot 2 with values MI = 12,24 and total tannins= 4842,18 ppm, finding an inverse tendency between MI and tannins totals levels for both lots in concordance with previous works [25, 26]. It occurs probably because the tannins content and astringency decrease along the maturation period until to achieve the ripening stage improves the flavor and organoleptic properties of the ripe fruit, which is synonymous with good sensory quality.

The *flavonoids content* was lower for Lot1 (MI = 15,27; Flavonoids 0,40 mg. Catechine / 100g; TPC = 251 mg Gallic ac. / 100g) than Lot 2 (MI = 12,24 Flavonoids = 0,94 mg Catechine / 100g and TPC = 453,87 mg ac. Gallic / 100g). The results revealed a direct correlation between the contents of flavonoids, anthocyanins, and TPC, denoting an inverse correlation between MI and flavonoids levels during the ripening and maturity stages (Fig. 4b). The decreasing of the "flavonoids levels " observed maybe because the structure of the flavonoid as” (o) condensed tannin" is synthesized as anthocyanins, through an increase in enzymatic activity as anthocyanins synthase (AS) and 3-glycosyl transferase (3GT) until achieving the ripening stage [21, 27].

Analysis of the physical parameter of color.

The high content of anthocyanins at the ripening and maturity stage affects the characteristic color of the fruits. The color attribute is one of the most influence on the visual quality of fresh fruit consumption. It was measured from the CIELab (Cartesian coordinates) perspective and CIELCh (polar coordinates) systems for each lot. The results are presented in Table 3.

Table 3: CIELAB and CIELCH average coordinates for pomegranate varieties represented in the color diagram of Fig.6

Coordinate	Lot 1 (Type “pale arils”)		Lot 2 (Type “red arils”)	
	Arils juice	Rind	Arils juice	Rind
L	72,1 ± 1,10	75,4 ± 1,07	58,16 ± 0,91	57,70 ± 1,16
a	16,01 ± 0,30	22,12 ± 0,63	42,05 ± 0,17	39,03 ± 0,43
b	22,00 ± 0,71	25,02 ± 0,47	9,96 ± 0,64	16,09 ± 0,52
C	27,21 ± 0,18	33,1 ± 0,60	48,12 ± 0,22	41,22 ± 0,55
h	53,97 ± 1,30	48,07 ± 0,90	12,58 ± 1,05	22,4 ± 0,79
ΔE	31,97 between arils L1-L2		41,99 between rinds L1-L2	

* *Four measurements for every three replicates of each sample were represented as mean ± standard deviation*

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Analyzing the results of the CIELab Cartesian coordinates for “*aril juice*", it is observed that the “+ a” coordinate increases, while “+ b” and “L” decrease, existing an inverse relation between them. The values of “+a” were highest for Lot 2, which analyzed together with the results of “+b” and “C” coordinates are interpreted as colors redder, less yellow, and darker than pomegranates of Lot 1. This color evaluation by the CIELab system (Fig.6) is in concordance with the high levels of anthocyanins (Fig.5c) and the visual qualification of color for the red arils of the pomegranates of Lot 2 (Fig. 7).

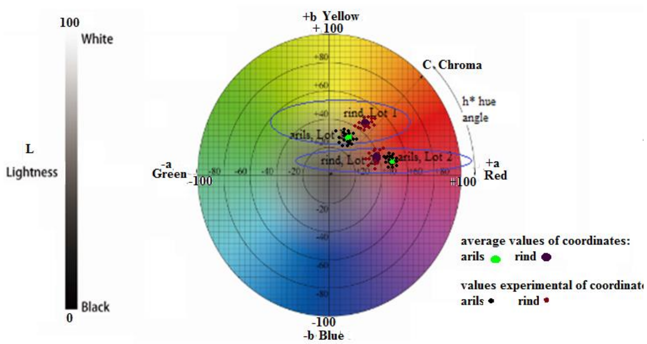

Fig. 6: Coordinates CIELab and CIELCh of arils juice and rind represented in the Color diagram.

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Polar coordinates CIELCh use Chroma "C"- which indicates purity or intensity of color- and the hue angle "h*(color shadiness) - which indicates the predominant color in the color space-.

Fig. 7: Variety of pomegranates from Abu Ziyad (a) and Kafer Sawm valleys (b).

This parameter h * mathematically is defined as measuring the angle concerning the "+ an" axis (Fig. 2). Concerning measure Chroma "C," it increases with consequent reduction of hue “h*,” deducing an inverse correlation between “C" and “h*” for arils and rind of both lots. So, lot 2 presented the lowest values “h*, locating the color samples on the “red area” of the color plane, and its high values "C" indicate more intense red color (purest red color) compared to the” hue pale pink ” for samples of Lot 1. In general, the rising values of “+ a” and “C” coordinates for aril, and rind fraction would indicate that the “increasing of the red hue” is associated with high anthocyanins content (Fig. 5c). This direct correlation between “+ a” and “C” coordinates and anthocyanins content is verified for Pearson’s correlation factors close to one, shown in Fig. 5a-b.

The average results of CIELab and CIELCh coordinates obtained for aril and rind fractions were simultaneously carried out to the Cartesian and polar planes of color. The color points drop at the same location using the two systems, as shown the Fig. 6. It proves that either system can be used to quantify the color parameter. The color found in the CIELab and CIELCh diagram was in concordance with the visually perceived color for the observer for each lot's pomegranate samples (Fig. 7). However, it is known that the advantage of the CIELCh over the CIELab system is it can be easily correlated with "previous systems" based on physical samples, such as the Munsell Color [28].

The parameter ΔE evaluated the total color difference numerically between the two lots, which is perceived “qualitatively” to the observer's first instance. The ΔE values obtained were upper than 3, which would quantify the high color difference between the pomegranates of the two lots as "very different," in concordance with Pankaj et al.(2013) [29] and Adekunte et al. (2010) [30], who classified the color difference ΔE as very different ΔE> 3; different 1,5<ΔE <3 and small difference 1,5 <ΔE.

The location and closeness of the experimental points of CIELab and CIELCh coordinate in the color diagram for aril juice and rind of the same variety of pomegranates (Fig. 6), lead to conclude that exist an interaction between the chemical components of arils and rind fractions because most of the phenolic compounds are exchanged through the porous structure of the arils and rind. Considering also, much of the phenolic constituents are transferred from the pomegranate rind to the arils juice during pressing and mechanical extraction [21].

The low values of “anthocyanins content,” “a” and “C” coordinates justify the paleness of arils (absence of redness hue) for the pomegranate Lot 1(Abu Ziyad cultivars), even though it presented the highest maturity index. Although the genotype plays a role, this phenomenon might be produced due to the rareness of negative or very cold temperatures in the production areas of Abu Ziyad, necessary to stimulate the synthesis of anthocyanins. These results obtained are similar to the presented for Spanish pomegranate from cold zones of Mollar-Elche [31, 10] and different to the results presented for Schwartz et al. (2009) [24]. This apparent contradiction between the results leads to the interpretation that the relationship between color and temperature is specific for each pomegranate.

The high averages of alkalinity recorded in Abu Ziyad's soils (pH~8,5) probably influence the arils color. Monomeric anthocyanin pigments reversibly change color with a pH change; the colored oxonium form exists at pH 1.0. The colorless hemiketal form predominates at pH 4,5, and the yellowish hue of anthocyanin pigments appear to pH bigger than 7 [16, 32]. According to this principle, pomegranate's color might be affected due to the presence of yellowish anthocyanin pigments characteristics to high pH levels, such as the case of Abu Ziyad’s soils (Fig. 7a).

IV. CONCLUSIONS

The results of the physicochemical properties lead to demonstrate that the pomegranates from Kafer Sawm ("red arils variety") had a higher content of antioxidants compounds than the pomegranate from Abu Ziyad ("pale arils variety"). Its high levels of anthocyanins reflect its high levels of anthocyanins, TPC, ascorbic acid, antioxidant capacity, and intense red color of arils. From the point of view of the color evaluation CIELab and CIELCh, exist a clear difference of color between the rinds and arils of "Abu Ziyad" and "Kafer Sawm "pomegranates, expressed by the parameter $\Delta E > 3$. Kafer Sawm pomegranates' high antioxidant power was related to the highest values of "+ a" and "C" coordinates, founding a direct correlation between these parameters. Instead, the hue angle "h*" presented an inverse correlation with "+ a" and "C" coordinates. These research results lead to conclude that "Kafer Sawm" pomegranates can be considered a better source of antioxidants with higher functional abilities than "Abu Ziyad pomegranates." The inverse relationship found between the high-sized diameters, juice yield, and low rind thickness of "Kafer Sawm" pomegranates makes this variety a profitable source of raw material for industrial processing. For pomegranates from Abu Ziyad, its high MI, sweetness, low levels of tannin and acidity, make this variety of pomegranate suitable for fresh consumption, with the color's disadvantage. The "pale" color of the arils is justified by the ripe fruit's low anthocyanin content. The genetic factor plays an important role in the pomegranates' color, founding this research that the relationship between "color of fruit - the temperature of production zone" is specific for various pomegranates. This research of physical properties revealed that the thickness of rind at the ripening stage showed an inverse correlation with arils mass, percentage of seeds, and arils moisture. Additionally, exist an inherence of color between arils and their respective rinds, denoted for the closeness of color coordinates "+ a," "C" and "b" of the arils and rinds in the color diagram and demonstrated by values of Pearson's coefficients close to one. Finally, the "ripening stage" is more successfully defined by the high content of soluble solids (Brix), low content of acidity, and total tannins rather than by the concentration of anthocyanins.

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