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EVALUATION OF POSTHARVEST MATURITY INDICES OF COMMERCIAL AVOCADO VARIETIES GROWN AT VARIOUS ELEVATIONS ALONG LEBANON'S COAST

by
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ABSTRACT
OF THE THESIS OF

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Title: Evaluation of Postharvest Maturity Indices of Commercial Avocado Varieties Grown at Various Elevations Along Lebanon's Coast

Avocado is known to be a climacteric fruit that must be harvested during the suitable physiological maturity stage to achieve the best edible characteristics and reach the required export standards. It is very hard to visually determine the optimum maturity phases in the different avocado varieties for harvesting especially because of the limited changes in the external fruit morphology during the maturity phase and because the harvest season is extended throughout several months. Therefore, some laboratory analyses are very crucial to deermine the best timing to harvest the fruit. The aim of this study is to evaluate the postharvest maturity indices over 3 harvest stages, mainly dry matter (DM), oil content (OC), fruit firmness, titratable acidity (TA), total soluble solids (TSS/Brix) and fruit weight in commercial avocado varieties in regard of different altitudes and agricultural practices. The varieties in this study were: Hass, Lambhass, Ettinger, Fuerte, Pinkerton, Reed and Horshim growing at different altitudes that range from 50 m to 400 m in 7 different regions in Lebanon. Statistical comparison of maturity indices under different locations by variety and harvest stage was performed using one way ANOVA as well as by principal component analysis (PCA). The results showed a high linear correlation between DM and OC over the different harvest stages. During the late harvest stage, the weight showed a negative correlation with fruit firmness and TSS. The minimum oil content % and dry matter % were recorded for Reed variety (8.2 DM% and 9.7 OC%) and the highest oil content % and dry matter % were recorded for Fuerte variety (28.5 DM% and 21.6 OC%). The data obtained during this study is used to achieve the best edible characteristics and export standards of commercial avocado varieties growing along the Lebanese coast.

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ABBREVIATIONS

Dry matter (DM)
Oil content (OC)
Titratable Acidity (TA)
Total Soluble Solids (TSS)
Gram (g)
Kilo gram force (KgF)
Percent (%)
Shelf life (SL)
Room Temperature (RT)
Degrees (°C)
Ansar (AN)
Mrwaniyeh (MR)
Nmeiriyeh (NM)
Abbasiyeh (ABB)
Kfar Hay (KH)
Markabta (MA)
Halba (HA)
Fuerte (FU)
Pinkerton (PI)
Reed (RE)
Hass (HA)
Lambhass (LH)
Ettinger (ET)
Horshim (HO)

This thesis is devoted to my parents, Mr. and Mrs. Salameh, my sisters, Ola and Sana, and my sweetheart, Arkan Chaya.

CHAPTER I

INTRODUCTION

Avocado (Persea Americana) is a climacteric fruit that can ripen even while still attached to the tree. It needs to be harvested when reaching the physiological maturity stage. The maturity stage of avocado is not morphologically observed on the fruits. Thus, to ensure good quality for local and export markets, studies should be intensively done to standardize the maturity of each avocado variety.

The Lebanese avocado industry is currently expanding with an estimated production of 7000 tons of fruit from an estimated planted area of 1200 hectares. Due to ongoing investments in this sector, production is expected to exceed 10,000 tons. Most of this output is consumed locally, with only 20% exported, primarily to Gulph countries. If the industry wants to develop export markets or exploit premium prices in domestic markets by extending the supply season, then more stringent maturity standards will be required.

Avocado fruit can be of three different horticultural races; the Mexican, the Guatemalan and the West Indian race. Many avocado cultivars that exist today resulted from the hybridization among these avocado races such as Fuerte, Hass, and Pinkerton. (Olarewaju, 2014). Noting that the avocado strain decides the flowering time of avocado trees.

Avocado is also known as the Alligator pear and has its flowers of the dichogamous type. Male and female parts mature separately, and each flower opens only twice. Type A flowers are functionally female in the morning, close at midday, and then reopen as functionally male in the afternoon of the following day. Type B flowers are functionally

female in the afternoon, close in the evening, and then reopen the following morning as functionally male. When the two flower types are grown together, this temporal overlap of mature male and female parts encourages cross-pollination and, thus, greater fruit production. Moreover, in some cases temperature variation, flowering failure, or incomplete fruit can cause the production of the avocado cukes. This type of avocado which mainly occurs in Fuerte leads the fruit to be seedless and resembles a cucumber and it is now produced in purpose in some countries.

Regarding the soil system, Avocado trees do well in loose soil composed of decomposed granite or sandy loam for proper drainage. Excess moisture damages plants and contributes to root rot. Moreover, raised beds and water channels are recommended for avocado cultivation in order to avoid excess moisture that hampers the shallow root system. In Lebanon, avocado trees are usually grown at 500-600 m above the sea level in which a suitable climate for their growth is provided. The shed tree leaves are kept at the top of the soil in addition to the mulch and compost in order to protect the roots from sunburns and provide with nutrients.

As the case of other crops, avocado trees need nutrients and fertilizers to thrive and grow. Basically, fields use different combinations of fertilizers. However, N, P, K, and Zn are usually provided to the trees regularly. Fungicides and insecticides are also used to preserve the tree health because some diseases such as phytophthora root rot can lead to a significant decrease in such elements and toxic accumulations. This goes in parallel with regular soil and tissue analysis to guarantee healthy tree conditions (Broadbent et al, 1989). Avocado trees in Lebanon are facing common types of diseases, pests, and viruses. Phytopthora cinammomi, bacterial canker, branch canker, scrab, and anthracnose are the main ones that are managed by Cupper spraying and raised beds. Also, different kinds of

pests such as Ambrosia beetle, white fly, Persea mites, ad others are causing serious damage to the fruits and branches. Furthermore, Avocado trees in Lebanon are subjected to the sun blot virus for which sanitary practices are required in addition to the virus-free seeds usage.

In the past, Avocado was not grown economically; it was grown mainly as a habit by some farmers, or it was used as wind gusts in lemon orchards. After the 80s some expatriates imported avocado to Lebanon, and this agriculture started to be improved by the concerned NGOs.

The most known avocado cultivars are FUERTE which means strong in Spanish due to its low temperature survivor in history, and HASS which is known to give a purple-black color when mature (Olarewaju, 2014).

By time, hass replaced fuerte as the highest demand variety due to Fuerte's inconsistent yield and because hass's color change can be evidence for ripening "ready to eat". This made hass very popular in the European countries and contributes to 90% of avocado trade. (Boza et al., 2018).

It was reported that Avocado fruit exhibits the single sigmoidal growth pattern which is described by rapid cell division and enlargement of the mesocarp at the initial period, then it slows down afterward. However, avocado fruit does not stop growing as long as it is attached to the tree. This growth continues by cell division because cell enlargement stops when the fruit reaches 50% of the final size. (Olarewaju, 2014). Cell division and expansion are stimulated by hormones such as auxins (Nitsch, 1953), gibberellins and cytokinin (Bower and Cutting, 1988).

Maturity is the fundamental criteria for fruit quality, specifically physiological maturity which is the developed till an ultimate growth is achieved in which the following

maturity stage can be accomplished. However, the horticultural maturity is related to the harvest and market needs. Thus, it is essential to have complete maturity before harvesting and before reaching the market.

Regarding harvesting, it is worth mentioning that avocado fruits can be kept on the trees up to 6 months after reaching the horticultural maturity (Bayram and Tepe, 2019). This strategy allows farmers to store fruits on the tree for late market needs. However, early harvest with the minimum maturity level is recommended to avoid diseases, fungal attacks, and weather damages.

The actual maturity stage of avocado fruit should be studied before harvesting in order to guarantee a high profit for farmers and the costumers' acceptance. These maturity characteristics can be examined through studying some maturity indices which are known to be ripening dependent. The parameters are weight, firmness, color, dimensions, dry matter, oil content, TSS, and acidity.

Generally, these maturity indices are not easy to study as they are expensive and time-consuming needing laboratory equipment and personnel. Therefore, faster and cheaper methods are to be used in such experiments such as the nondestructive NIR device which measures the dry matter in few seconds. Wedding et al. (2013) reported promising results using NIRS to predict the DM of „Hass" avocado fruit. This means that measuring avocado fruit non-destructively could be achieved by avocado industries, particularly, as NIRS provides a fast approach to perform analysis.

Farmers usually do early harvest to benefit from the high profit of the avocado fruits. However, this will lead to picking immature fruits that are of bad quality when ready to be eaten. This is also the case with the export to the European markets as early as possible targeting high prices. Therefore, the NIR device can be a solution for such cases

especially for exporting hass fruits. This device works with different correction factors for DM% done by several authors. (Olarewaju, 2014). The correction error will decrease as more samples are measured and more calibration is done.

It is also possible to use the HIS hyperspectral imaging for avocado which in addition to its nondestructive strategy, it detects spatial distribution of chemical composition. This was used for several fruits and can be beneficial for avocado as well. (Ibrahim et al., 2021).

The oil content of the avocado fruit tends to increase with the growing season. However, it shows a higher oil accumulation in rainfall although it is expected to have high levels in warm conditions (Kruger et al., 1999).

Sometimes MC is low regardless of the fruit maturity, it can be a cause of direct sunlight. Also, sometimes a high MC % maybe found in smaller fruits due to premature seedcoat senescence. So, this parameter is not the most reliable one (Magwaza and Tesfay, 2015).

Note that the most common attribute to avocado maturity is the decrease in moisture and increase in dry matter and oil content. TSS has been recommended to be a good maturity index for maturity, but it was not actually. MC and DM were accurate and fast while OC was less accurate and time consuming.

As a climacteric fruit, avocado continues to produce ethylene after being detached from the tree. Ethylene is responsible for aging and ripening of the fruit. When dealing with cultivation for economic purpose, the ripening caused by ethylene creates a border for farmers making it difficult to transport avocado for long periods of time. For this reason, a chemical called MCP can be used to control this fast ripening.

1-Methylcyclopropene (1-MCP) is a synthetic plant growth regulator that is usually used to downregulate the ripening of fruits (Watkins, 2006). It is structurally related to the natural plant hormone known as ethylene.

1-MCP has nontoxic mode of action, negligible residue, and is effective at very low concentrations (usually ≤1 μL/L). The action of 1-MCP is considered to occur due to a physical similarity to ethylene that allows it to strongly bind to the metal in the ethylene receptor for a long period and therefore the produce will not respond to ethylene until new receptors are regenerated in the system. 1-MCP has been a very useful tool in our basic understanding of the biology of fruit ripening. It has been used as a supplement to molecular approaches for identifying and understanding senescence and ripening processes under the direct control of ethylene perception and action (Kubheka et al., 2020).

The study undergoing is dealing with common avocado varieties in Lebanon including Fuerte, Hass, Lambhass, Reed, Ettinger, and Horshim. The mentioned varieties were harvesting in a 2-week interval from 7 different locations distributed in south and north Lebanon including Abbasiyeh, Ansar, Nmeiriyeh, Mrwaniyeh, Halba, Markabta, and Kfar Hay. These locations differ in their elevation above the sea level, and they have different agricultural practices as well.

To the best of our knowledge such study is done for the first time in Lebanon, and it can be used by key industry groups as maturity-based strategies.

CHAPTER II

MATERIALS AND METHODS

A. Location

Avocado trees are grown in tropical and subtropical areas where there is enough sunlight and suitable temperature. In Lebanon, Avocado is known to be planted in the South and the North. Fruits of different varieties were picked by hand from 6 different locations of different elevations. The fields were in Nmeiriyeh, Mrwaniyeh, Kfar Hay, Ansar, Abbasiyeh, and Markabta. Fig. 1 shows the distribution of these locations on the Lebanese map.

The studied locations vary in their climate, temperature, altitude, rain fall and more importantly the agricultural practices. Each field plot was split into rows and trees were coded using a tag plate. Fruits were harvested from November 2020 till March 2021 on a two-weeks interval.

The fields included in this experiment were chosen to be GAP (good agricultural practices) certified or at least applied, thus applying good and healthy irrigation, fertilization, and pest management programs for the trees.

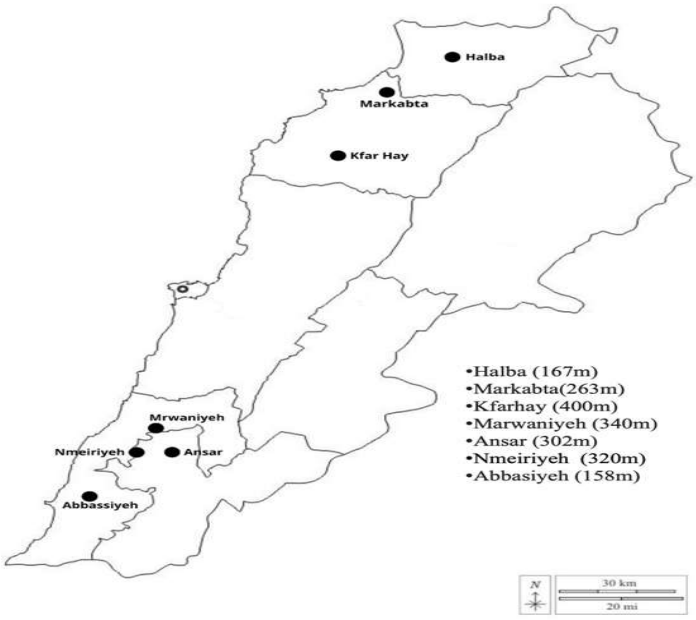


Figure 1: Map of the south (Nmeiriyeh, Mrwaniyeh, Ansar and Abbasiyeh) and north locations (Halba, Kfar Hay, Markabta) used in this study and their altitudes.

B. Plant material

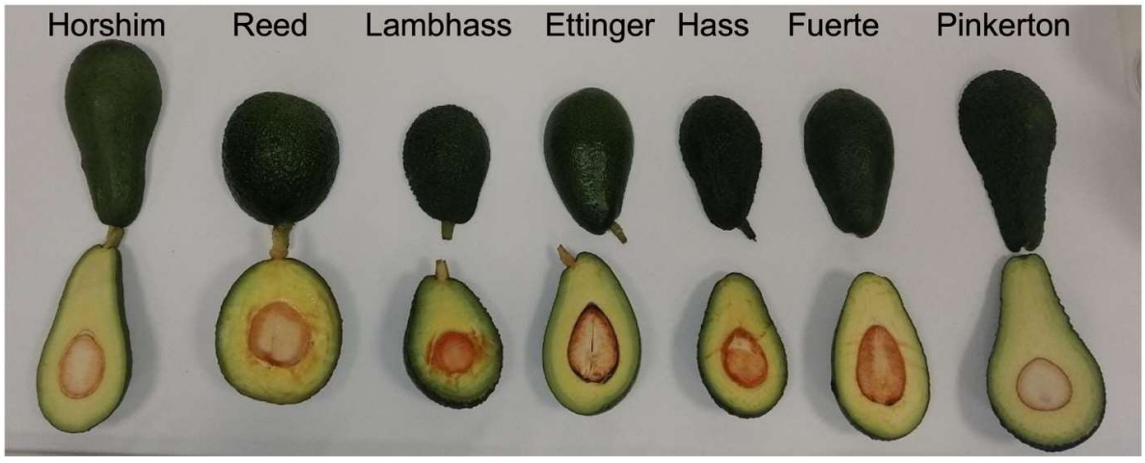


Figure 2 : The seven avocado varieties studied in this experiment

Fuerte, Pinkerton, Hass, Lamb Hass, Ettinger, Reed, and Horshim were mainly collected from the studied fields. 4-6 fruits were picked from each tree and coded according to the location, farmer's name, plot number, row, and tree number. The fruits were placed in perforated transparent bags and transferred to the laboratory through a cold chain for the postharvest physiochemical analysis. This harvesting process was done regularly each 2 weeks and in the early morning starting from November 2020 till March 2021. On the same day, the avocado samples were visually inspected at the laboratory to ensure that they were not subjected to any damage during transportation and if they were, the damaged ones were excluded from the samples (Kassim et al., 2020). All the work surfaces, tools, and utensils were cleaned and disinfected.

Table 1: A table showing Avocado varieties harvested from the Lebanese coastal locations

		Location						
		Abbasiyeh	Ansar	Halba	Kfar Hay	Markabta	Mrwaniyeh	Nmeiriyeh
Variety	ETTINGER		X	X	X		X	
	FUERTE	X	X	X	X	X	X	X
	HASS	X	X		X	X	X	X
	HORSHIM		X					
	LAMBHASS	X	X	X	X	X	X	X
	PINKERTON	X	X		X	X	X	X
	REED	X	X		X			X

C. Experimental study:

The avocado fruits were subjected to several measurements starting from **weighing** 3 fruits from each tree individually using a digital balance.

The fruits were then destructed to measure the **firmness** of each fruit in KgF. The firmness was measured 4 times by pressing an Effegi FT 011 (0-5kg) penetrometer equipped with an 11mm plunger (the two sides with and without skin).

Afterward, each fruit was divided into 2 parts. The flesh of the first part was labeled and stored in the freezer for the **oil content** test. Fruit samples were ground, and small portions were weighed and freezed followed by freeze drying. 0.5g of dry sample was weighed in a tared XT4 Filter bags (Ankom Technology) and sealed very well. Then the bags were put in the Soxhlet extractor. A mixture of Hexane Acetone (1:1) was prepared and around 300ml was put in the 500ml round bottom flask with boiling chips. The setup for Soxhlet extraction was connected. (Mantle, round bottom flask, extractor, condenser). The cooler and the heater were turned on. As soon as the solvent started to evaporate the heat was regulated. After 4 hours the heat was turned off and the bags were removed from the extractor and kept in the hood for few minutes in order to dry the excess solvent. Then the bags were cooled in a desiccator and weighed after 1 hour in the oven.

The second part was used for the **dry matter** percentage test. The dry matter test was done using the coring method where a cylinder-shaped flesh sample of approximately 5g was removed from the two sides of 4 fruits and weighed before and after 36 hours in the oven at 70 C, or by using a microwave until reaching a constant weight. The dry matter percentage was calculated using this formula [100* (dry weight/fresh weight)] (Ranney *et al.*, 1992). Then the average of the four values was calculated for each tree sample.

The remaining parts were then blended into juice and stored in a freezer for a later brix (TSS) test by placing one or two drops of the juice on the prism of the digital

refractometer, where it gives the **sugar content** value in percentage (PR-32 α Palette; Atago, Japan).

5 ml of the juice was diluted with 95 ml of dH2O to measure the pH using a standard pH meter. The **titratable acidity** was conducted using 0.1 M NaOH until reaching a constant pH of 8.1. Titratable acidity was calculated as the number of milliliters of NaOH added from the burette multiplied by an appropriate factor using this equation [(X*0.075*N)/ml of juice added) *100], where X is the amount of NaOH used and 0.075 is the conversion factor which depends on the type of acid found in avocado (mainly tartaric acid).

The remaining fruits from each tree were coded and kept for **ripening at room temperature** and then the firmness and dry matter were remeasured to check the time needed by each variety to ripen in relation to the studied locations.

D. Statistical analysis

After the data was entered and cleaned from extreme values, statistical comparison of all parameters was performed using t-test for comparing the varieties and maturity indices. ANOVA was used to compare the previously mentioned parameters in addition to the locations. Differences were considered statistically significant for p values < 0.05 using R Studio statistical software. Principal component analysis (PCA) was performed over the 3 harvesting stages in order to observe the clustering behavior of the varieties and correlations between maturity indices. Shapiro-Wilk normality tests and studentized residual plots were used to test error assumptions of variance analysis, including random, homogenous, and normal distribution of error. Means were calculated using the LSMEANS statement, and significant differences between the treatments were determined by the Tukey-Kramer test

with $\alpha = 0.05$ and are mentioned in each figure or table. Statistical comparison of maturity indices under different locations by variety and harvest stage was performed using one way ANOVA parametric test followed by Student Newman Keuls (SNK) posthoc test. As a non-parametric alternative to ANOVA, the Kruskal-Wallis test was used followed by Dunn's Test. Differences between locations for the same variety were considered statistically significant for p values < 0.05 using RStudio statistical software.

CHAPTER III

2020-2021 SEASON RESULTS

A. DRY MATTER

1. Hass

Avocado Hass variety was harvested from 6 different locations (Abbasiyeh, Ansar, Markabta, Kfar Hay, Mrwaniyeh and Nmeiriyeh) over 4 harvesting stages between November 2020 and March 2021. As shown in figure 3 below, the lowest value of dry matter (DM) in Hass variety was recorded at Kfar Hay in early December (18.85%), while the highest DM value was recorded at Nmeiriyeh in March (33.93%). In the early harvest stage (late November early December) Markabta showed the highest DM percentage (28.37%), while during the second stage (late December) fruits at Nmeiriyeh recorded the highest DM value (30.2%). In the third harvest (January) Markabta Hass fruits showed the highest value (31.96%), while during the last harvest (March) where Markabta was not included, Nmeiriyeh Hass fruits gave the highest dry matter percentage (33.93%).

The results obtained showed an increase in Dry matter % with harvesting date at Mrwaniyeh, Markabta and Ansar, while it showed some fluctuation in the remaining locations.

A comparison was done between the locations harvested at the same dates. There is a significant difference between the mean DM percentages of avocado Hass fruits harvested from Kfar Hay and Markabta in (December and January), Ansar and Abbasiyeh in late December, Mrwaniyeh and Nmeiriyeh in December. In March, fruits were harvested from 4 locations where the mean DM% in Abbasiyeh and Ansar showed significant difference with that of Mrwaniyeh and Nmeiriyeh.

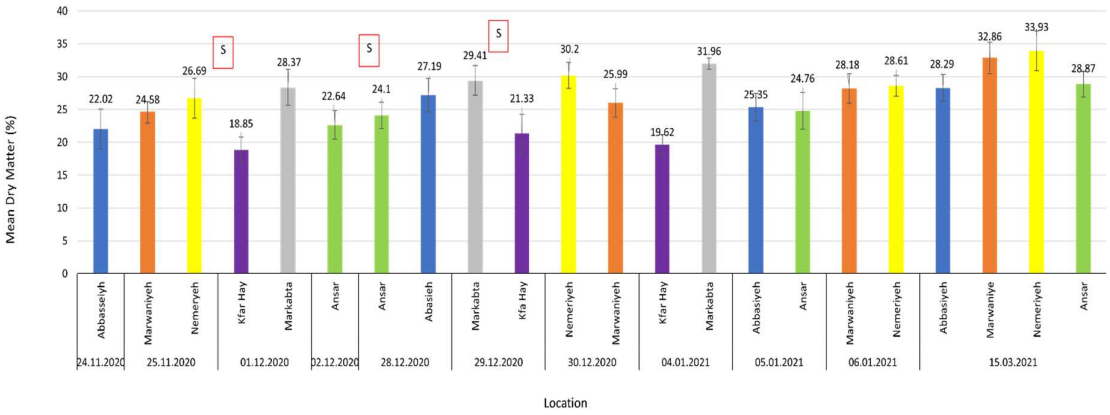


Figure 3: Dry matter percentages of Hass avocado variety between November 2020 and March 2021

2. Fuerte

Avocado Fuerte variety was harvested from 7 different locations (Abbasiyeh, Ansar,Halba, Markabta, Kfar Hay, Mrwaniyeh, and Nmeiriyeh) over 4 harvesting stages between November 2020 and March 2021.

As shown in figure 4 below, the lowest value of dry matter in Fuerte was recorded at Abbasiyeh in January (22.65%), while the highest value was recorded at Nmeiriyeh in March (39.19%). In both the early harvest stage (late November – early December) and the second stage (late December) Markabta showed the highest DM percentage (29.9% and 31.55% respectively). During the third harvest (January) Mrwaniyeh Fuerte fruits showed the highest dry matter percentage (32.78%), while during the last harvest (March) where Mrwaniyeh and Markabta were not included, Nmeiriyeh Fuerte fruits had the highest dry matter percentage (39.19%).

The results obtained showed an increase in Dry matter % with harvesting date at Ansar, while it showed some fluctuation in the remaining locations.

A comparison was done between the locations harvested at the same dates. There is a significant difference between the mean DM percentages of avocado Fuerte fruits harvested from Ansar and Abbasiyeh in (late December and January), Ansar and Nmeiriyeh in March. In early December, fruits were harvested from 3 locations where the mean DM% in Kfar Hay showed a significant difference with that of Markabta and Halba.

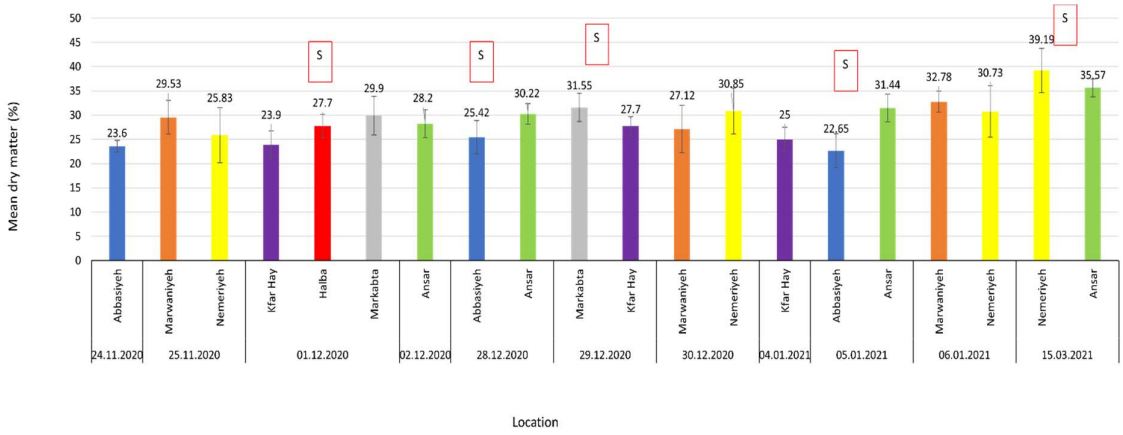


Figure 4: Dry matter percentages of Fuerte avocado variety between November 2020 and March 2021

3. Reed

Avocado REED variety was harvested from 4 different locations (Abbasiyeh, Ansar, Kfar hay, and Nmeiriyeh) over 4 harvesting stages between November 2020 and March 2021.

As shown in Figure 5 below, the lowest percentage of dry matter in Reed was recorded at Nmeiriyeh in November (13.13%), while the highest DM value was recorded at Ansar in March (25.7%). In both the early harvest stage (late November-early December) and second stage (late December), Ansar showed the highest DM percentage (19.66% and 19.38% respectively). In the third harvest (January) Kfar Hay Reed fruits

showed the highest value (19.39%), while during the last harvest (March) where Kfar Hay was not included, Ansar Reed fruits gave the highest dry matter percentage (25.7%). The results obtained showed an increase in Dry matter % with harvesting date at Kfar Hay, while it showed some fluctuation in the remaining locations.

A comparison was done between the locations harvested at the same dates. There is a significant difference between the mean DM percentages of avocado Reed fruits harvested from Ansar and Abbasiyeh in both January and March.

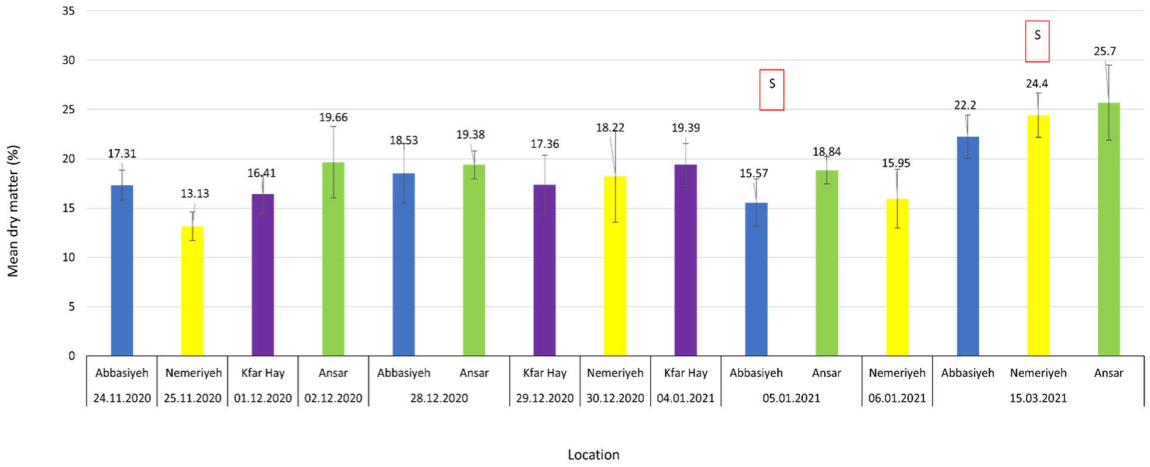
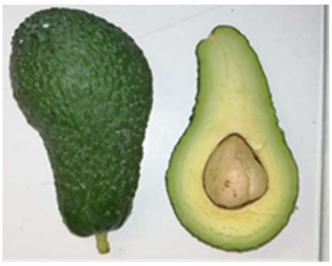


Figure 5: Dry matter percentages of Reed avocado variety between November 2020 and March 2021



4. Pinkerton

Avocado Pinkerton variety was harvested from 6 different locations (Abbasiyeh, Ansar, Markabta, Kfar Hay, Mrwaniyeh, and Nmeiriyeh) over 4 harvesting stages between November 2020 and March 2021.

As shown in Figure 6 below, the lowest percentage of dry matter in Pinkerton was recorded at Kfar Hay in January (20.1%), while the highest DM percentage was recorded at Nmeiriyeh in March (33.95%). In the early harvest stage (late November-early Deember) Markabta showed the highest DM percentage (23.6 %), while during the second stage (late December) fruits at Markabta as well recorded the highest DM percentage (27.8%). In the third harvest (January) Nmeiriyeh Pinkerton fruits showed the highest percentage (27.09%), while during the last harvest (March) where Markabta was not included, Nmeiriyeh Pinkerton fruits gave the highest dry matter percentage (33.95%).

The results obtained showed an increase in Dry matter % with harvesting date at Mrwaniyeh, Nmeiriyeh and Ansar, while it showed some fluctuation in the remaining locations.

A comparison was done between the locations used at the same dates. There is a significant difference between the mean DM percentages of avocado Pinkerton fruits harvested from Kfar Hay and Markabta in December and January and from Nmeiriyeh and Ansar in March.

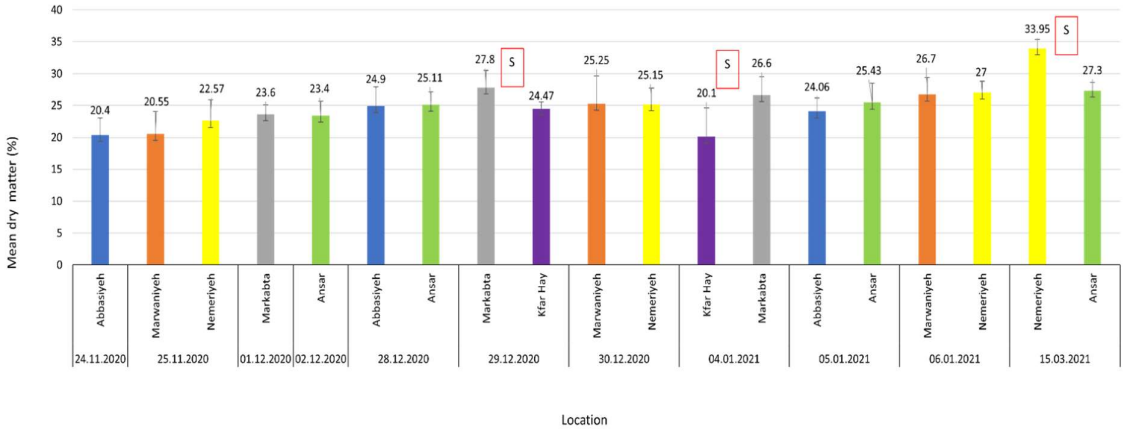


Figure 6: Dry matter percentages of Pinkerton avocado variety between November 2020 and March 2021

5. Ettinger

Avocado Ettinger variety was harvested from 4 different locations (Ansar, Kfar Hay, Mrwaniyeh and Halba) over 3 harvesting stages between November 2020 and January 2021.

As shown in figure 7 below, the lowest percentage of dry matter in Ettinger was recorded at Kfar Hay in early December (23.02%), while the highest DM percentage was recorded at Halba in late December (30.89%). In the early harvest stage (late November-early December) Halba showed the highest DM percentage (27.25 %), while during the

second stage (late December) fruits at Halba as well recorded the highest DM percentage (30.89%). In the third harvest (January) Mrwaniyeh fruits showed the highest value (30.37%).

The results obtained showed an increase in Dry matter % with harvesting date at Mrwaniyeh, Kfar Hay, Halba and Ansar.

A comparison was done between the locations harvested at the same dates. There is a significant difference between the mean DM percentages of avocado Ettinger fruits harvested from Kfar Hay and Halba in late December.

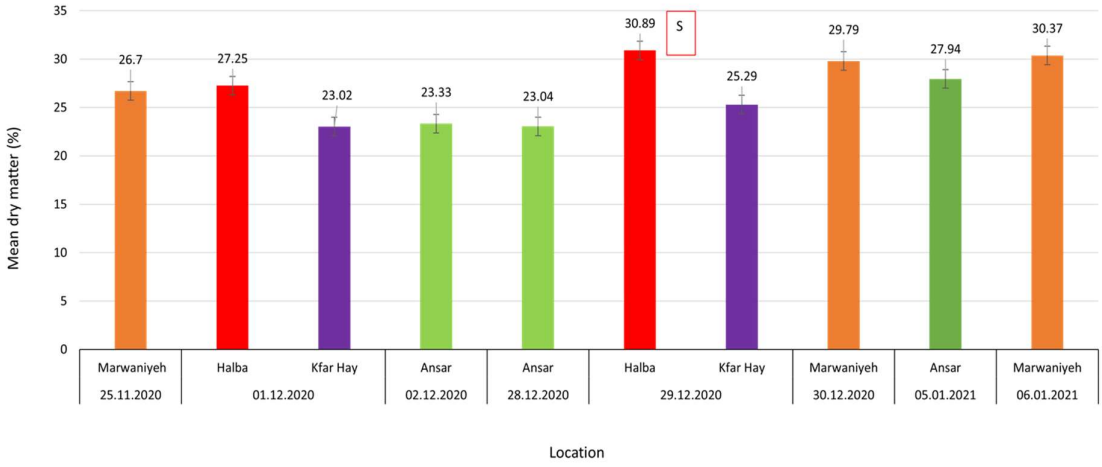


Figure 7: Dry matter percentages of Ettinger avocado variety between November 2020 and January 2021

6. Lambhass

Avocado Lambhass variety was harvested from 6 different locations (Abbasiyeh, Ansar, Markabta, Kfar hay, Mrwaniyeh, and Nmeiriyeh) over 4 harvesting stages between November 2020 and March 2021.

As shown in Figure 8 below, the lowest value of dry matter was recorded at Abbasiyeh in January (18.64%), while the highest DM value was recorded at Ansar in late December (24.88%). In the early harvest stage (late November-early December) Ansar showed the highest DM percentage (22.5 %), while during the second stage (late December) fruits at Ansar as well recorded the highest DM percentage (24.88%). In the third harvest (January) Mrwaniyeh fruits showed the highest value (24.04%), while during the last harvest (March) Lambhass was only harvested from Abbasiyeh and had a DM of 23.89 %.

The results obtained showed an increase in Dry matter % with harvesting date at Mrwaniyeh while it showed some fluctuation in the remaining locations.

A comparison was done between the locations harvested at the same dates. There is a significant difference between the DM percentages of avocado Lambhass fruits harvested from Ansar and Abbasiyeh in late December.

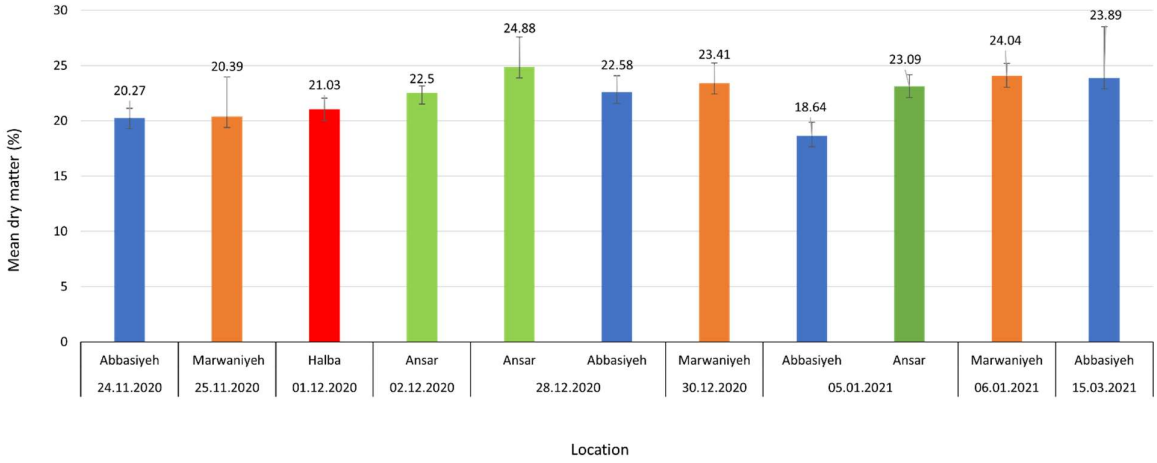
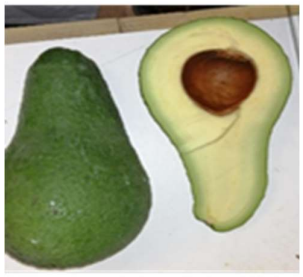


Figure 8: Dry matter percentages of Lambhass avocado variety between November 2020 and March 2021



7. Horshim

Avocado Horshim variety was harvested from only one location (Ansar) over 4 harvesting stages between December 2020 and March 2021.

As shown in figure 9 below, the lowest value of dry matter was recorded in early December (22.9 %), while the highest DM value was recorded in March (29.82%). The results obtained showed an increase in Dry matter % with harvesting date from December 2020 till March 2021.

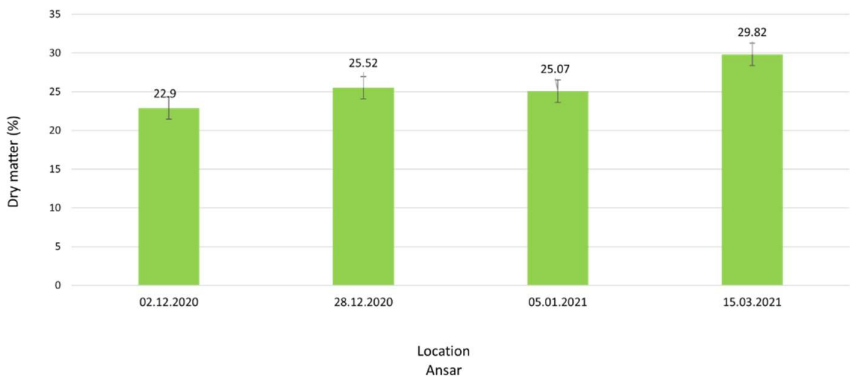


Figure 9: Dry matter percentages of Horshim avocado variety between November 2020 and March 2021

When comparing the dry matter percentage of the varieties throughout thr harvesting season, it was shown that Reed Avocado increased by 33% from the early to the late stage. However, lambhass dry matter increased by only 12%. The remainig varieties had a moderate increase ranging from 22% to 28%.

B. OIL CONTENT

The oil content in avocados depends on many factors, such as the agro-ecological conditions and the fruit development stage. Minimum and maximum oil content percentages for each variety have been established as international standards.
The first season was between November 2020 and March 2021 showed that all varieties had an increase in the oil content during the season.

In March 2021, the Reed and Lambhass avocado varieties recorded the lowest oil content percentage (13%, 12.36% respectively) and the Fuerte variety recorded the greatest oil content percentage (24.5%) (Figure 10).

The altitude of the location within the variety also influenced the oil content. For example, in November, the oil content of the LambHass variety was 8.8 % in Abbasiyeh and 15 % in Marwaneiyh. Similarly, the oil content of Pinkerton was 10.7% in Abbasiyeh and 14.5% in Mrwaniyeh in November. This trend was not observed in some varieties such as Reed when oil content was 6.14 % in Abbsaeihh and 7.5% in Nmeiriyeh in November and increased to 12 % in both locations in March (Figure 38). Despite the fact that an increase in oil content was a general tendency across all varieties throughout the growing season, this increase showed a distinct magnification per variety. Hass and Pinkerton oil content, for example, increased from 11% in November to 19% in March, while Lambhass increased from 8.8% to 12.3% percent during the same time period (Figure 11-12).

When observing the Oil content % results throughout the 3 harvesting stages all together, it was observed that the oil content % of Fuerte, Hass, Pinkerton, and Reed avocado fruits had increased by around 31% from the early to the late harvest stage. However, Lambhass fruits showed around 18% increase in OC % throughout the 3 harvesting stages.

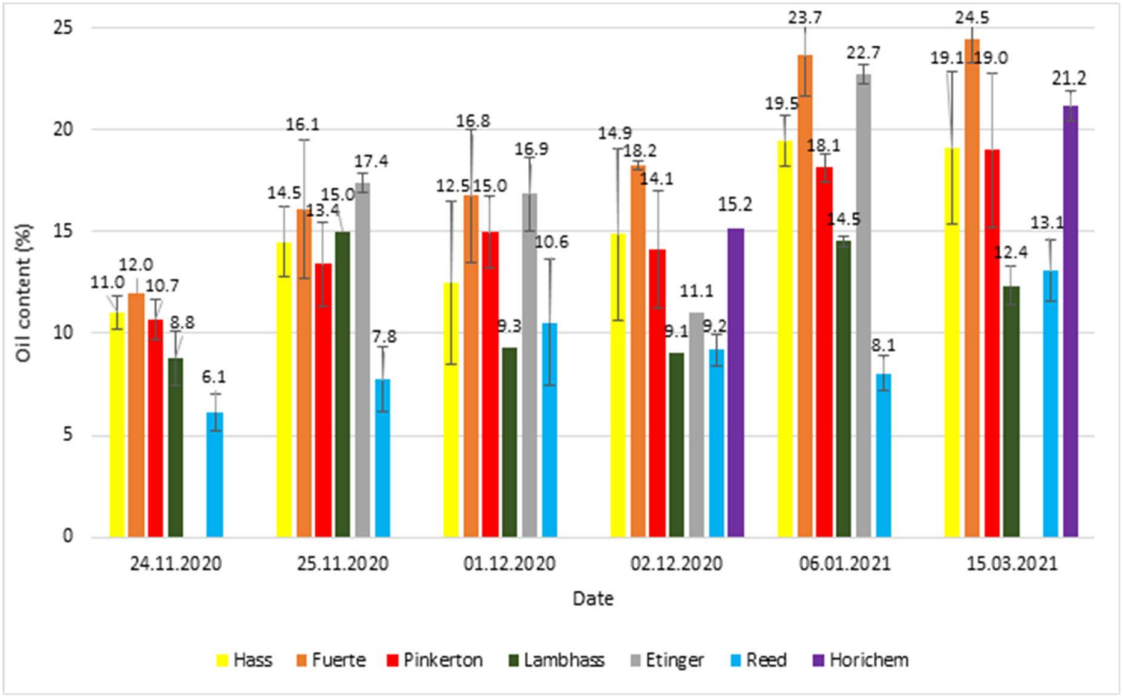


Figure 10: Oil content (%) for the different avocado varieties throughout the growing season

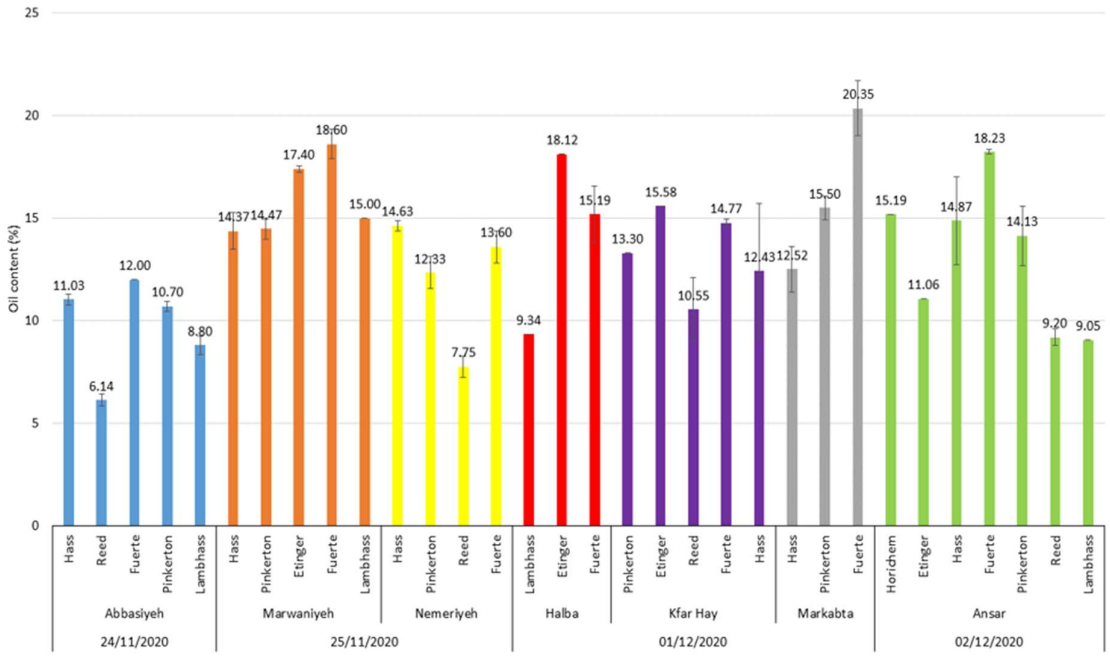


Figure 11: Oil content (%) between November and early December 2020

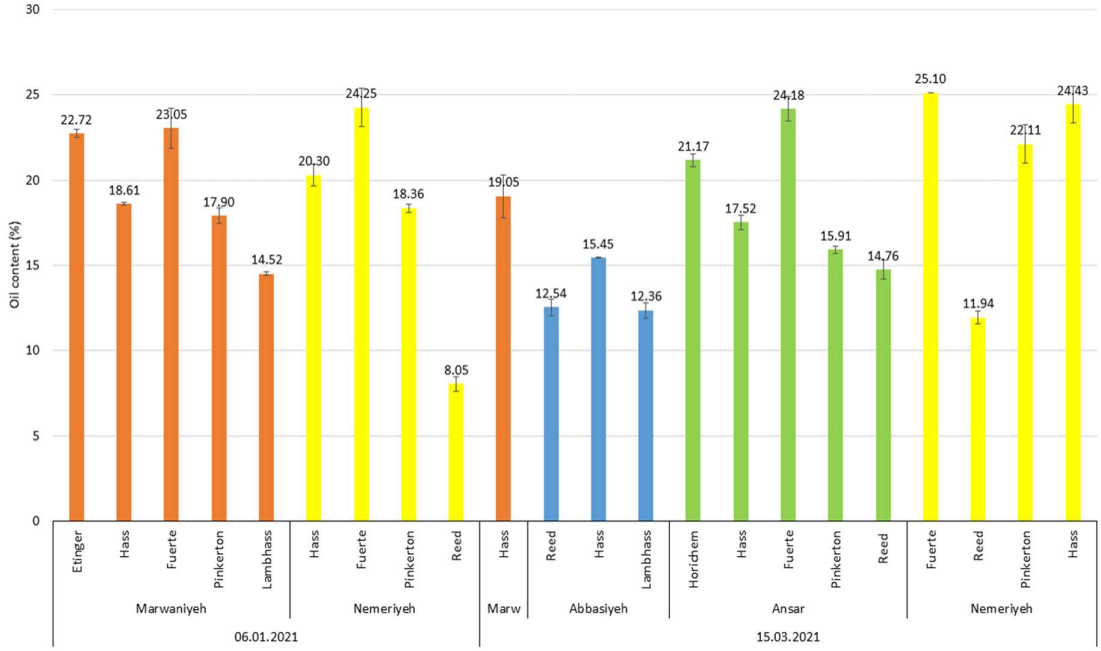


Figure 12: Oil content (%) between January and March 2021

C. FIRMNESS WITHOUT SKIN

1. Hass

Avocado Hass variety was harvested from 6 different locations (Abbasiyeh, Ansar, Markabta, Kfar Hay, Mrwaniyeh, and Nmeiriyeh) over 4 harvesting stages between November 2020 and March 2021.

As shown in figure 13 below, the lowest value of firmness without skin in Hass was recorded at Kfar Hay in North of Lebanon in early December (15.42 kgf), while the highest firmness value was recorded at Nmeiriyeh in the south of Lebanon in December (21.67 kgf).

In the early harvest stage, during November and December Nmeiriyeh showed the highest firmness value (18.49 kgf), while during the second stage in late December fruits at Nmeiriyeh recorded the highest firmness value (21.67 kgf). In the third harvest in January, Abbasiyeh Hass fruits showed the highest value (18.78), while during the last harvest in March, Nmeiriyeh Hass fruits gave the highest firmness value (18.90 kgf).

The results obtained showed minor fluctuations in the firmness values with the harvesting dates in all locations.

A comparison was done between the locations harvested at the same dates. There is a significant difference between the mean firmness of avocado Hass fruits harvested from Kfar Hay and Markabta in early December, Mrwaniyeh and Nmeiriyeh in late December, Ansar and Abbasiyeh during January.

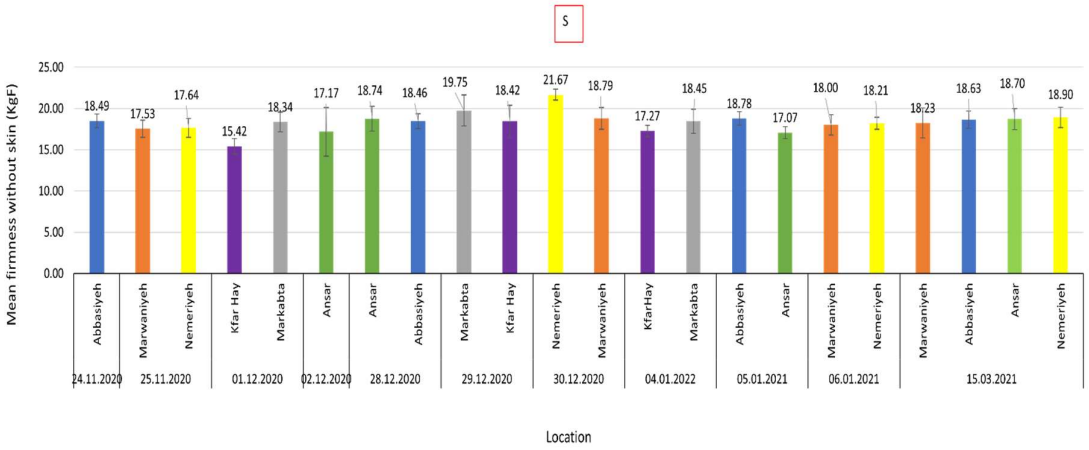


Figure 13: Firmness without skin (KgF) of Hass avocado variety between November 2020 and March 2021

2. Fuerte

Avocado Fuerte variety was harvested from 7 different locations (Abbasiyeh, Ansar,Halba, Markabta, Kfar Hay, Mrwaniyeh, and Nmeiriyeh) over 4 harvesting stages between November 2020 and March 2021.

As shown in figure 14 below, the lowest value of firmness without skin of Fuerte was recorded at ansar (13.52 Kgf), while the highest firmness value was recorded at Nmeiriyeh in March (17.96 Kgf).

In the early harvest stage, during November and December Ansar showed the highest firmness value (17.81 Kgf), while Nmeiriyeh showed the highest values during the second, third, and last harvest (17.11, 16.47, and 17.96 respectively).

The results obtained showed firmness value decrease with harvest stages in Ansar and Abbasiyeh, while it showed fluctuations in the firmness values with the harvesting dates in the other locations.

A comparison was done between the locations harvested at the same dates. There is a significant difference between the mean firmness of avocado Fuertes fruits harvested from Mrwaniyeh and Nmeiriyeh in the first 3 harvesting stages (November, December, and January). A significant difference was also obtained between the mean firmness of fruits in Ansar and Nmeiriyeh in March.

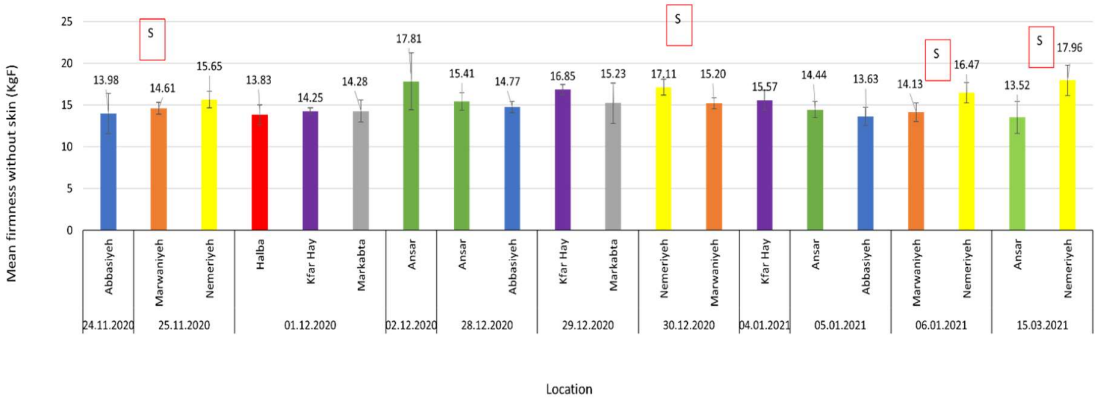


Figure 14: Firmness without skin (KgF) of Fuerte avocado variety between November 2020 and March 2021

3. Reed

Avocado Reed variety was harvested from 4 different locations (Abbasiyeh, Ansar, Kfar Hay, and Nmeiriyeh) over 4 harvesting stages between November 2020 and March 2021.

As shown in figure 15 below, the lowest value of firmness without skin of reed was recorded at Abbasiyeh (11.48 Kgf), while the highest firmness value was recorded at Nmeiriyeh in March (15.86 Kgf).

In the first and third harvest stage, during November and January, Ansar showed the highest firmness values (14.58 and 14.43 Kgf respectively), Abbasiyeh showed the

highest values during the second harvest (14.81 kgf), while in the last harvest Nmeiriyeh gave the maximum value (15.86 kgf).

The results obtained showed minor fluctuations in the firmness values with the harvesting dates in all locations.

A comparison was done between the locations harvested at the same dates. There is a significant difference between the mean firmness of avocado Reed fruits harvested from Abbasiyeh and Ansar in January.

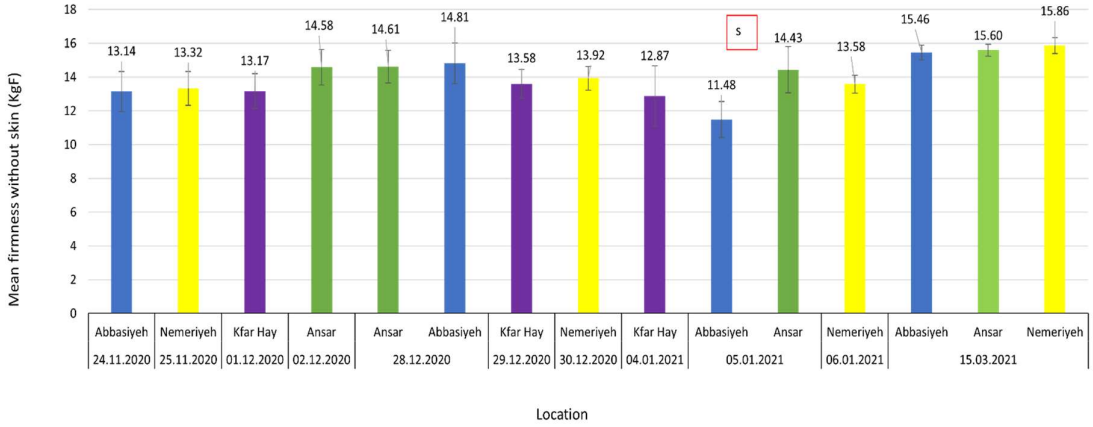


Figure 15: Firmness without skin (KgF) of Reed avocado variety between November 2020 and March 2021

4. Lambhass

Avocado LambHass variety was harvested from 4 different locations (Abbasiyeh, Ansar, Halba, and Mrwaniyeh) over 4 harvesting stages between November 2020 and March 2021.

As shown in figure 16 below, the lowest value of firmness without skin of Lambhass was recorded at Ansar in December (12.27 Kgf), while the highest firmness value was recorded at Abbasiyeh in March (16.88 Kgf).

In the first harvest stage during November, Halba showed the highest firmness value (15.20 kgf), Ansar showed the highest firmness value in the second stage (16.40 kgf), while Abbasiyeh showed the highest values in both the third and last harvest stage (15.43 and 16.88 kgf respectively).

The results obtained showed increase in firmness values with time at Abbasiyeh, while it was fluctuating in the others.

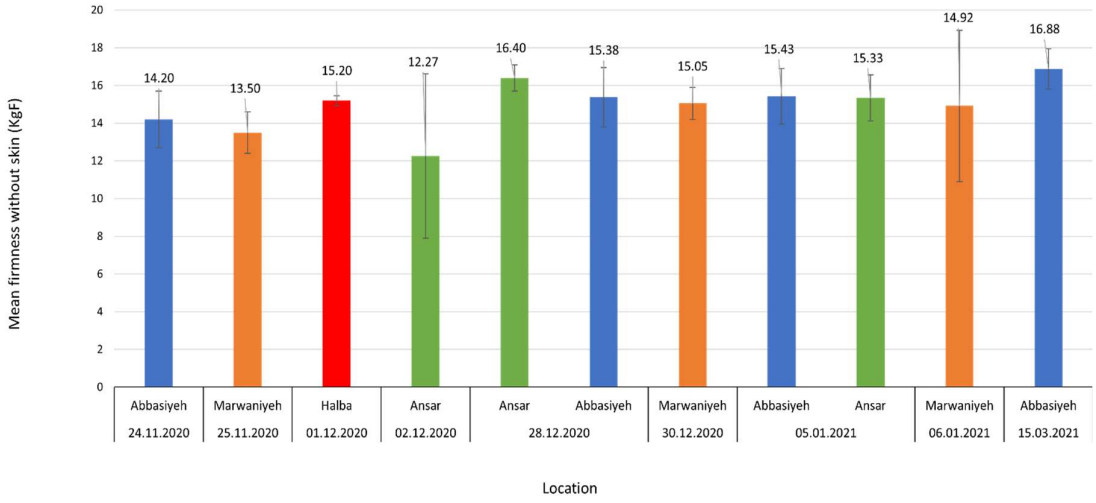


Figure 16: Firmness without skin (KgF) of Lambhass avocado variety between November 2020 and March 2021

5. Ettinger

Avocado Ettinger variety was harvested from 4 different locations (Ansar,Halba, Kfar Hay, and Mrwaniyeh) over 3 harvesting stages between November 2020 and January 2021.

As shown in figure 17 below, the lowest value of firmness without skin of Ettinger was recorded at Kfar Hay in early December (9.40 Kgf), while the highest firmness value was recorded at Halba in late December (15.50 Kgf).

In the first harvest stage, Ansar showed the highest firmness values (13.33 kgf), Halba showed the highest values during the third harvest (15.50 KgF), while in the last harvest where Halba was not included, Ansar gave the maximum value (12.47 KgF).

The results obtained showed that the firmness value increase with time in both Halba and Kfar Hay, while it was fluctuating in others.

A comparison was done between the locations harvested at the same dates. There is a significant difference between the mean firmness of avocado Ettinger fruits harvested from Halba and Kfar Hay during December.

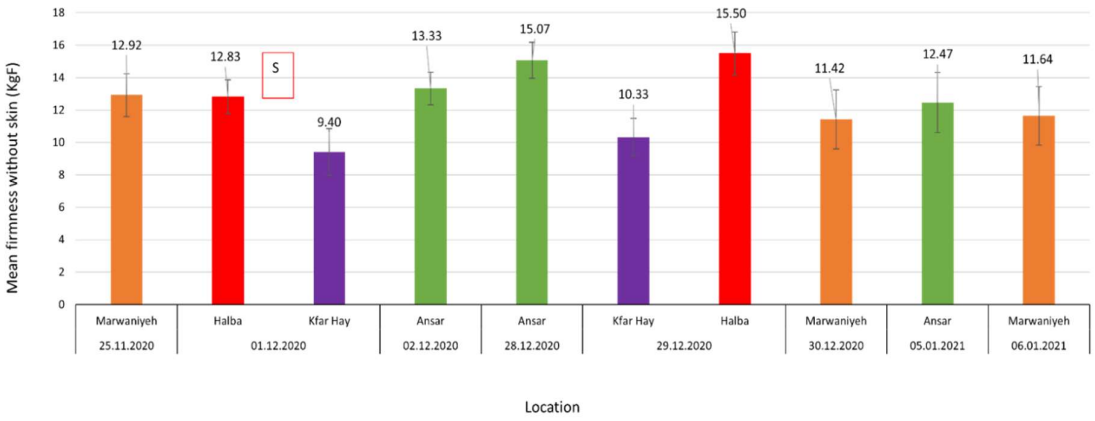


Figure 17: Firmness without skin (KgF) of Ettinger avocado variety between November 2020 and January 2021

6. Pinkerton

Avocado Pinkerton variety was harvested from 6 different locations (Abbasiyeh, Ansar, Markabta, Kfar Hay, Mrwaniyeh and Nmeiriyeh) over 4 harvesting stages between November 2020 and March 2021.

As shown in figure 18 below, the lowest value of firmness without skin in Pinkerton was recorded at Kfar Hay in north of Lebanon in early December (15.70 KgF), while the highest firmness value was recorded at Nmeiriyeh in south of Lebanon in late December (20.35 KgF).

Mrwaniyeh showed the highest firmness value of Pinkerton fruits in the first and third harvest stages during November and January (18.11 KgF and 19.28 KgF respectively), while Nmeiriyeh showed the highest values in the second and last harvest stage (20.35 KgF and 18.68 KgF respectively).

The results obtained showed that the firmness values were increasing in Mrwaniyeh with harvest time, while it was fluctuating in other locations.

A comparison was done between the locations harvested at the same dates. There is a significant difference between the mean firmness of avocado Pinkerton fruits harvested from Ansar and Abbasiyeh in late December, Mrwaniyeh and Nmeiriyeh in late December and January.

Figure 18: Firmness without skin (KgF) of Pinkerton avocado variety between November 2020 and March 2021

7. Horshim

Avocado Horshim fruits were harvested from only 1 location (Ansar) over 4 harvesting stages between December 2020 and March 2021.

As shown in figure 19 below, 13.67 KgF was the lowest firmness value of Horshim in January, while the highest value was obtained during late December (17.33 KgF).

The values of firmness were fluctuating with the harvesting time from December till March.

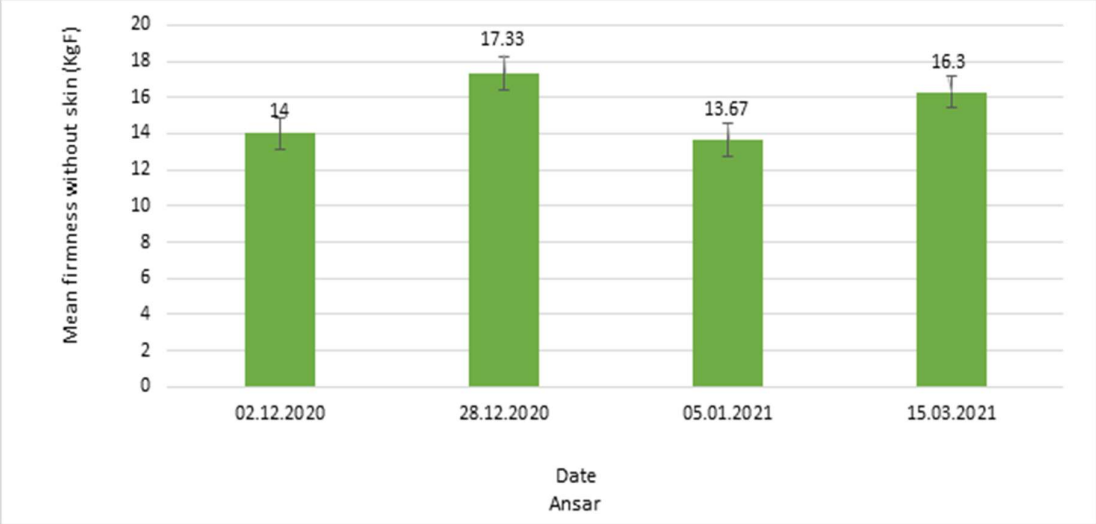


Figure 19: Firmness without skin (KgF) of Horshim avocado variety between November 2020 and March 2021 at Ansar

D. WEIGHT

1. Hass

Avocado Hass variety was harvested from 6 different locations (Abbasiyeh, Ansar, Markabta, Kfar Hay, Mrwaniyeh and Nmeiriyeh) over harvesting stages between November 2020 and March 2021.

As shown in figure 20 below, the lowest value of fruit weight in Hass was recorded at Markabta in late December (129.8 g), while the highest weight was recorded at Abbasiyeh in March (237.78 g).

In the first and third harvest stage, Abbasiyeh showed the highest weight values (201 g and 225 g respectively), while during the second stage in late December fruits at Mrwaniyeh recorded the highest weight value (201.9 g). In the last harvest stage Abbasiyeh showed the highest weight value (237.78 g).

The results obtained showed that the weight in Nmeiriyeh fruits was increasing with time and fluctuating in the other varieties. In all locations, fruits reach their highest values in the last harvest stage.

A comparison was done between the locations harvested at the same dates. There is a significant difference between the weight values of all locations except Kfar Hay and Markabta in early December.

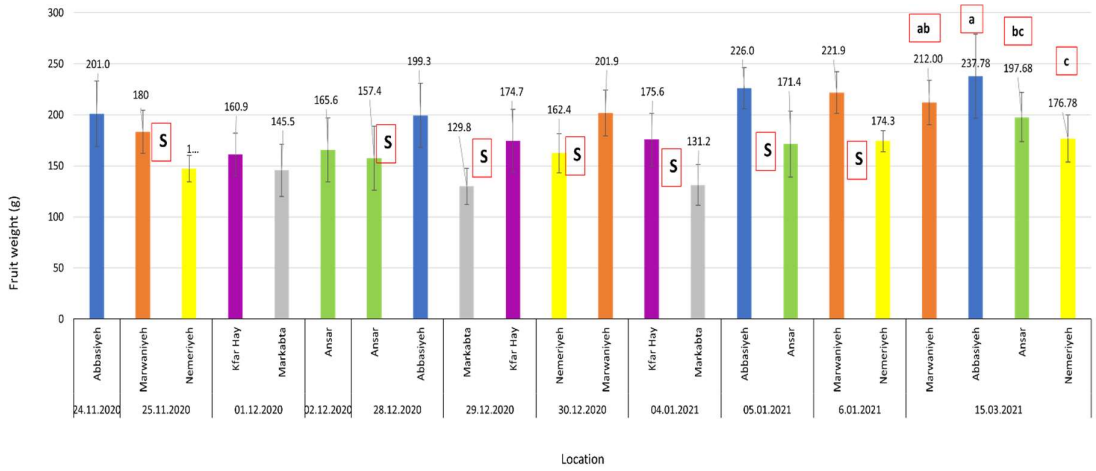


Figure 20: Weight of Hass avocado variety between November 2020 and March 2021

2. Fuerte

Avocado Fuerte variety was harvested from 7 different locations (Abbassieh, Ansar, Halba, Markabta, Kfar Hay, Mrwaniyeh, and Nmeiriyeh) over 4 harvesting stages between November 2020 and March 2021.

As shown in figure 21 below, the lowest value of weight of Fuerte was recorded at Abbasiyeh (248.7 g) in November, while the highest weight value was recorded at Ansar in March (339.47 g).

In the first and second harvest stage Markabta fruits showed the highest weight values (330.7 and 341.4 g respectively). In the third stage Abbasiyeh showed the highest value (311.4 g), while in the last sage during March the highest weight was obtained in Ansar (339.47 g)

The results obtained showed that the weight values of Fuerte fruits increase with harvest stages in Ansar, Mrwaniyeh, Markabta and Abbasiyeh, while it showed decreases in Kfar Hay and Nmeiriyeh.

A comparison was done between the locations harvested at the same dates. There is a significant difference between the mean weight of Fuertes fruits harvested from Ansar and Nmeiriyeh in the last harvesting stage.

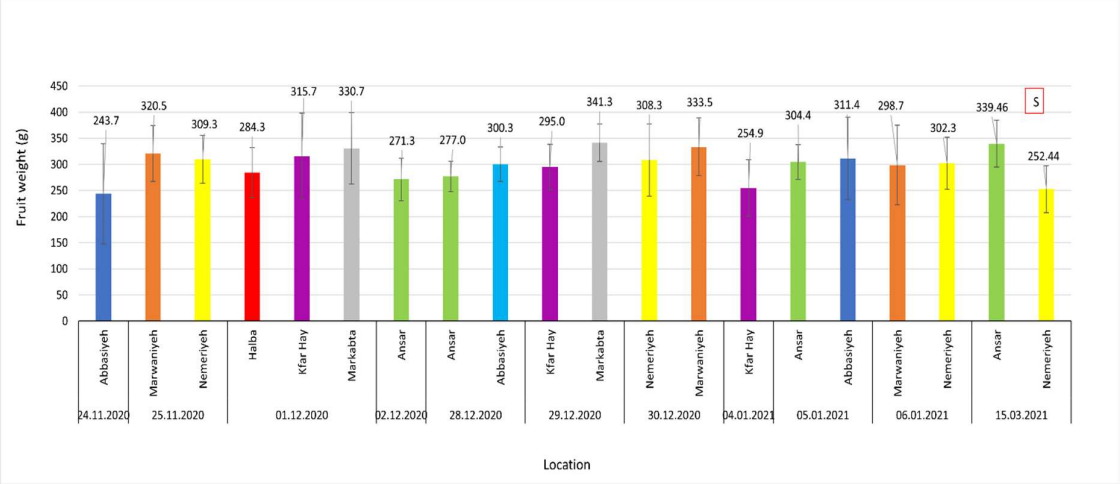


Figure 21: Weight of Fuerte avocado variety between November 2020 and March 2021

3. Reed

Avocado Reed variety was harvested from 4 different locations (Abbasiyeh, Ansar, Kfar hay, and Nmeiriyeh) over 4 harvesting stages between November 2020 and March 2021.

As shown in figure 22 below, the lowest values of the weight of reed was recorded at Nmeiriyeh (235.9 g) in November, while the highest weight was recorded at Ansar in February (15.86 KgF).

Fruits harvested from Ansar showed the highest weight value in the first, second, and third harvest (284.4, 306.2, and 341.1 g respectively). While in the last harvest where Ansar was not included, Abbbasieh fruit gave the highest weight value (329.22 g).

The results obtained showed minor fluctuations in the firmness values with the harvesting dates in all locations.

A comparison was done between the locations harvested the same dates. There is a significant difference between the mean weight of avocado Reed fruits harvested from Abbasiyeh and Ansar in December and January.

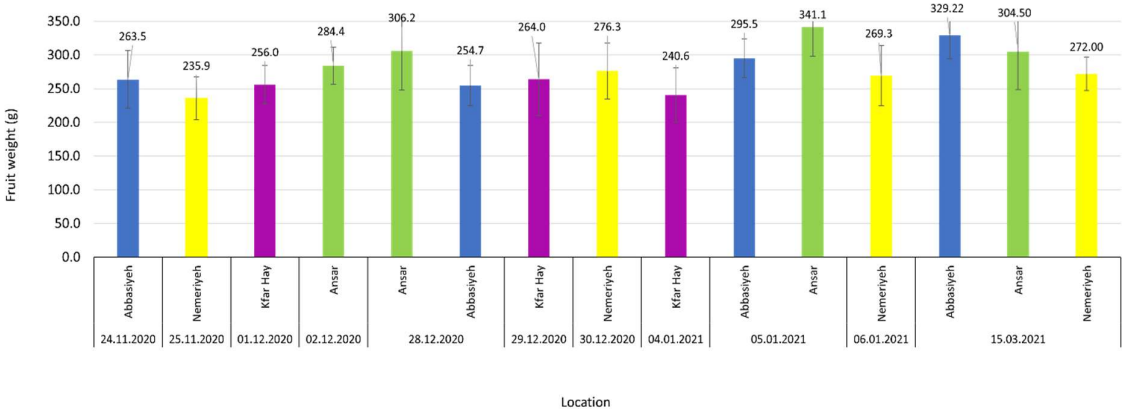


Figure 22: Weight of Reed avocado variety between November 2020 and March 2021

4. Lambhass

Avocado Lambhass variety was harvested from 4 different locations (Abbasiyeh, Ansar, Halba, and Mrwaniyeh) over 4 harvesting stages between November 2020 and March 2021.

As shown in figure 23 below, the lowest weight value of Lambhass was recorded at Abbasiyeh in November (176.5 g), while the highest weight was recorded at Mrwaniyeh in December (292.5 g).

Mrwaniyeh fruits were always giving the highest weight from November till march.

Fluctuation in fruit weight was shown in all locations with the time of harvest.

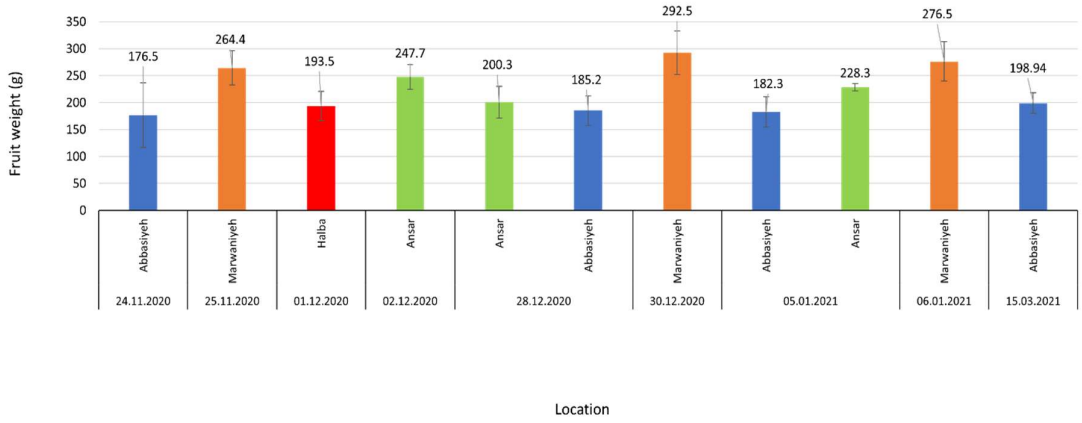


Figure 23: Weight of Lambhass avocado variety between November 2020 and March 2021

5. Ettinger

Avocado Ettinger variety was harvested from 4 different locations (Ansar,Halba, Kfar Hay, and Mrwaniyeh) over 3 harvesting stages between November 2020 and January 2021.

As shown in figure 24 below, the lowest weight value of Ettinger was recorded at Halba in early December (263.7 g), while the highest weight value was recorded at Mrwaniyeh in November (475 g).

Mrwaniyeh fruits were always giving the highest weight from November till March.

The results obtained showed that the weight value increased with time in Halba and decreased in Kfar Hay, while it was fluctuating in other locations.

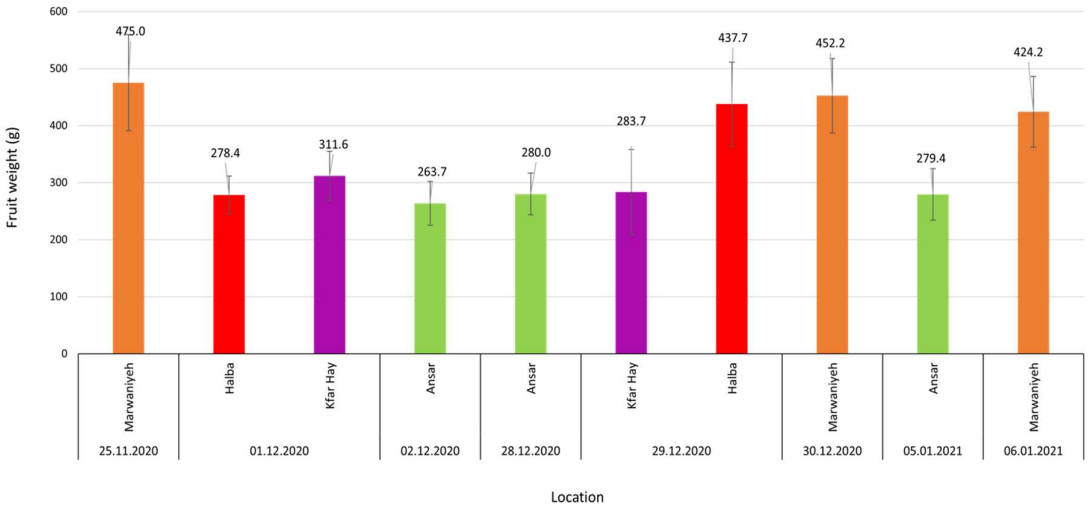


Figure 24: Weight of Ettinger avocado variety between November 2020 and January 2021

6. Pinkerton

Avocado Pinkerton variety was harvested from 6 different locations (Abbasiyeh, Ansar, Markabta, Kfar Hay, Mrwaniyeh, and Nmeiriyeh) over 4 harvesting stages between November 2020 and March 2021.

As shown in figure 25 below, the lowest value of weight in Pinkerton was recorded at Markabta in January (216.32 g), while the highest weight value was shown in Nmeiriyeh in November (365.92 g).

Nmeiriyeh fruits showed the highest value in the first harvest (365.92 g). In the second harvest, Mrwaniyeh showed the highest weight average (355.38 g). In the third harvest, the highest weight was obtained at Mrwaniyeh (337.01 g), while Nmeiriyeh gave the highest weight during the last harvest (296.46 g).

The results obtained showed that the weight of Pinkerton fruits was decreasing in Markabta and fluctuating in all locations with date of harvest.

When comparing the values between locations harvested at the same day, a significant difference of weight value was shown between Nmeiriyeh and Mrwaniyeh in December.

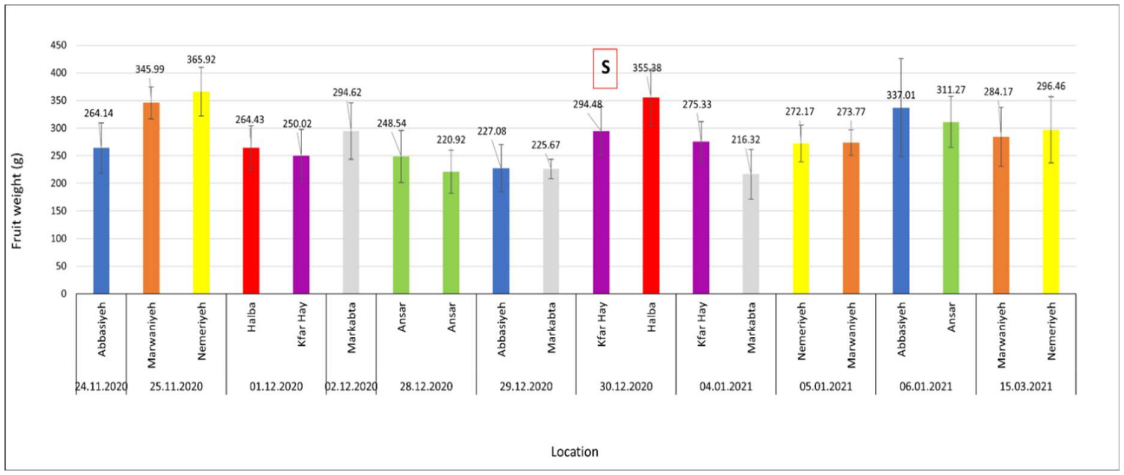


Figure 25: Weight of Pinkerton avocado variety between November 2020 and March 2021

7. Horshim

Avocado Horshim fruits were harvested from only 1 location (Ansar) over 4 harvesting stages between November 2020 and March 2021.

As shown in figure 26 below, 288.7 g was the lowest weight of Horshim in December, while the highest value was obtained during January (325.6 g). The values of firmness were fluctuating with the harvesting time from December till March.

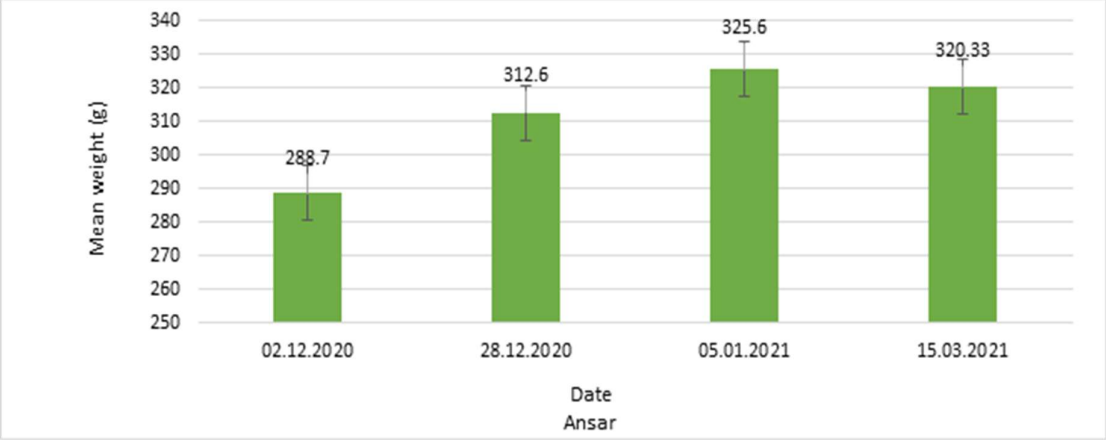


Figure 26: Weight of Horshim avocado variety between November 2020 and March 2021

E. TITRABLE ACIDITY

1. Hass

Avocado Hass variety was harvested from 6 different locations (Abbasiyeh, Ansar, Markabta, Kfar hay, Mrwaniyeh, and Nmeiriyeh) over 4 harvesting stages between November 2020 and March 2021.

As shown in figure 27 below, the lowest value of acidity in Hass was recorded at Nmeiriyeh in January (0.085 g/100ml), while the highest acidity value was recorded at Abbasiyeh in November (0.24 g/100 ml).

In the 4 harvesting stages, avocado Hass fruits harvested from Abbasiyeh had the highest acidity values compared to other locations. In the early harvest stage (late November-early December) Abbasiyeh fruits recorded an acidity value of 0.24 g /100ml, during the second stage (late December) fruits at Abbasiyeh recorded an acidity value of 0.233 g/100ml. In the third harvest (January) Abbasiyeh Hass fruits recorded an acidity value of 0.119 g/100ml, while during the last harvest (March), Abbasiyeh Hass fruits had an acidity value of 0.183 g/100ml.

The results obtained showed some fluctuation in acidity values in all locations for the 4 harvesting stages.

A comparison was done between the locations harvested at the same dates. There was a significant difference between the mean acidity values of avocado Hass fruits harvested in December between Ansar and Abbasiyeh, Markabta and Kfar Hay. There was also a significant difference between the mean acidity values of avocado Hass fruits harvested in Nmeiriyeh and Mrwaniyeh in December and January.

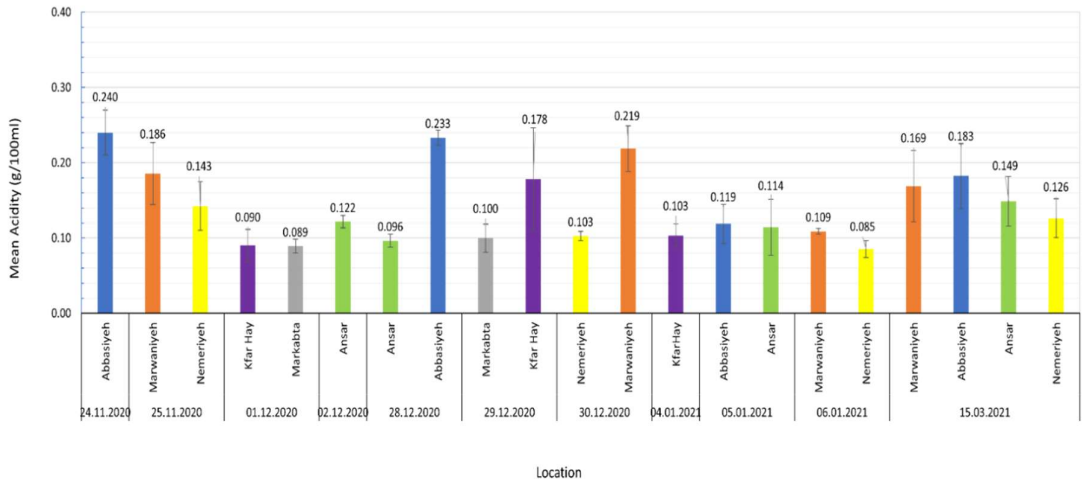


Figure 27: Acidity values of Hass avocado variety between November 2020 and March 2021

2. Pinkerton

Avocado Pinkerton variety was harvested from 6 different locations (Abbasiyeh, Ansar, Markabta, Kfar Hay, Mrwaniyeh, and Nmeiriyeh) over 4 harvesting stages between November 2020 and March 2021.

As shown in figure 28 below, the lowest value of acidity in Pinkerton was recorded at Nmeiriyeh in December (0.07 g/100ml), while the highest acidity value was recorded at Abbasiyeh in November (0.15 g/100 ml).

In the early harvest stage (November-early December) Abbasiyeh showed the highest acidity value (0.15 g /100ml), while during the second stage (late December) fruits at Kfar Hay recorded the highest acidity value (0.14 g/100ml). In the third harvest (January) Abbasiyeh Pinkerton fruits showed the highest value (0.13 g/100ml), while during the last harvest (March), Nmeiriyeh Pinkerton fruits had the highest acidity value (0.09 g/100ml).

The results obtained showed a decrease in acidity with harvesting date at Mrwaniyeh, while there was some fluctuation in all other locations.

A comparison was done between the locations harvested at the same dates. There was a significant difference between the mean acidity values of avocado Pinkerton fruits harvested in November between Mrwaniyeh and Nmeiriyeh, in December and January between Ansar and Abbasiyeh.

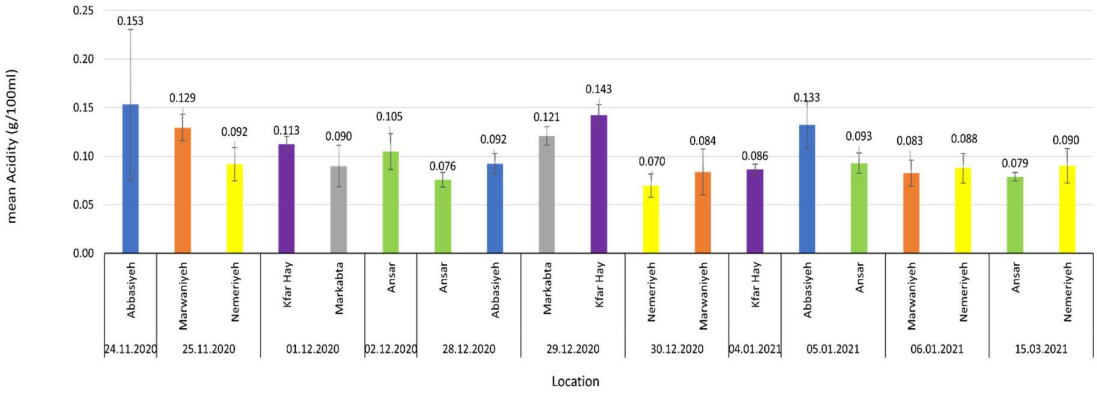


Figure 28: Acidity values of Pinkerton avocado variety between November 2020 and March 2021

3. Fuerte

Avocado Fuerte variety was harvested from 7 different locations (Abbasiyeh, Ansar, Markabta, Halba, Kfar Hay, Mrwaniyeh, and Nmeiriyeh) over 4 harvesting stages between November 2020 and March 2021.

As shown in figure 29 below, the lowest value of acidity in Fuerte was recorded at Abbasiyeh in December (0.06 g/100ml), while the highest acidity value was recorded at Kfar Hay in December (0.23 g/100 ml).

In the early harvest stage (November-early December) Abbasiyeh showed the highest acidity value (0.15 g /100ml), while during the second stage (late December) fruits at Kfar Hay recorded the highest acidity value (0.23 g/100ml). In the third harvest (January) Abbasiyeh Fuerte fruits showed the highest value (0.15 g/100ml), while during the last harvest (March), Ansar Fuerte fruits had the highest acidity value (0.16 g/100ml).

The results obtained showed an increase in acidity with harvesting date at Ansar, while there was some fluctuation in all other locations.

A comparison was done between the locations harvested at the same dates. There was a significant difference between the mean acidity values of avocado Fuerte fruits harvested in November and December between Mrwaniyeh and Nmeiriyeh. There was also a significant difference between the mean acidity values of avocado Fuerte fruits harvested in March between Ansar and Nmeiriyeh.

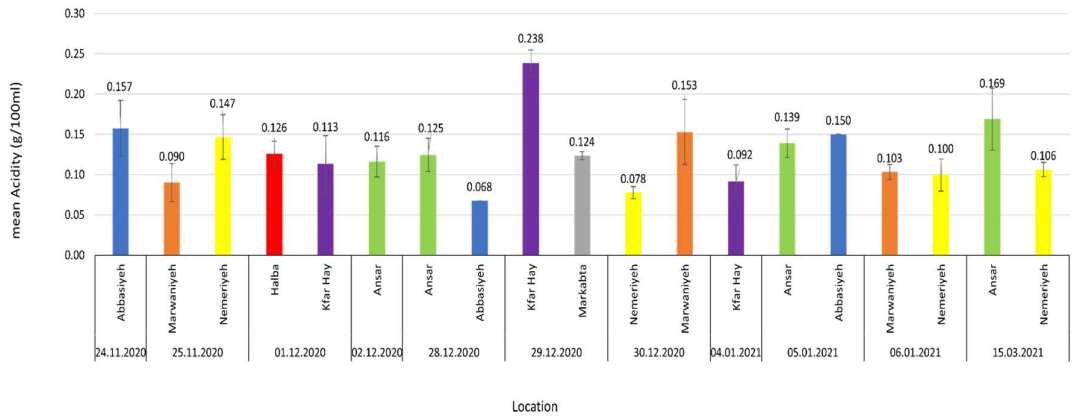


Figure 29: Acidity values of Fuerte avocado variety between November 2020 and March 2021

4. Ettinger

Avocado Ettinger variety was harvested from 4 different locations (Ansar, Halba, Kfar Hay, Mrwaniyeh) over 3 harvesting stages between November 2020 and January 2021.

As shown in figure 30 below, the lowest value of acidity in Ettinger was recorded at Ansar in December (0.07 g/100ml), while the highest acidity value was recorded at Halba in December (0.26 g/100 ml).

In the early harvest stage (November-early December) Mrwaniyeh showed the highest acidity value (0.13 g /100ml), while during the second stage (late December) fruits at Halba recorded the highest acidity value (0\.26 g/100ml). In the third harvest (January) Mrwaniyeh Ettinger fruits showed the highest acidity value (0.10 g/100ml).

The results obtained showed an increase in acidity with harvesting date at Kfar Hay and Halba, while there was some fluctuation in all other locations.

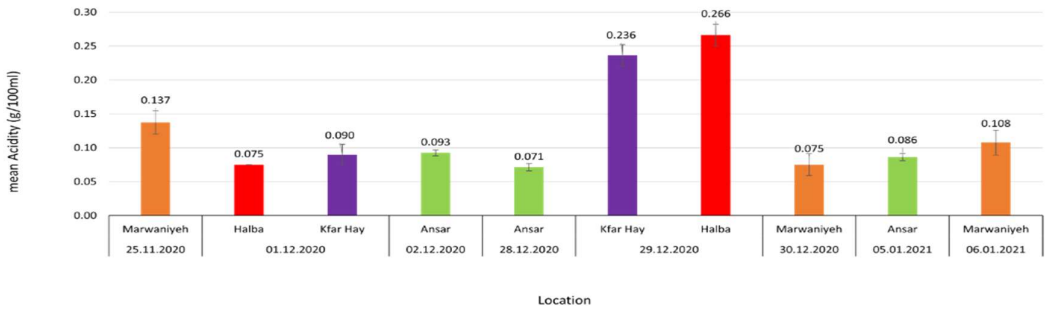


Figure 30: Acidity values of Ettinger avocado variety between November 2020 and January 2021

5. Reed

Avocado Reed variety was harvested from 4 different locations (Abbasiyeh, Ansar, Kfar Hay and Nmeiriyeh) over 4 harvesting stages between November 2020 and March 2021.

As shown in figure 31 below, the lowest value of acidity in Reed was recorded at Nmeiriyeh in December (0.07 g/100ml), while the highest acidity value was recorded at Kfar Hay in December (0.22 g/100 ml).

In the early harvest stage (November-early December) Abbasiyeh showed the highest acidity value (0.14 g /100ml), while during the second stage (late December) fruits at Kfar Hay recorded the highest acidity value (0.22 g/100ml). In the third harvest (January) Abbasiyeh Reed fruits showed the highest value (0.18 g/100ml), while during the last harvest (March), Abbasiyeh Reed fruits had the highest acidity value (0.21 g/100ml).

The results obtained showed an increase in acidity with harvesting date at Abbasiyeh, while there was some fluctuation in all other locations.

A comparison was done between the locations harvested at the same dates. There was a significant difference between the mean acidity values of avocado Reed fruits

harvested in December and January between Ansar and Abbasiyeh. There was also a significant difference between the mean acidity values of avocado Reed fruits harvested in March between Ansar and Nmeiriyeh.

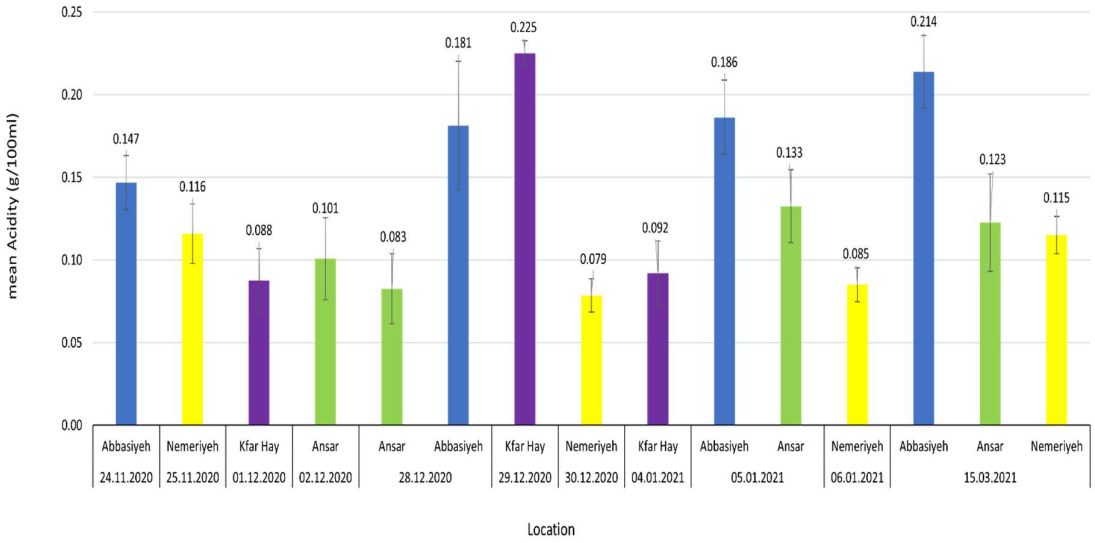


Figure 31: Acidity values of Reed avocado variety between November 2020 and March 2021

6. Lambhass

Avocado Lambhass variety was harvested from 4 different locations (Abbasiyeh, Mrwaniyeh, Halba and Ansar) over 4 harvesting stages between November 2020 and March 2021.

As shown in figure 32 below, the lowest value of acidity in Lambhass was recorded at Ansar in December (0.08 g/100ml), while the highest acidity value was recorded at Abbasiyeh in December (0.22 g/100 ml).

Over the 4 harvesting stages, avocado Lambhass fruits harvested from Abbasiyeh recroded the highest acidity values compared to other locations. In the early harvest stage (November-early December) Abbasiyeh had an acidity value of 0.221 g

/100ml, while during the second stage (late December) fruits at Abbasiyeh recorded an acidity value of 0.227 g/100ml. In the third harvest (January) Abbasiyeh Lambhass fruits had an acidity value of 0.15 g/100ml.

The results obtained showed some fluctuation of acidity values in all locations.

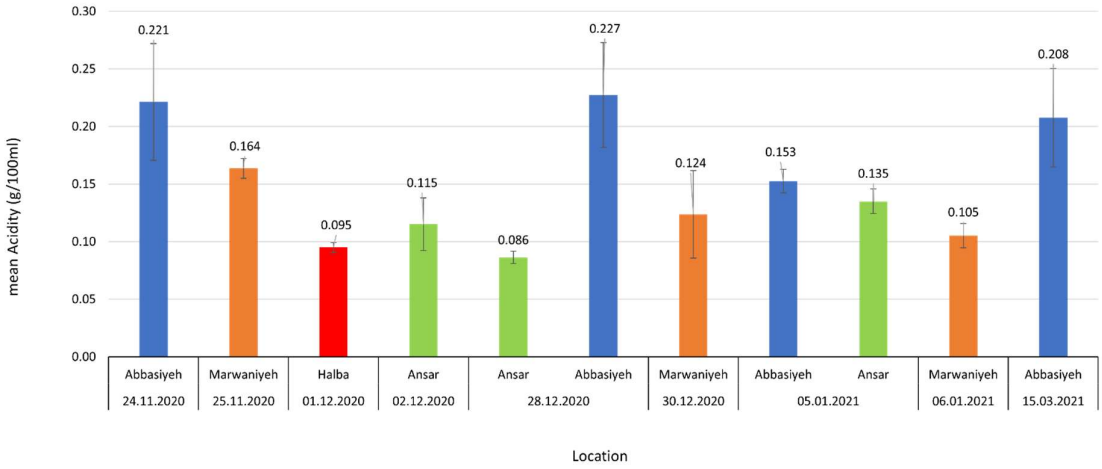


Figure 32: Acidity values of Lambhass avocado variety between November 2020 and March 2021

7. Horshim

Avocado Horshim variety was harvested from only 1 location (Ansar) over 4 harvesting stages between December 2020 and March 2021.

As shown in figure 33 below, the lowest value of acidity was recorded in December (0.1 g/100ml), while the highest acidity value was recorded in March (0.24 g/100ml). The results obtained showed an increase in acidity with harvesting date from late December 2020 till March 2021.

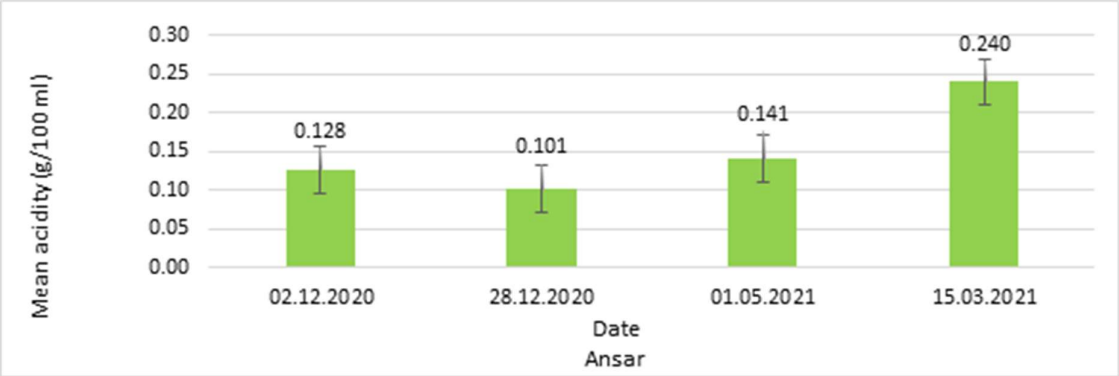


Figure 33: Acidity values of Horshim avocado variety between November 2020 and March 2021

F. TOTAL SOLUBLE SOLIDS

1. Hass

Avocado Hass variety was harvested from 6 different locations (Abbasiyeh, Ansar, Markabta, Kfar hay, Mrwaniyeh and Nmeiriyeh) over 4 harvesting stages between November 2020 and March 2021.

As shown in figure 34 below, the lowest percentage of Total Soluble Solids TSS content in Hass was recorded at Kfar Hay in early December (7.28%), while the highest TSS percentage was recorded at Abbasiyeh in March (10.47%).

In all harvesting stages, Abbasiyeh Hass avocado fruits always had the highest TSS content compared to other locations. These TSS percentages were 9.6% in the early harvest stage (November-early December), 10.18% in the second stage (late December), 10.28% in the third harvest (January) and 10.47% in the last harvest (March).

The results obtained showed an increase in TSS percentages with harvest stages in Abbasiyeh and Kfar Hay and some fluctuation in the other locations.

A comparison was done between the locations harvested at the same dates. There was a significant difference between the mean TSS percentages of avocado Hass fruits harvested in November and January between Mrwaniyeh and Nmeiriyeh.

There was a significant difference between the mean TSS percentages of avocado Hass fruits harvested in Kfar Hay and Markabta in December. There was also a significant difference between the mean TSS content in December and January between Ansar and Abbasiyeh.

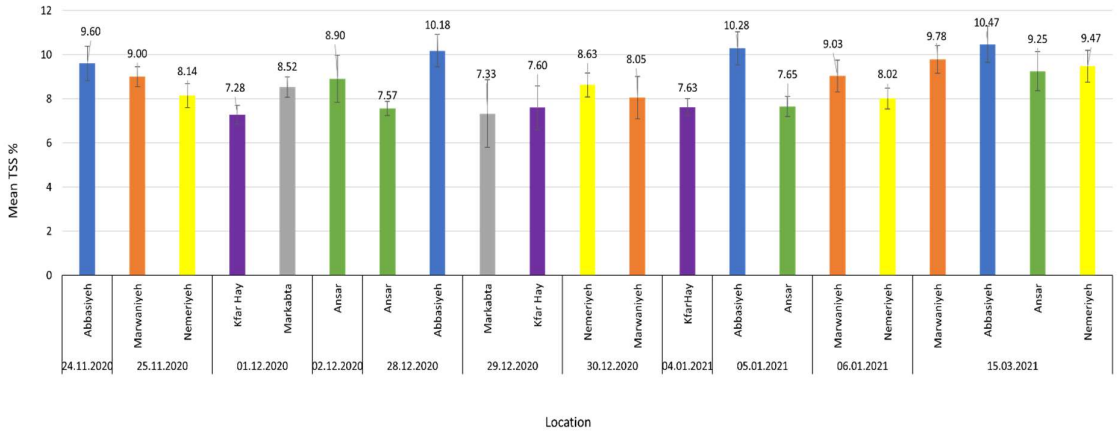


Figure 34: Total Soluble Solids TSS content of Hass avocado variety between November 2020 and March 2021

2. Pinkerton

Avocado Pinkerton variety was harvested from 6 different locations (Abbasiyeh, Ansar, Markabta, Kfar Hay, Mrwaniyeh, and Nmeiriyeh) over 4 harvesting stages between November 2020 and March 2021.

As shown in figure 35 below, the lowest percentage of TSS in Pinkerton was recorded at Markabta and Kfar Hay in December (6.85%), while the highest TSS percentage was recorded at Ansar in December (10.65%).

In the early harvest stage (November-early December) Mrwaniyeh showed the highest TSS percentage (9.43%), while during the second stage (late December) fruits at Ansar recorded the highest TSS percentage (10.65%). In the third harvest (January) Abbasiyeh and Mrwaniyeh Pinkerton fruits showed the highest TSS percentage (9.3%), while during the last harvest (March), Nmeiriyeh Pinkerton fruits had the highest TSS percentage (8.93%).

The results obtained showed a decrease in TSS with harvesting date at Markabta, while there was some fluctuation in all other locations.

A comparison was done between the locations harvested at the same dates. There was a significant difference between the mean TSS percentages of avocado Pinkerton fruits harvested in November in Mrwaniyeh and Nmeiriyeh. There was also a significant difference between the mean TSS percentages in December in Ansar and Abbasiyeh.

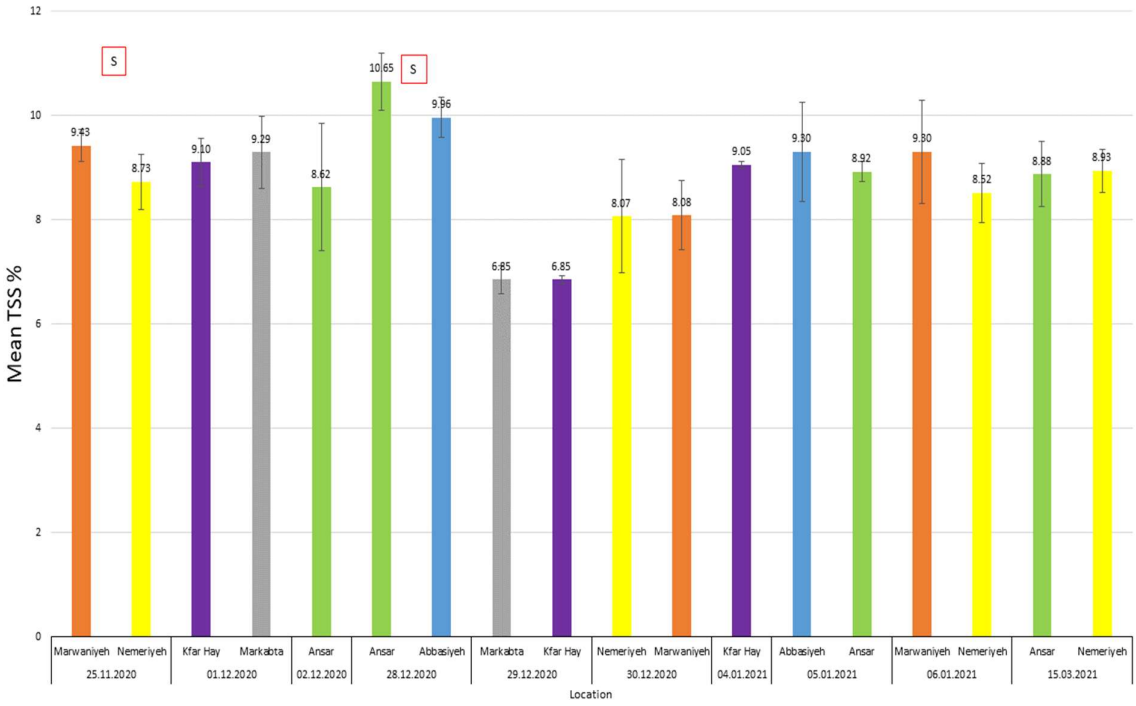


Figure 35: Total Soluble Solids TSS content of Pinkerton avocado variety between November 2020 and March 2021

3. Fuerte

Avocado Fuerte variety was harvested from 7 different locations (Abbasiyeh, Ansar, Markabta, Halba, Kfar Hay, Mrwaniyeh, and Nmeiriyeh) over 4 harvesting stages between November 2020 and March 2021.

As shown in figure 36 below, the lowest percentage of TSS in Fuerte was recorded at Kfar Hay in December (6%), while the highest TSS percentage was recorded at Abbasiyeh in December (12%).

In the early harvest stage (November-early December) avocado Fuerte fruits harvested from Halba showed the highest TSS percentage (9.33%), while during the second stage (late December) fruits at Abbasiyhe recorded the highest TSS percentage (12%). In the third harvest (January) Mrwaniyeh Fuerte fruits showed the highest

percentage (9.33%), while during the last harvest (March), Nmeiriyeh Fuerte fruits had the highest TSS percentage (8.65%).

The results obtained showed an increase in TSS with harvesting date at Mrwaniyeh, while there was some fluctuation in all other locations.

A comparison was done between the locations harvested at the same dates. There was a significant difference between the mean TSS percentages of Mrwaniyeh and Nmeiriyeh avocado Fuerte fruits harvested in November, December and January. There was also a significant difference between the mean TSS percentages of avocado Fuerte fruits harvested in early December between Halba and Kfar Hay.

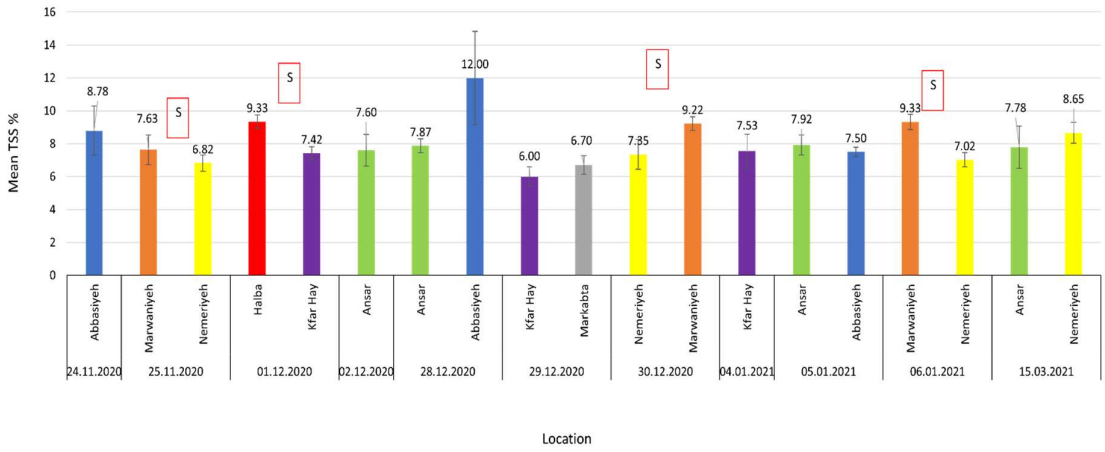


Figure 36: Total Soluble Solids TSS content of Fuerte avocado variety between November 2020 and March 2021

4. Ettinger

Avocado Ettinger variety was harvested from 4 different locations (Ansar, Halba, Kfar Hay, Mrwaniyeh) over 3 harvesting stages between November 2020 and January 2021.

As shown in figure 37 below, the lowest percentage of TSS in Ettinger was recorded at Kfar Hay in December (6.4%), while the highest TSS percentage was recorded at Ansar in December (9.55%).

In the early harvest stage (November-early December) avocado Ettinger fruits harvested from Halba showed the highest TSS percentage (8.9%), while during the second stage (late December) fruits at Ansar recorded the highest TSS percentage (9.55%). In the third harvest (January) Mrwaniyeh Ettinger fruits showed the highest TSS percentage (8.22%).

The results obtained showed some fluctuation of TSS percentage in all locations.

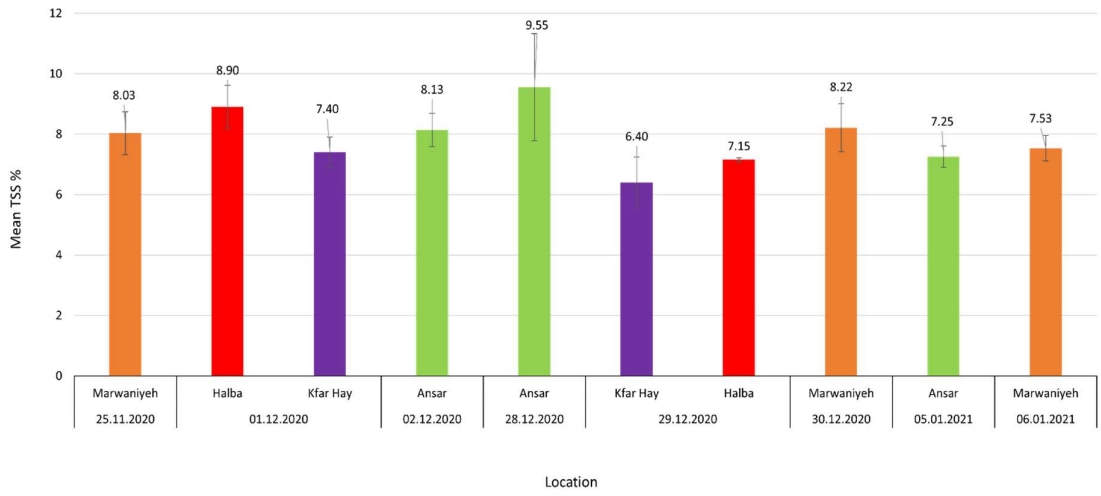


Figure 37: Total Soluble Solids TSS content of Ettinger avocado variety between November 2020 and January 2021

5. Reed

Avocado Reed variety was harvested from 4 different locations (Abbasiyeh, Ansar, Kfar Hay and Nmeiriyeh) over 4 harvesting stages between November 2020 and March 2021.

As shown in figure 38 below, the lowest percentage of TSS in Reed avocado fruits was recorded at Kfar Hay in December (6.3%), while the highest TSS percentage was recorded at Abbasiyeh in January (9.35%).

In the early harvest stage (November-early December) Reed avocado fruits harvested from Abbasiyeh showed the highest TSS percentage (8.8%) while during the second stage (late December) fruits at Abbasiyeh recorded the highest TSS percentage (9.17%). In the third harvest (January) Abbasiyeh Reed fruits showed the highest percentage (9.35%), while during the last harvest (March), Nmeiriyeh and Abbasiyeh Reed fruits had the highest TSS percentage (8.5%).

The results obtained showed a fluctuation of TSS percentages in all locations.

A comparison was done between the locations harvested at the same dates. There was a significant difference between the mean TSS percentages of avocado Reed fruits harvested in December and January between Ansar and Abbasiyeh.

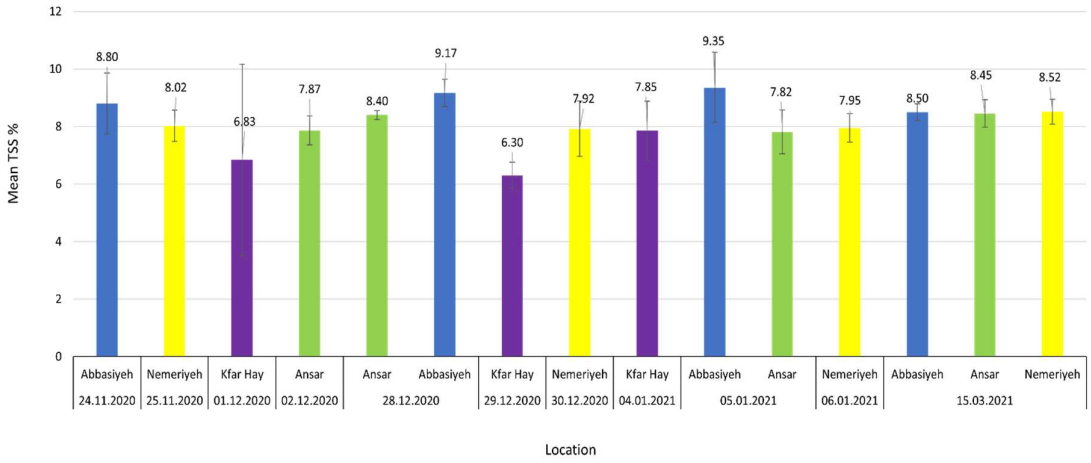


Figure 38: Total Soluble Solids TSS content of Reed avocado variety between November 2020 and March 2021

6. Lambhass

Avocado Lambhass variety was harvested from 4 different locations (Abbasiyeh, Mrwaniyeh, Halba and Ansar) over 4 harvesting stages from November 2020 till March 2021.

As shown in figure 39 below, the lowest percentage of TSS in avocado Lambhass fruits was recorded at Ansar in January (8.85%), while the highest TSS percentage was recorded at Ansar in December (13.4%).

In the early harvest stage (November-early December) Abbasiyeh showed the highest TSS percentage (11.04%), while during the second stage (late December) fruits at Ansar recorded the highest TSS percentage (13.4%). In the third harvest (January) Abbasiyeh Lambhass fruits showed the highest TSS percentage (9.28%).

The results obtained showed some fluctuation of TSS percentages in all locations.

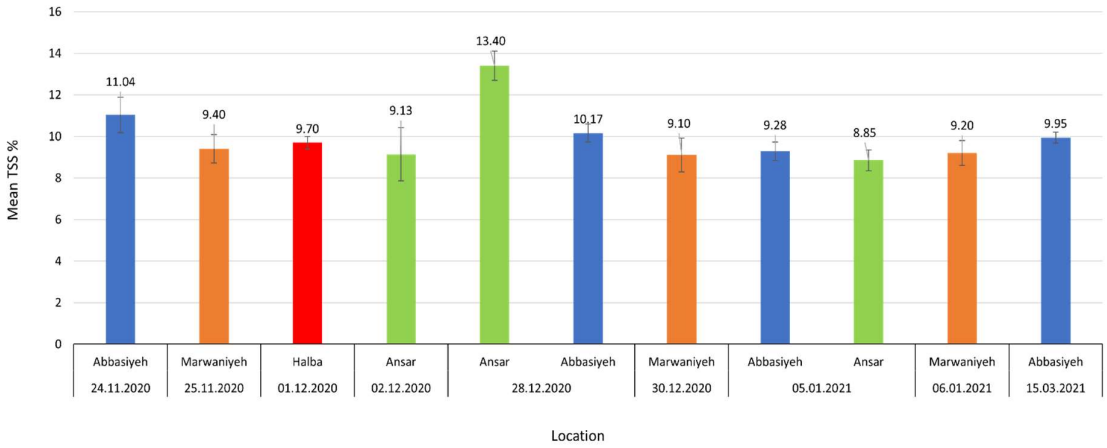


Figure 39: Total Soluble Solids TSS content of Lambhass avocado variety between November 2020 and March 2021

7. Horshim

Avocado Horshim variety was harvested from only 1 location (Ansar) over 4 harvesting stages between December 2020 and March 2021.

As shown in figure 40 below, the lowest percentage of TSS was recorded in early December (7.27%), while the highest TSS percentage was recorded in March (8.9%). The results obtained showed a fluctuation in TSS percentage with harvesting dates from December 2020 till March 2021.

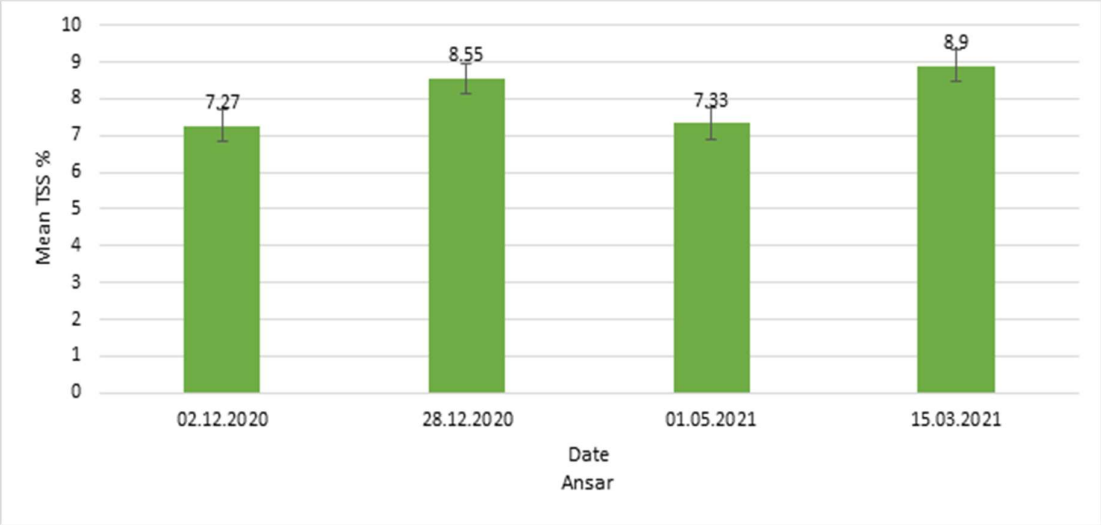


Figure 40: Total Soluble Solids TSS content of Horshim avocado variety between November 2020 and March 2021

CHAPTER IV

PRINCIPAL COMPONENT ANALYSIS PCA

A PCA was done for the avocado fruits to study the correlation between the maturity indices throughout the harvesting season. For this analysis the harvesting dates were presented as three harvesting stages to observe the data clearly.

Three Principal component Analysis (PCA) were performed for the avocado fruits to study the correlation between the maturity indices and to observe the clustering behavior of the varieties throughout the 3 harvesting sages in the season.

During the first harvesting stage, a strong correlation was observed between the dry matter % and the oil content % (r^2=0.77).

The 1st principal component was positively correlated with the variables dry matter (%), oil content (%), and weight (g) and negatively correlated with the TSS (%) and TA (%). The 2nd principal component had a positive correlation with dry matter % and firmness without skin (KgF) and a negative correlation with weight (g).

The factor map of the early harvesting stage allowed the detection of classes or groups of individuals associated with maturity indices as per figure 41. Cluster 1: high TSS (%), firmness without skin (KgF) and TA (%), low weight (g), Cluster 2: low firmness without skin (KgF), dry matter (%) and oil content (%), Cluster 3: high dry matter (%), oil content (%) and weight (g), low firmness without skin (KgF) and TSS (%).

During the mid-harvest stage, the correlation between the oil content % and dry matter %tended to get stronger (r^2=0.98).

The 1st principal component was positively correlated with the variables weight (g), dry matter (%) and oil content (%) and moderately negatively correlated with the TSS (%)

and firmness without skin (KgF). The 2nd principal component had a positive correlation with dry matter (%), firmness without skin (KgF) and oil content (%), moderate negative correlation with weight (g) and TA (%).

The factor map of the mid harvesting stage allowed the detection of classes or groups of individuals associated with maturity indices as per figure 40.

Cluster 1: high firmness without skin (KgF), low weight (g) and TA (%)

Cluster 2: low dry matter (%) and oil content (%)

Cluster 3: high dry matter (%) and oil content (%)

During the late harvest stage, the correlation between the dry matter % and oil content % of the avocado fruits was still strong (r^2=0.95). The weight showed a negative correlation with firmness without skin (r^2= - 0.72) and the TSS% (r^2= - 0.74). The TSS% was positively correlated with the firmness without skin (r^2=0.71).

The 1st principal component was positively correlated with the variables Firmness without skin (KgF) and TSS (%) and negatively correlated with the weight (g). The 2nd principal component had a positive correlation with dry matter % and oil content % and a negative correlation with TSS (%).

The factor maps of the three harvesting stages allowed the detection of classes or groups of individuals associated with maturity indices as per figure 40.

Cluster 1: high TA (%), low dry matter (%) and oil content (%)

Cluster 2: high firmness without skin (KgF) and TSS (%), low weight (g)

Cluster 3: high dry matter (%) and oil content (%) and low TA (%)

The individuals are shown in APPENDEX 3.

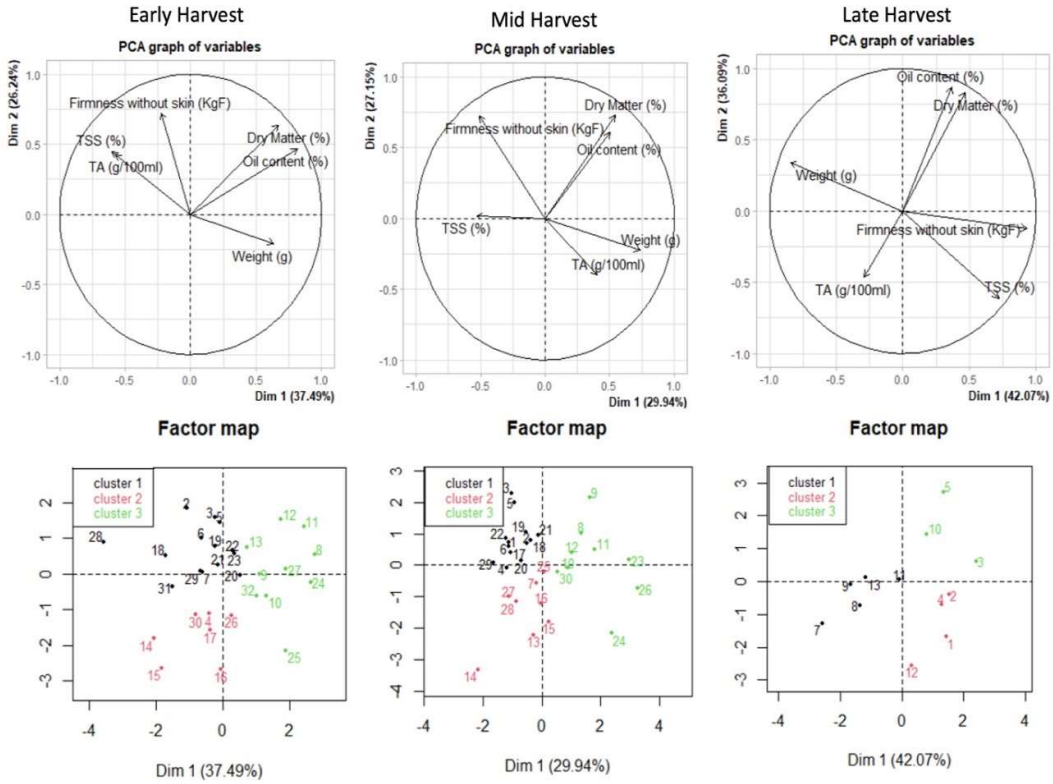


Figure 41: PCA graphs showing the correlation and clustering behavior of the studied maturity indices

CHAPTER V

RADAR DATA INTERPRETATION

A radar chart for every maturity index was done to compare and visualize the behavior of all avocado varieties throughout the whole season (figure 42). Regarding the titratable acidity, the percentage varied between 0.10% for Pinkerton and 0.16% for Horshim. The other varieties range between 0.11 and 0.12%. (Fuerte, Reed and Hass, Ettinger and Lambhass in increasing order).

The firmness without skin of the avocado fruits showed a variation among the varieties where Ettinger had the lowest value (12.41 KgF), while the firmest variety was Hass (18.20 KgF). The other varieties' firmness ranged between 14.04 KgF and 17.92 KgF. (Reed, Fuerte, Horshim, Lambhass, and Pinkerton in increasing order).

Concerning the total soluble solid percentage (TSS%), the values ranged from 7.81% for Ettinger to 9.52% for Lambhass. The remaining varieties varied between 7.90% and 8.82%. (Fuerte, Horshim, Reed, Hass, and Pinkerton in increasing order).

Fruit weight (g) showed an obvious variation among varieties with Ettinger being the heaviest (345.1 g), and Hass being the lightest (177.46 g). The rest of the verities showed approximately uniform values between 211.66 g and 315.5 g. (Lambhass, Pinkerton, Reed, Fuerte, and Horshim ascendingly).

Regarding the dry matter, Reed variety had the lowest percentage with 18.21%, while Fuerte had the highest dry matter content (28.5%). The other varieties had their dry matter ranging between 22.42% and 26.65% (Lambhass, Pinkerton, Hass, Ettinger, and Horshim in ascending order).

A clear difference in oil content was observed between the studied varieties with Reed having the lowest value (9.74%), and Fuerte having the highest value (21.6%). The

other OC% values ranged from 12.33 % to 19.825% (Lambhass, Pinkerton, Hass, Ettinger and Horshim in increasing order).

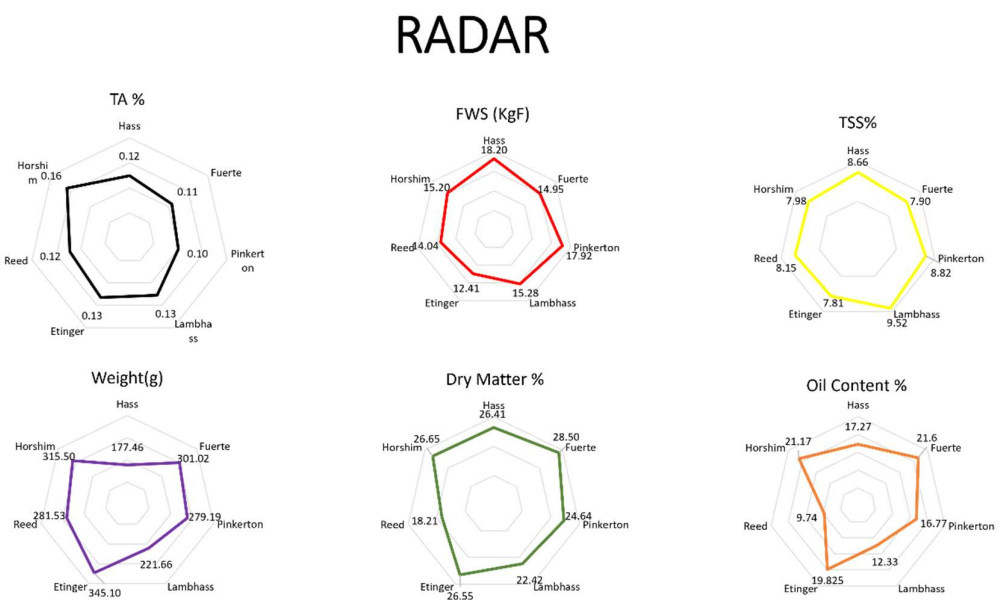


Figure 42: Radar showing the behavior of each maturity indices according to the different avocado varieties.

CHAPTER VI

2021-2022 SEASON RESULTS

Another season was done to verify the previous data for the most significant maturity indices and to test the use of non-destructive methods for dry matter quantification.

Since this study is done for export purpose a new section was added during this season which aims to test the effect of MCP treatment; a chemical that inhibits ethylene effects thus delaying ripening. During this season fruits were harvested from south and north Lebanon with a slight modification for the north locations but keeping the same conditions.

A. Dry matter

Several maturity parameters were measured during the second season and focus was shed on the dry matter for being the most important parameter. This helped to verify the data of the first season and have more representative conclusions.

B. Near Infrared device NIR

Since the dry matter is considered as the most significant parameter to study the maturity of avocado fruits, the NIR device was used to measure the DM% of fruits and the results were then compared to that obtained by the oven.

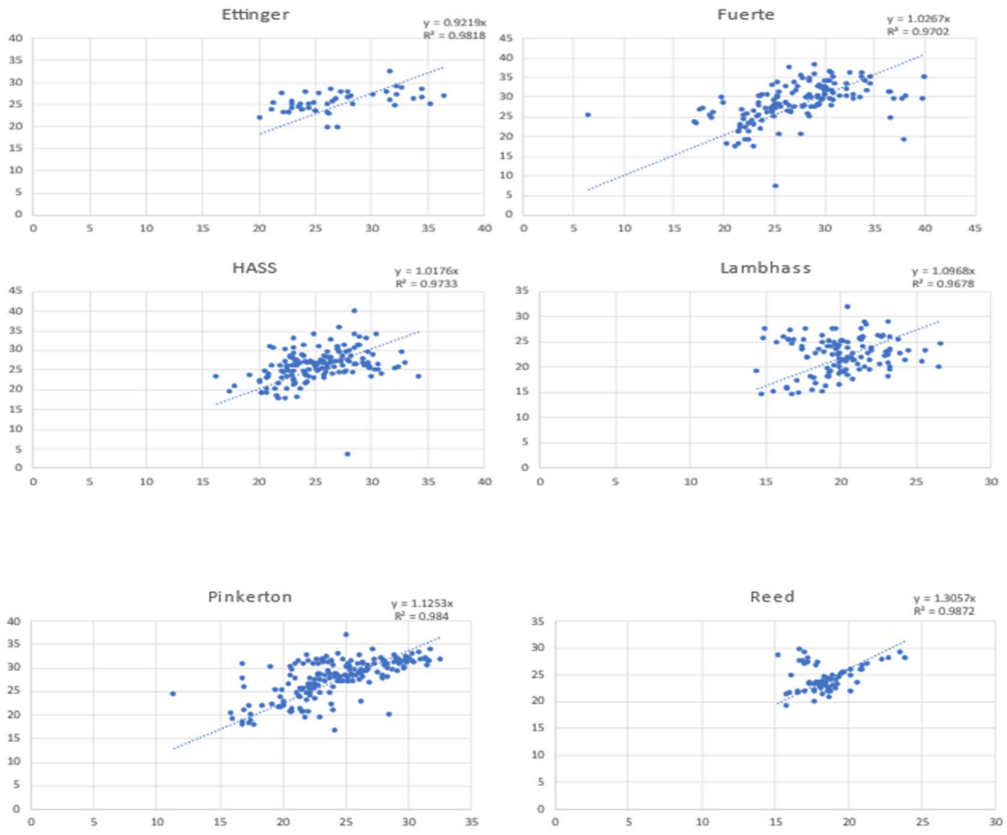


Figure 43: graphs showing the correlation between the dry matter using the oven and NIR device

The graphs show a strong correlation between the dry matter of the avocado varieties studied between the oven and the NIR device with R>0.9. This ensures the use of this non-destructive method as a method to rely on in order to obtain fast dry matter findings.

C. Shelf Life

One fruit from each sample was stored at room temperature in order to test fruits' shelf life in relation to the variety and the location from which it was harvested.

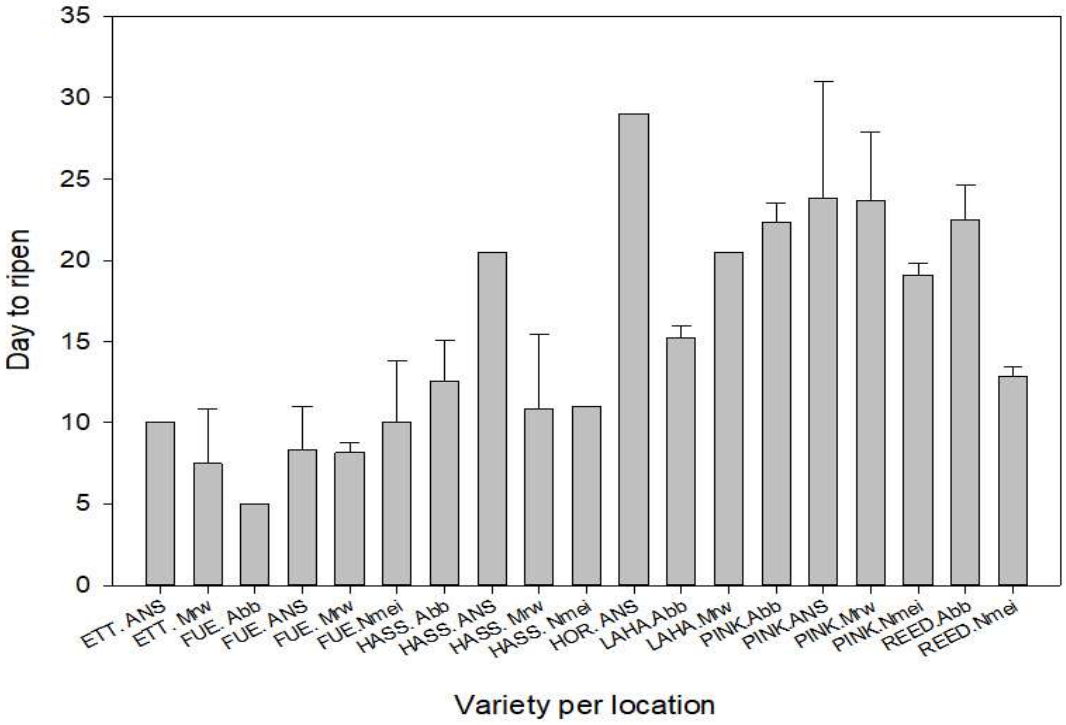


Figure 44: a graph showing the shelf life of different avocado varieties harvested from different locations during the early harvest stage

Avocado fruits from each sample were kept at room temperature to study their shelf life in relation to the variety and the studied location. This experiment took place during the second harvesting season starting from November 2021 till March 2022. The harvesting dates were categorized into 3 harvesting stages to simplify the findings.

During the early harvest stage, the fruits with the longest shelf life were Horshim harvested from Ansar, while the lowest shelf life was obtained for Fuerte at Abbasiyeh. Ettinger fruits were harvested from Ansar and Mrwaniyeh. Avocado from ansar showed a

longer shelf life (10 days) than those harvested from Mrwaniyeh (7.5 days). Fuerte Avocado fruits were harvested during this stage from 4 locations, Abbasiyeh, Ansar, Mrwaniyeh, and Nmeiriyeh. Fuerte fruits from Nmeiriyeh showed to have the longest shelf life (10 days), while those from Abbasiyeh showed to have the lowest (5 days). Hass avocados were also harvested from 4 locations from which Fuerte were taken. Hass fruits from Ansar had the highest shelf life (21 days), while fruits from Nmeiriyeh and Mrwaniyeh took around 10 days to ripen. Horshim was only harvested from Ansar where it showed a high shelf life (28 days). Regarding Lambhass, they were harvested from Abbasiyeh and Mrwaniyeh where their shelf life was 15 days and 20 days respectively. Pinkerton fruits were harvested from 4 locations Abbasiyeh, Ansar, Mrwaniyeh, and Nmeiryeh with the highest value at both Ansar and Mrwaniyeh (22 days), while the lowest in Nmeiriyeh (17 days). Concerning Reed avocados, they were harvested from Abbasiyeh and Nmeiriyeh with 22 days and 12 days shelf life respectively.

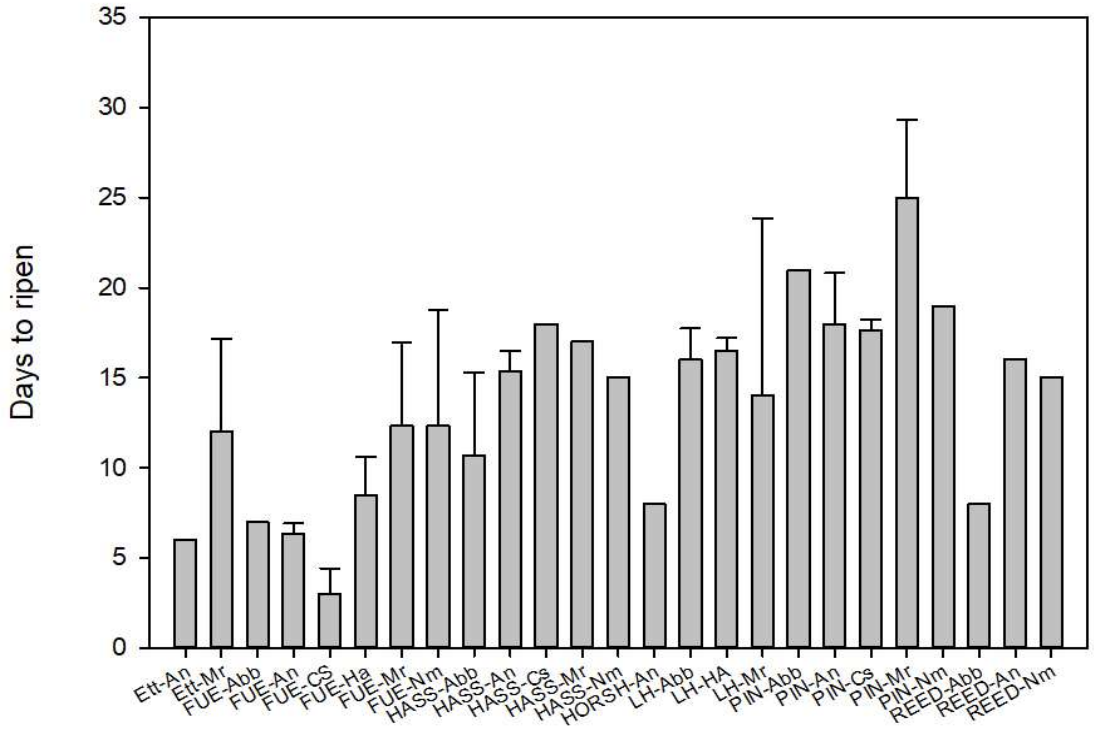


Figure 45: a graph showing the shelf life of different avocado varieties harvested from different locations during the mid-harvest stage.

During the mid-harvest stage, the fruits with the longest shelf life were Pinkerton harvested from Mrwaniyeh (25 days), while the lowest shelf life was obtained for Fuerte at Cheikh El Sahel (2 days). Ettinger fruits were harvested from Ansar and Mrwaniyeh. Avocado from Mrwaniyeh showed a longer shelf life (12 days) than those harvested from Ansar (6 days). Fuerte Avocado fruits were harvested during this stage from 6 locations, Abbasiyeh, Ansar, Mrwaniyeh, Halba, Cheikh El Sahel, and Nmeiriyeh. Fuerte fruits from Nmeiriyeh and Mrwaniyeh showed to have the longest shelf life (10 days), while those from Cheikh El Sahel showed to have the lowest (2 days). Hass avocados were also harvested from 5 locations Abbasiyeh, Ansar, Mrwaniyeh, Cheikh El Sahel, and Nmeiriyeh. Hass fruits from Cheikh El Sahel had the highest shelf life (17 days), while

fruits from Abbasiyeh took around 10 days to ripen. Horshim was only harvested from Ansar where it showed a shelf life of 7 days. Regarding Lambhass, they were harvested from Abbasiyeh, Mrwaniyeh, and Halba. The longest shelf life was for fruits harvested from Halba (16 days), while the shortest was from Mrwaniyeh (13 days). Pinkerton fruits were harvested from 5 locations Abbasiyeh, Ansar, Mrwaniyeh, Cheikh El Sahel and Nmeiryeh with the highest value at Mrwaniyeh (25 days), while the lowest in Cheikh El Sahel (16 days). Concerning Reed avocados, they were harvested from Abbasiyeh, Ansar, and Nmeiriyeh with the longest shelf life for fruits from Ansar (16 days), while fruits from Abbasiyeh took 7 days to ripen.

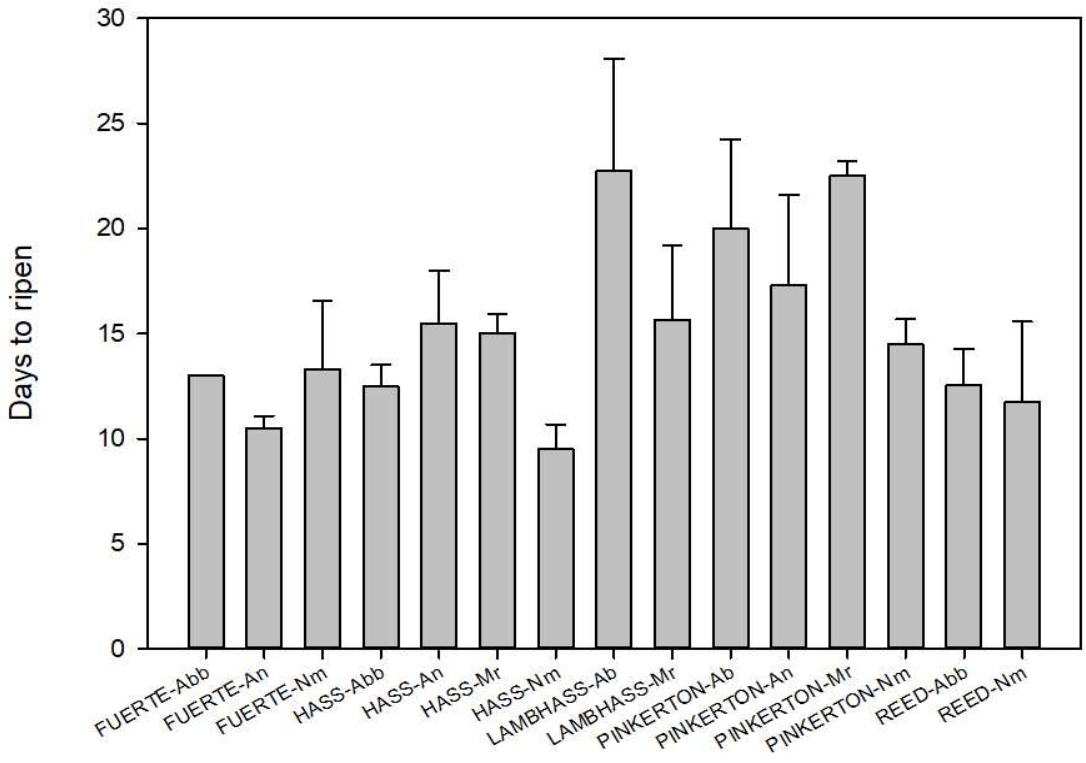


Figure 46: a graph showing the shelf life of different avocado varieties harvested from different locations during the late-harvest stage

During the late-harvest stage, the fruits with the longest shelf life were Lambhass harvested from Abbasiyeh (23 days), while the lowest shelf life was obtained for Hass at Nmeiriyeh shared with Fuerte from Ansar (9 days). Fuerte Avocado fruits were harvested during this stage from Ansar, Abbasiyeh, and Nmeiriyeh. Fuerte fruits from Nmeiriyeh showed to have the longest shelf life (13 days), while those from Ansar showed to have the lowest (10 days). Hass avocados were also harvested from 4 locations Abbasiyeh, Ansar, Mrwaniyeh, and Nmeiriyeh. Hass fruits from Ansar had the highest shelf life (15 days), while fruits from Nmeiriyeh took around 10 days to ripen. Regarding Lambhass, they were harvested from Abbasiyeh and Mrwaniyeh. The longest shelf life was for fruits harvested from Abbasiyeh (21 days), while the shortest was from Mrwaniyeh (15 days). Pinkerton fruits were harvested from 4 locations Abbasiyeh, Ansar, Mrwaniyeh, and Nmeiryeh with the highest value at Mrwaniyeh (22 days), while the lowest in Nmeiriyeh (15 days). Concerning Reed avocados, they were harvested from Abbasiyeh and Nmeiriyeh with the longest shelf life for fruits from Ansar (12 days), while fruits from Abbasiyeh took around 11 days to ripen.

D. MCP treatment

1-MCP is a gaseous ethylene action inhibitor. It which irreversibly binds to the ethylene receptors in the fruit to prevent ethylene-dependent responses. The binding affinity of 1-MCP for the receptors is approximately 10 times greater than that of ethylene so it competes with it. In addition to the ethylene blocking action, 1-MCP also influences ethylene biosynthesis in some species through feedback inhibition (Kubheka et al., 2020). MCP maintains fruit quality and extends storage life by preserving membrane integrity under extended storage.

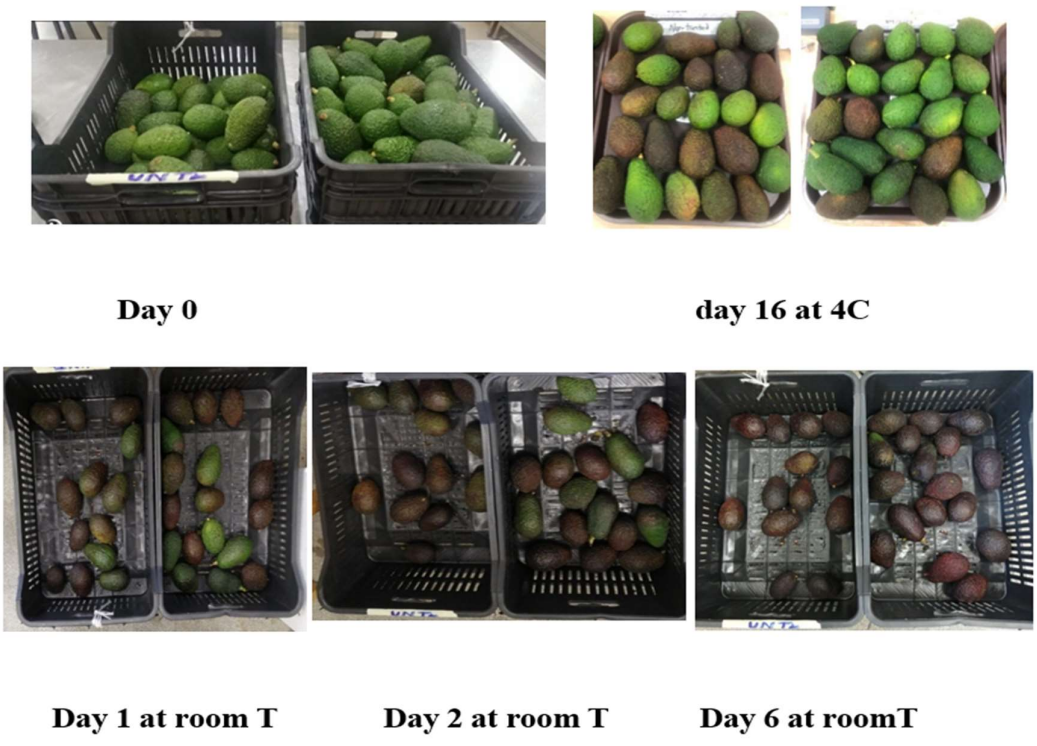


Figure 47: MCP-treated and un-treated avocado fruits' morphology at different stages.

The results in figure 48 show the trend of dry matter % of the untreated and MCP-treated avocado fruits. The fruits were stored at 4 °C, and their dry matter was measured using the NIR device. Then fruits were stored at room temperature to study the shelf life. The dry matter % in both case almost went parallel till the last stag of the study by which fruits were keptat room tempersture. The DM percentage for the untreated fruits increased by 1.56% throughout the study focusing on the last stage. However, that of the MCP-treated fruits almost stayed constant**.**

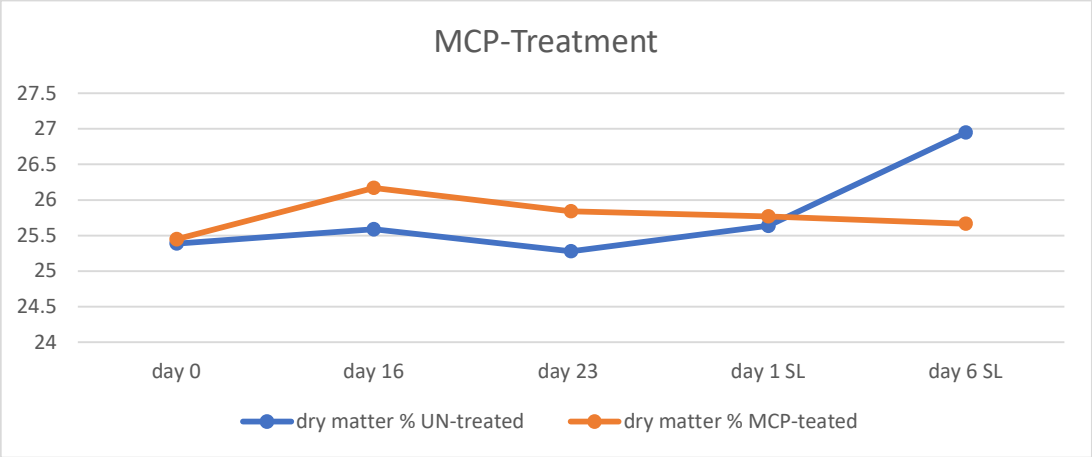


Figure 48: a graph showing the dry matter % of avocado fruits MCP-treated and un-treated from day zero till 16 at 4 °C, and then from day 1 till day 6 at room temperature, (SL= Shelf life)

The firmness without skin of avocado samples was studied too at the fruits' shelf life between day 1 and day 6. The firmness of the untreated samples decreased by 79% throughout the time period. However, the firmness of the MCP-treated fruits decreased by only 48 % which shows the effect of MCP on the fruit firmness (table 2).

Table 2: firmness without skin of the MCP- treated and untreated avocado fruits while stored at room T.

	Firmness without skin Kgf	
	Un-treated	**MCP-treated**
day 1 SL	1.06	1.63
day 6 SL	0.22	0.89
difference %	**79.20%**	**48.50%**

CHAPTER VII

DISCUSSION

The avocado production system in Lebanon currently lacks a validated technological model, which increases production uncertainty. Fruit production must ensure the delivery of a high-quality product to the market that meets importing countries' international standards, taking into account agronomic factors such as cultivation, harvest, post-harvest, logistics, storage, and marketing. As a result, one of the primary goals of this research is to identify specific parameters that ensure the production of high-quality fruit in order to position Lebanon and its avocado production in global markets.

In this study, the physicochemical parameters were measured to characterize the initial quality and to determine the best harvest time of seven avocado varieties growing in multiple locations that vary in their altitudes. Our data did not show a significant correlation between fruit weight and orchard's altitude. For instance, the orchard with the smallest Hass fruits (139.4 g) was Markabta located at the one of the highest altitudes (263 m) from the North location. While the biggest Hass weight value (213.1 g) was observed at Abbasiyih; one of the south locations at 158 m altitude. By contrast, Fuerte fruit weight did not show any significant differences between locations with the highest value recorded in Markabta (334.2 g). Nevertheless, (Carvalho *et al.*, 2014) observed a larger fruit size and diameter for higher and medium altitudes in 'Hass' avocados in Mexico. Given the fact that in our study no direct relationship was found between fruit weight and altitudes, more evaluations and factors must be considered such as agricultural practices, crop management, environmental conditions, and others (APPENDIX I). Considering that the firmness is a very reliable parameter to check the ripening of the fruit (White *et al.*, 1999),

it was measured without skin among the studied locations where the firmest varieties were Hass and Pinkerton from south Lebanon (18.9 KgF), this seemed to be higher than what was mainly found in literature for avocado which could be a reason of the climate and agricultural practices, and the date of harvest as well (Arzate-Vázquez *et al.*, 2011). Based on Kokawa *et al.* (2020), avocado fruit firmness can be classified into a 4-category scale ranges: soft (0–65 N), medium-soft (66–130 N), medium-hard (131–195 N), and hard (196–300 N). Thus, most of the fruits at the different harvested date was falling in the medium-hard category. However, the softest variety was Ettinger harvested from the north (9.86 kgf). The variation among locations for the firmness was obvious for several varieties which followed the same trend of softer fruits from the north. As expected, the hardness of avocado fruits trend to decrease throughout the season (Vallejo-Pérez *et al.*, 2015).

The increase in the dry matter is closely associated with avocado fruit maturation and the ripening process (Kassim and Workneh, 2020). As the season progressed, the dry matter of all varieties in all locations was increased but in a different rate. Throughout the entire season, Lambhass experienced the lowest increase rate of only 3%, while Fuerte experienced the highest increase rate of approximately 11%. To the best of our knowledge, this is the only study that includes such a wide range of varieties and locations. As a result, comparing the data to the literature is more challenging. All of the locations included in this study obtained dry matter percentages greater than 18 % at early harvest, except the Reed variety, which registered a range between 13.1% to 18.8%. The differences in the dry matter observed between the orchards were due to the difficulty of visually recognizing the physiological maturity stage of fruits in the field, which does not mean that each orchard cannot achieve the same percentage of dry matter in the fruits.

According Donetti and Terry (2014), the dry matter increased with maturity, regardless of the growing area. Furthermore, in this study, fruit with similar dry matter but from different orchards geographical locations ripened at different rates which vary from 7 to 21 days. The results showed a trend during the second harvest stage where north locations were included. These locations tend to have fruits with a shorter shelf life than south locations in several varieties. During the whole season Fuerte and Ettinger showed a short shelf life, while Pinkerton was always taking more time to ripen, which is correlated with other parameter such as firmness. This could also be a result of the altitude and agricultural practices within each field as well as the time of harvest; the maturity stage of the fruit at the time of harvest (graph 44, 45, 46). These findings can help farmers to verify their harvest strategy and timing, as well as avocado's export criteria. As a result, segregation of DM into faster or slower ripening fruit might be achieved per a single orchard location, but not segregation for absolute ripening time, because of the orchard-to-orchard difference. Due to the fact that exporting avocado needs around a month to reach the target market, more stringent management should be done to ensure good quality. The inhibitor MCP can be used as a recommended ethylene inhibitor to maintain fruit quality (Kubheka et al., 2020). The result in the study done verified the effect of MCP on increasing the shelf life until reaching the export markets which lead to successful export of 5 tons of avocado to Netherland by Rene Moawad Foundation. It was shown that this product has no effect on the dry matter. However, it influences the firmness of the fruit being 0.22 for untreated and 0.89 for the treated samples. This maintained of high firmness after MCP treatment was also observed with many other crops such as apples (McArtney et al., 2011)

Fruit ripening results in an increase in oil content as well as a decrease in moisture content (Osuna-García *et al.*, 2010). The percentage of oil in the fruit is directly

proportional to the percentage of dry matter, allowing the latter to be used as a maturity indicator (Carvalho *et al.*, 2014). Starting in 1925, the California Avocado Industry in the United States used a minimum standard of 8% oil content in the pulp of avocado fruits, but in the 1980s, they began using minimum oil content percentages for each cultivar: 10.0 % for Fuerte and 11.2% for Hass (Carvalho *et al.*, 2015). Many studies considered that avocado oil content could be served as a good indicator of fruit maturity (Kassim *et al.*, 2013). As the fruit matures, the concentration of oil within the mesocarp increases as described by Kassim *et al.* (2013). This increase in oil results in a reduction in the water by the same amount within the fruit implying that the percentage of total water plus oil remains constant throughout the avocado life (Kassim *et al.*, 2013). The minimum oil content necessary for marketing avocado fruit is 8%. After maturation, values greater than 20% can occur. These values occur in the period between harvesting, when commercial maturity is reached and full maturation, when the oil content increases, and change occurs in the oil composition. Our data shown that oil content is variety dependent and ranging from 8% in Reed to 24.2% in Fuerte. No distinct correlation could be drawn in our study between the effect of altitudes on the percentage dry matter and oil content of the different avocado varieties. This could be due to multiple factors, such as the variety, agro-ecological conditions of growth and the fruit development stage (Carvalho *et al.*, 2014). On the other hand, a positive correlation between dry matter and oil content is strongly confirmed by the PCA models throughout the entire growing season. This correlation was mentioned in many previous studies (Snijder *et al.*, 2003). However, Hofman *et al.*, 2000 suggested that the percentage of oil content and dry matter are not suitable indicators of fruit maturity in late harvested Hass due to the inconsistent physiological changes in late season. As a consequence, the concept of the suitable maturity and use of fruits from low-

altitude orchards during the early season and from high-altitude orchards during the late season needs to be revised for many consecutive years to take into consideration several factors including the agricultural practices (APPENDIX II), weather conditions and disease management. In general, few studies have looked at the impact of altitude on fatty acid quantity and quality. As a result, it's been discovered that the concentration of fatty acids rises with altitude (Carvalho et al., 2015). In this regard, under these environmental conditions, it is possible to increase fruit size percentages, which will improve extra quality percentages, pulp yield, and nutrient content, among other things **(Ramirez Gill et al., 2019).** However, under these environmental conditions, the limitations of lower yields and longer production cycles must be considered.

The total soluble solid (TSS) of avocado fruits was measured for all varieties from the studied locations. The results showed that the highest TSS was recorded for Hass and Lambhass (10.2 %), while the lowest one was for Fuerte (6.7%). This contradicts with what found where Fuerte avocado had a higher TSS range than Hass (Olarewaju, 2014). There was a significant difference in the TSS values between different locations and elevation and this was also the case with Olarewaju in 2014. The values of the brix for all varieties didn't show a consistent trend as expected according to Bertling and Bower (2006). However, in our study the TSS showed fluctuation throughout the season which was also obtained by Olarewaju in 2014 leading to consider the TSS not suitable for maturity quantification. Therefore, the case with avocado cannot follow the rule of sugar accumulation throughout the growing season like the case of other crops including cherries, kiwifruit, and certain grapes cultivars (Olarewaju, 2014). The titratable acidity of the avocado different Cultivars was studied and compared among the studied locations. The highest acidity value was recorded for Lambhass harvested from Abassiyeh of south

Lebanon (0.18%), while the lowest one was shown for Ettinger, and Pinkerton fruits harvested from Ansar and Nmeiriyeh (0.08%). Regarding this parameter, a significant difference was obtained between locations of different elevations where the most acidic fruits were harvested from low altitude locations (Abbasieh,158 m), and the lower acidic fruits were mainly from high altitude locations (Ansar,302 and Nmeiriyeh,320m). this difference in TA and the effect of elevation can also be observed with other crops including olive fruits in which higher acidity was showed in lower altitude locations (Akça Uçkun and Aksoy, 2020), while it shows the opposite trend for other fruits such as citrus (Rokaya *et al.*, 2016). The decrease in TA of ripened fruit may be due to the consumption of organic acid during respiration as the fruit ripens and increasing its pH. It has been suggested that during storage, fruits utilize organic acids for metabolic activities, and this results in a decrease in the TA content during the storage periods which is similar with the present findings. The values for other varieties also showed significant difference between locations in the same variety. Noting that the differences in TA% among locations could also be due to the agricultural practices and climate in addition to the elevation which also applies to different crops such as pineapple (Dorey *et al.*, 2016). Note that it is considered challenging to compare the TA results with literate because this parameter is more common for other types of fruits than Avocado. The difference between locations might be due to the difference in environmental location, maturity stage and harvesting season. According to Hernández-Muñoz *et al.* (2006) the total acidity is a measure of the organic acid content.

To our knowledge, this is the first study that took into account the effect of geographical locations on ripening and physiochemical characteristics for optimum harvest time per location and variety on the majority of commercial avocado varieties. This

research will be repeated over several seasons to confirm the findings and account for seasonal variations in weather and precipitation rate. This will allow for a better understanding of correlations between all maturity indices, particularly dry matter and oil content values, as well as a recommendation for the best time to harvest during the maturity phase.

APPENDIX I

Tables showing the weather in South and North Lebanon during the seasons of harvest (2020-2021)

Weather data 2020 North

Month	Air temperature [°C]	Relative humidity [%]	Precipitation [mm]	Solar radiation [W/m2]
January	9.11 - 15.02	56.81 - 87.88	0 - 43.8	19 - 131
February	4.63 - 16.47	58.04 - 93.31	0 - 31.6	22 - 159
March	10.57 - 19.33	62.91 - 84.57	0 - 73.2	28 - 226
April	14.82 - 20.48	60.77 - 86.3	0 - 21.6	100 - 252
May	18.56 - 28.25	44.66 - 77.07	0 - 10.6	63 - 264
June	20.9 - 26.16	54.01 - 83.64	0	145 - 293
July	25.39 - 29.45	64.33 - 78.44	0	170 - 285
August	26.81 - 28.89	51.87 - 76.99	0	212 - 264
September	26.2 - 29.54	58.87 - 80.08	0	165 - 207
October	22.05 - 27.92	34.65 - 74.41	0	92 - 189
November	14.06 - 23.87	65.98 - 87.92	0 - 120.8	11 - 131
December	10.07 - 17.22	61.45 - 90.58	0 - 54.2	39 - 106

Weather data 2020 South (TYR)

Month	Air temperature [°C]	Relative humidity [%]	Precipitation [mm]	Solar radiation [W/m2]
January	9.7 - 16.15	51.61 - 83.62	0 - 27	8 - 148
February	9.29 - 17.63	51.17 - 81.93	0 - 37	39 - 159
March	13.48 - 22.24	47.43 - 88.62	0 - 24	27 - 218
April	14.84 - 19.58	41.32 - 84.27	0 - 40	147 - 296
May	17.72 - 22.15	47.04 - 82.01	0 - 3	158 - 291
June	21.18 - 26.18	56.1 - 79.06	0	206 - 292
July	25.3 - 29.04	63.65 - 76 89	0	208 - 282
August	26.43 - 29.16	61.58 - 80.81	0	179 - 268
September	26.2 - 29.52	68.12 - 79.42	0	174 - 213
October	21.8 - 27.71	31.1 - 79.34	0	103 - 185
November	15.86 - 23.19	43.69 - 86.32	0 - 82	42 - 157
December	13.3 - 17.78	37.08 - 90.09	0 - 43	22 - 117

Weather data 2021 South (TYR)

Month	Air temperature [°C]	Relative humidity [%]	Precipitation [mm]	Solar radiation [W/m2]
January	10.15 - 19.44	34.57 - 75.08	0 - 43.6	16 - 143
February	9.88 - 20.84	41.67 - 85.22	0 - 33.2	31 - 181
March	10.96 - 23.96	44.17 - 83.88	0 - 10.8	36 - 229
April	13.54 - 25.34	46.81 - 83.09	0 - 21.4	80 - 281
May	19.8 - 23.97	63.31 - 80.52	0 - 0.2	184 - 183
June	22.04 - 26.59	58.09 - 80.87	0 - 0.2	258 - 283
July	25.82 - 28.76	62.93 - 79.63	0 - 1.2	161 - 280
August	27.04 - 28.77	64.18 - 75.16	0	232 - 271
September	23.45 - 27.68	54.65 - 77.45	0	128 - 240
October	20.5 - 25.61	53.02 - 78.39	0	71 - 193
November	15.35 - 25.61	15.87 - 82.74	0 - 16	19 - 152
December	11.96 - 20.03	30.22 - 81.11	0 - 12.6	19 - 120

Weather data 2021 North

Month	Air temperature [°C]	Relative humidity [%]	Precipitation [mm]	Solar radiation [W/m2]
January	7.2 - 17.76	61.4 - 80.65	0 - 16	14 - 127
February	8.3 - 16.81	49.15 - 84.07	0 - 54.2	30 - 175
March	11.29 - 21.36	59.19 - 82.66	0 - 29.2	32 - 215
April	11.92 - 23.94	62.65 - 82.93	0 - 30.6	28 - 256
May	19.92 - 23.89	65.2 - 78.82	0	241 - 279
June	22.88 - 27.34	62.26 - 78.33	0	148 - 279
July	26.62 - 28.99	55.48 - 79.2	0	187 - 264
August	27.19 - 30.27	57.81 - 73.94	0	196 - 242
September	22.54 - 28.3	56.29 - 69.39	0 - 4.4	51 - 210
October	20.27 - 26.3	46.67 - 74.08	0 - 10.2	58 - 195
November	15.61 - 21.42	39.05 - 78.63	0 - 10.8	43 - 139
December	8.94 - 18.2	54.05 - 83.86	0 - 22.4	18 - 114

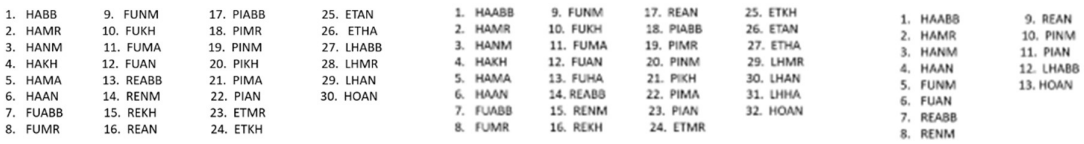
APPENDIX II

A table showing the min agricultural practice applied by the GAP certified fields. The first three columns representing the south, and the last representing the north.

	Mrwaniyeh	**Abassiyeh**	**Ansar**	**Halba**
fertilization	Ammonium Sulfate (500 Kg/Year) Organic Matter (450 Kg/Year) Potassium Humate (5Kg/Year) Ferrous Sulfate (300Kg/Year) 16-8-24 + S + Ca (10Kg/Year) Triple Super Phosphate (500Kg/Year) Potassium Nitrate (225Kg/Year) Magnesium Sulfate (500Kg/Year)	30-10-10 NPK foliar fertilizer (30 g/tree for young trees and 150g/tree for the aged ones each year);	No fertilizers applied	Boron each 4 months
pesticide	Abamectin Fosetyl-Al Chlorpyriphos (Not Approved in GAP) Copper Oxychloride July, august, September, October	No pesticides mentioned	Copper oxychloride (1 Kg /Dunam)	No pesticides used
irrigation	720 - 840 L/Tree each 10 days starting July till October	64 Liters per irrigation per tree every other day starting first June till October 10	180 Liters (0.18 m3) per Tree every six days starting first June till October	1-3 hours each 2 days

APPENDEX III

Individuals of the factor map for early, mid, and late harvest seasons respectively.



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