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Skin Separation in Majhul Fruits

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Abstract Skin separation of ripped date fruits, is not only un-pleasant trait, but also significantly diminishes their market value and causes financial loss to the growers. Our investigation indicate that it is caused partly by high diurnal, cyclic stresses of turgor pressure fluctuations before the ripening stage of the fruit and also affected by the environmental conditions. It also indicated, that mechanical properties of ripe fruit skin in Majhul dates has an impact on its separation from the soft tissues. Our experimental study indicated prominent differences of the skin mechanical properties (visco-elasticity) between separated and non separated fruit skin. Procedures for the prevention of skin separation are suggested.

Keywords Majhul date, Fruit, Skin separation, Visco elasticity

1. Introduction

Date Palm (*Phoenix dactilifera* L.) fruits has a long growing period which lasts in Israel from spring till autumn. During the first stage of the Majhul fruit growth, namely *Kimeri*,[9] it increases in size. Towards the end of this stage, that lasts for a number of months[4-5], the date changes its color from green to yellow and the cell growth stops. At this stage namely *Khalal*, the date accumulation of sugar start without change of the cell size. The *Khalal* stage continue several weeks until sugar content reaches a certain limit and the ripening process starts. The ripening stage namely *Rutab*, is characterized by an intensive enzymatic activity and the fruit date is disconnected from nutrients and water supply systems. The turgor pressure within the mesocarp cells totally decline and the fruit is softened. Then the large, thin walled cells of the mesocarp disintegrate, and the small, thick walled cells of the epidermis and hypodermis stay intact but their connection with the mesocarp weakens[5;6; 11; 12; 15; 19;20] The next stage namely *Tamar* is characterized by water loss and shrinking of the mesocarp. The skin surface area decreases and wrinkles are formed because of skin retaining the initial surface area it had at the end of the *Khalal* stage. The skin may adhere to the mesocarp and being wrinkled or it may be separated by forming air filled empty space between it and the shrinked pulpy mesocarp layers[8; 19;20]. It should be noted that the start of skin separation is during the period before ripening is complete, as the fruit is still supplied with water and nutrients from the tree, but it can only be observed after ripening as the mesocarp losses water and softens. This process is changable under different cultivation procedures or varieties of climate conditions with similar agro-technical operations. In this paper we present results which confirm our suggestion that the skin separation is related to the mechanical properties of the skin at this stage.

The skin defines the shape of the fruit during pre-ripped stages as a result of the internal turgor pressure. Since the skin, like most of biological structures, has visco-elastic properties[14], and when surface area increases, it may cause irreversible extensions of the skin. It is therefore important to study its mechanical behavior and it may be assumed that the mechanical properties of the skin in "separated" and "non separated" fruit skins are dissimilar. "Skin separation" is indicated as the ratio between the wrinkled area and the total surface area of the fruit. Fruits with separated area exceeding 10% are disqualified for export having lower value. There are large differences between the rate of skin separation in the various cultivars of dates as well as in the same cultivar grown in different regions in Israel. In Majhul, grown in the Arava Valley region, near the Gulf of Aqaba, which has a desert climate, skin separation is minimal and most of the harvest is of high export quality. On the other hand, the same cultivar, grown in the Jordan Valley in the northern part of Israel (near the Sea of Galilee), with a Mediterranean (temperate) climate, the percentage of skin separation is high. It may exceed 10% of the skin area and only about 10-20% of the harvest is qualified for export. The investigation of skin separation were studied in two directions: 1) Histological and anatomical differences between "skin separating" and "non skin separating" dates and 2) the impact of climate conditions. Climate condition enhanced increase of skin separation under the same cultivar in one location and a low percentage in another one. Gophen[10] found histological and physiological differences in the skins of

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Barhee, which is highly susceptible to skin separation and Dayri, which has a low level of "skin separate". Hilgerman [13] indicates that both types of dates differ in the content of "crude fat". Nixon[18] documented that high turgor pressure prior to ripening may increase the tendency of skin to be separated. In Israel it was found that the percentage of skin separation in dates grown in the desert (Arava Valley) with dry nights was lower than that in locations with humid nights. Nixon[18] found that the percentage of skin separation is increased by cutting back the strands of the bunch, On the other hand the removal of the inner strands of the bunch aimed at getting larger fruit, reduced skin separation. Bernstein[8] found that the shortening of the strands increases the supply of water to the dates on the upper end of the strand and restricts the supply to those located on the lower end, resulting in lower level of skin separation in that area. The possibility that climatic differences may change the properties of the cuticle has been brought up by I. Shomer (Personal communication). Bernstein[8] noted that "Skin separation" is affected by the climatic conditions. Our investigations were aimed at the searching of confirmation of the correlation between "separation" and the mechanical properties of the skin.

2. Material and Methods

Most of the experimental tests were carried out on fruits of Majhul collected from various regions of different climate condition in Israel. The Majhul fruits were chosen for the study because of the availability of both "skin separating" and "non skin separating" states and because of the large financial loss caused by separation.

Microscopic sections of the skin of "separated" and "non separated" Majhul fruits were done in order to find out if anatomical differences exist between varieties of dates. The sections of 10-15 μ thickness were stained by a "Double Joel" dye and some of them also with Aniline Blue which shows the presence of lignification in the cell walls under fluorescent illumination. The mechanical properties of the skin were measured on longitudinal strips of skin taken from mature harvested fruits, (*Tamar* stage) which could be smoothly peeled. At this stage the fruits had already undergone several times expansions and contractions and skin separation was visible. The longitudinal selections of specimens for the mechanical tests was based on the facts that they had an inherently higher strength than the transverse ones[7; 9] and suffered less from imperfections such as microscopic cracks which might cause early failure during the tests. The two polar ends of the selected fruits were cut off (scalpel) leaving a central belt of about 20 mm long from which the longitudinal strips were removed for testing. The ends cut off fruits were soaked in water for about 4 hours and the skin was peeled and dried on paper for 24 hours. Then, 5 mm wide stripes were cut, placed on white paper and inspected for visible cracks or other skin damages [16]. The thickness of the dried test stripe was measured and glued to a test frame by "Super Glue". The frames were made of thick paper and had a square hole of 10 mm in the center and narrow side plates, possibly being cut during the tensile tests. The exact width of the test strips was measured prior to the tensile tests. The measured parameters were stress, strain, modulus of elasticity (E) and creep (a visco-elastic property). Stress is by definition the force per unit cross sectional area of the test strip. It is measured in MPa units. (1MPa =101.94 g/mm^2). Strain is the ratio of the elongation of the test strip to its original length. In our tests it was stated as a percentage. The modulus of elasticity (E) is the ratio between stress and strain and is expressed in MPa.[21] High E values indicate a stiff skin while low values are a sign of a soft, slack skin. It may also be calculated from the slope of the stress-strain curve[3] and, in visco-elastic materials, it is a function of the stress level as well as time. These curves may be used for the identification of "skin separated" and "non skin separated" dates. For this purpose only the lower stress values are used which roughly correspond to the estimated values encountered during the diurnal turgor variations, They include the initial elastic (linear) range and a small part of the curved viscous range but for comparative purposes these curves have been linearized (with a relatively high coefficient of correlation) to allow the use of a single value of E.[7; 17] Creep is the elongation of the test strip, kept at constant stress for a certain time. It is caused by viscous flow (visco-elastity) and is therefore time dependent. When the stress is released the strip will generally not return to its original length and a residual strain will remain. The skin samples were tested with a tension testing machine which was specially designed and built for this purpose. It measures the tensile force on the specimen when it is strained by a micrometer stage, which is advanced in steps of 0.1 mm. Stress and strain are calculated from the force, the elongation and the dimensions of the test strip (cross section and initial length).

Each frame was mounted in the tension testing machine. The side plates of the frame were cut and the initial length of the test strip was measured at zero stress. These dimensions are used for the calculation of the strain afterwards. Then the step by step elongation was started and the stress noted at each step. This procedure was carried out within a short time as possible to avoid creep errors. Stripes which ruptured during the test possibly because of unforseen microscopical defects were discarded[2]. Creep is measured by tensioning a sample to various, stepped, strain values starting from 4% and down to 1%. The stress, which is proportional to the turgor pressure[9], is applied as a step function. It varied from 1.36 MPa at a strain test of 4% to 0.5 MPa at of 1% for "non skin separated" fruits and from 0.66 MPa at 4% to 0.25 MPa at a test strain of 1% for the "skin separated" fruits. The start was zero, increasing quickly to the value corresponding to the desired test strain and remains constant for 20 min. Then it was quickly reduced to zero and kept at that level for another 20 min. Such a test procedure gave a quick evaluation of the creep behavior in a reasonable time at comparable conditions[1]. During this test the strain is measured every 5 minutes and a strain vs. time curve is drawn for each test strain. The duration of 20 min. for each stress level was determined by preliminary tests (no data presented) which showed that the strain values stabilized and changed only insignificantly by the end of this period. This test allows the determination of the residual strain at each test strain level and to estimate the strain at which the residual strain disappears and the behavior of the skin becomes purely elastic (elastic limit). Below this strain level any stress (turgor) fluctuations will not cause a permanent extension of the skin. Fluctuations in diameter and the ambient relative humidity during the development of the date were measured on the tree by LVDT sensors and recorded by a remote measuring system designed and built by "Phytech" which allowed the measurement of diameters from 15 mm to 70 mm with an accuracy of 0.1 mm. The diameter measuring sensors were attached to selected dates during the entire growing and maturation periods.

3. Results

Microscopical observations of "separated" and "non separated" trans-sections of Majhul fruits skin indicated similarity of anatomical structures with similar skin cell sizes. It may therefore be assumed that this parameter has no impact on skin separation (Fig.1). However, mechanical analysis, of fruit skins having up to 50% "skin separation" in comparison with "non skin separation" ones, indicated prominent differences. Tensile tests showed that the "non skin separated" fruits had a higher modulus of elasticity (E), mostly 30 MPa and above. The "skin separated" fruits had significantly lower values of E, mostly in the order of 20 MPa and below (Fig.2). Preliminary tensile tests of "skin separated" and "non skin separated" fruits grown under various agro-culture conditions were carried out. They showed high values of E in the "non skin separated" and low values of the "skin separated" fruits. (Unpublished data).

Strain Vs. time figures of "non skin separated" and "skin separated" Majhul fruit skins from the upper and lower test ranges are given in Fig. 3. The vertical line (left, Y axsis) is presenting the increase of the strain of the test value. At that point the stress stays constant for 20 minutes. During that time the strain is enhanced due to viscous flow and then leveled out close to the end of this period. The second vertical line at 20 minutes indicates the decrease of the strain as the stress is reduced to zero. Fig. 4 shows the variation of the residual strain as a function of the strain test. The line is crossing the zero residual strain ordinate axis at about 1.2%, which is the elastic limit for the skin of Majhul in the longitudinal direction. Fig. 5 represents the changes of the diameter of Majhul fruit at the end of the growing stage (*Kimiri*). The diameter increases at night by about 0.3 mm and shrinks less during daytime so that the net diurnal growth is about 0.1 mm. It increases during this stage in an ascending saw tooth curve. At the end of the growing stage (fourth of August in this case) the fruit starts a series of diurnal expansions and contractions with amplitudes similar to those before the end of the growth. These fluctuations are synchronized with those of the relative humidity values. Fig. 6 represents recorded curves of fruit diameter of trees grown in Jordan valley, close to the Sea of Galilee and relative humidity (about 90% at night and 40% during daytime). It should be noted that the strain in this particular fruit was 2.3%, which is indicative of skin separation, as has been shown before and might be expected for crops grown in this region.

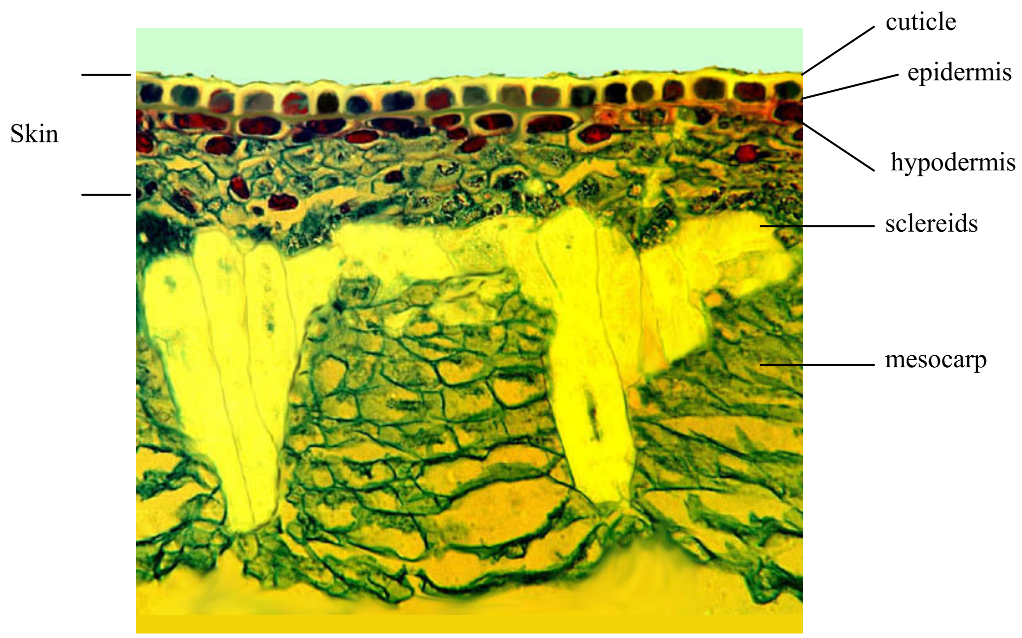

Figure 1. A Microscopic section of a Majhul skin, stained with "Double Joel" stain and Aniline Blue

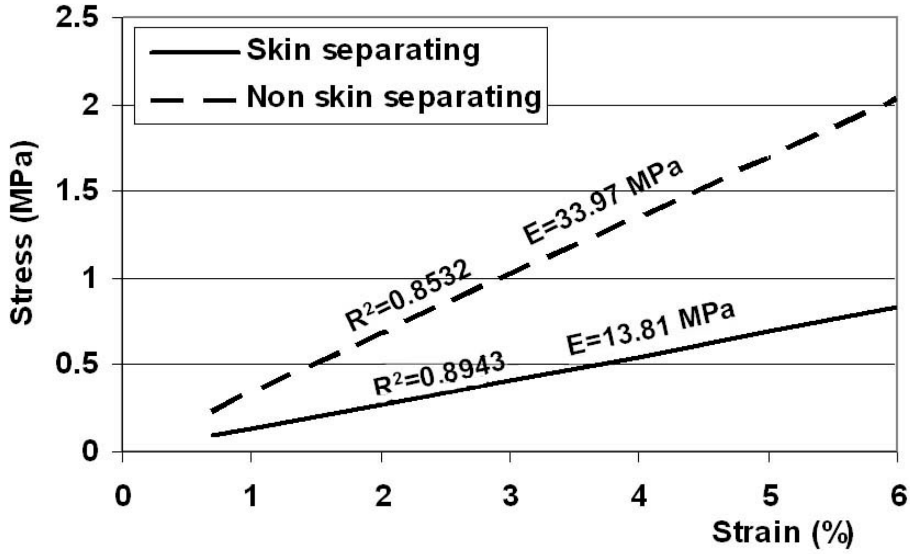

Figure 2. Stress Strain Diagram of "skin separating" and " non skin separating" Majhul date skins. (Mean values)

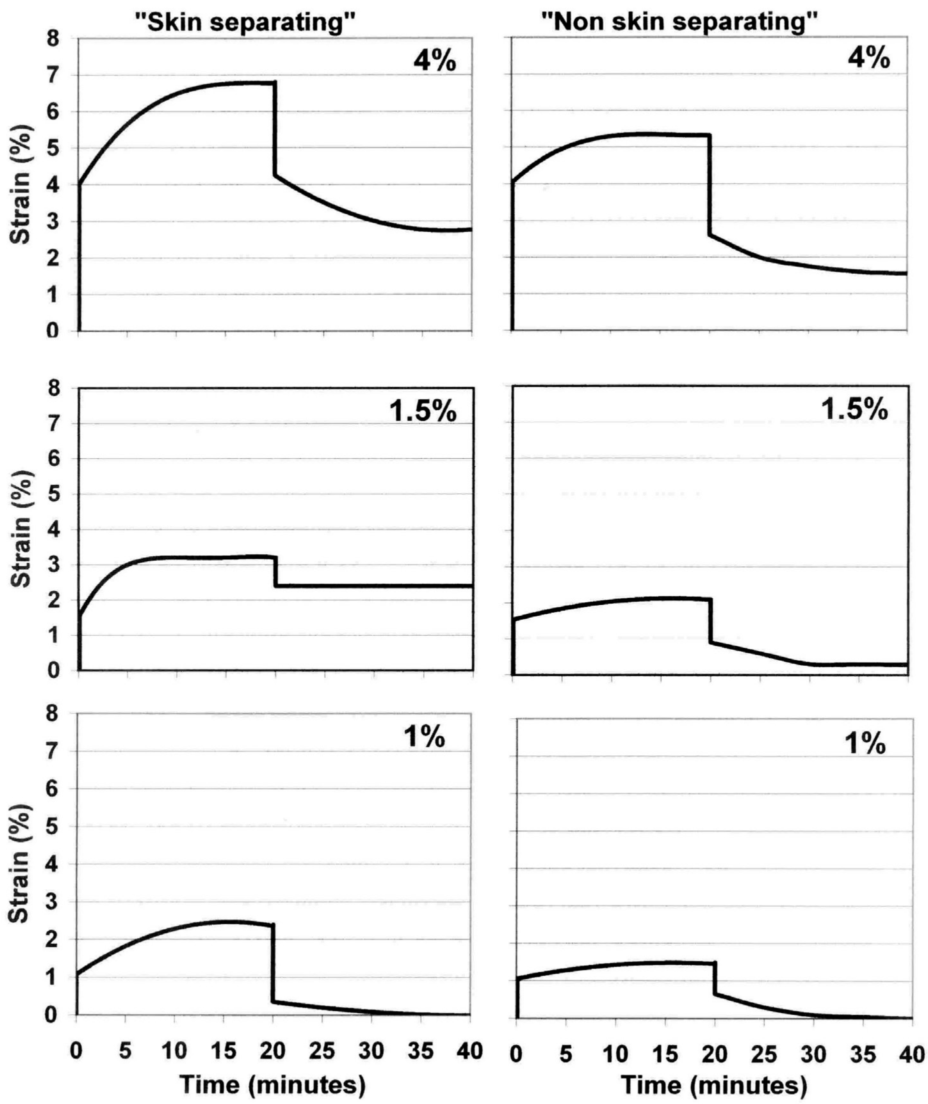

Figure 3. Sample Creep (Strain/Time) diagrams of "skin separating" and "non skin separating" Majhul date skins at various test strains

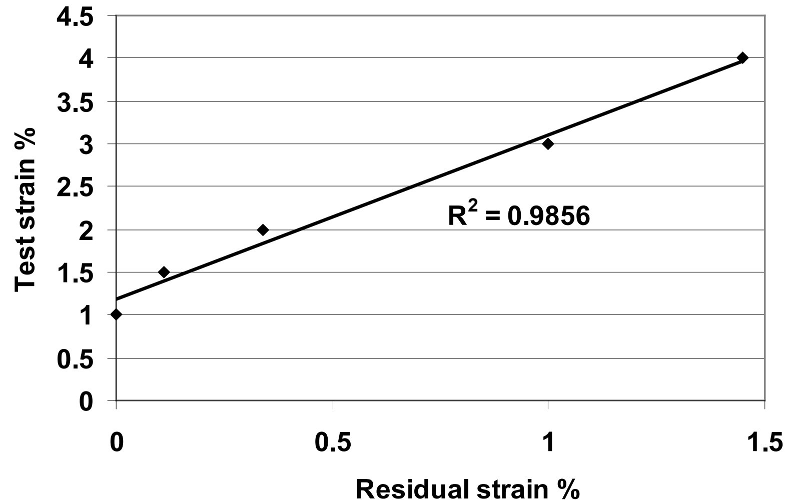

Figure 4. Determination of the elastic limit of "non skin separating" Majhul date skins

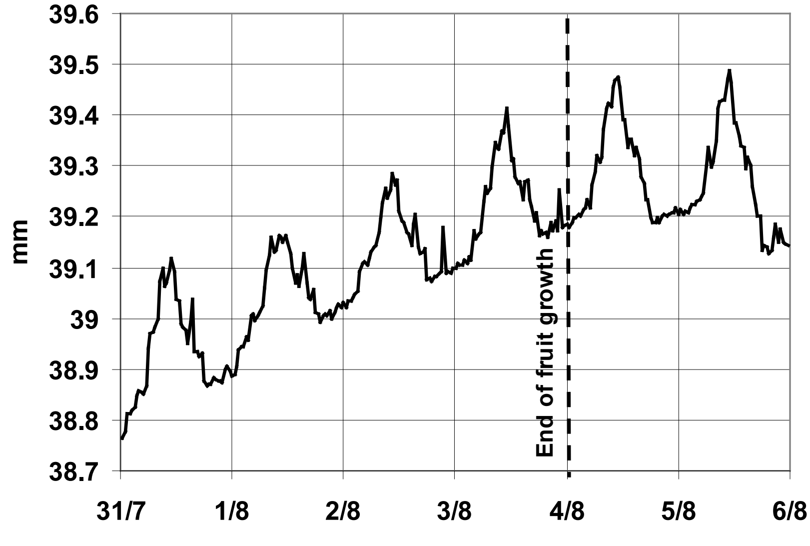

Figure 5. A recording of the diameter changes of a Medjhool date at the end of the *Kimiri* stage and the beginning of the *Khalal* stage (11)

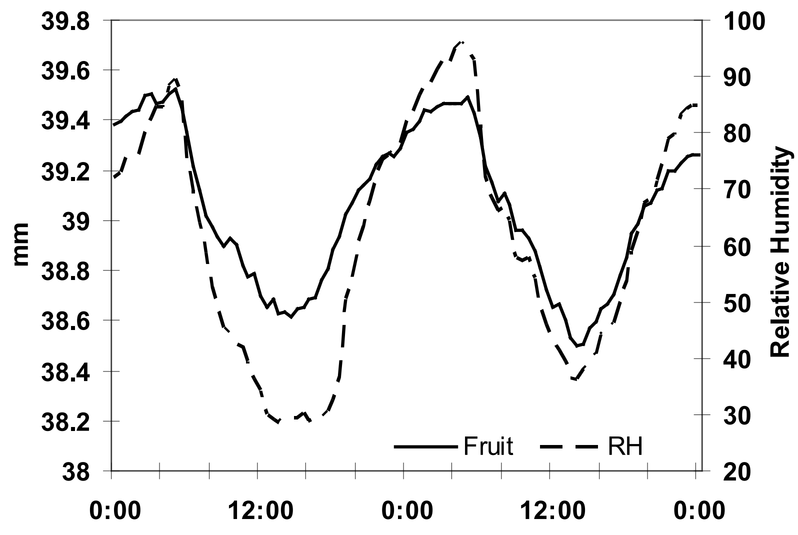

Figure 6. Simultaneous recordings of the diameter of the date and the relative humidity

4. Discussion

The results of total tensile tests indicated that the skin of "non skin separated" is stiffer and more resistant to stretching than the soft, pliable skin of the "skin separated" fruits. The visco-elastic properties of the skin govern its mechanical behavior. At low stresses the resulting strain will be directly proportional to the stress (elastic behavior). At higher stress levels the strain rises faster than the stress due to viscous flow and the skin will not return to its initial size once the stress is reduced (Creep). At the same time the modulus of elasticity (E) decreases and a firm, high E skin will be reduced to a slack state. Creep tests were carried out on Majhul fruits under various strain values confirming this assumption. At high strain values there is a marked decrease in E and once the stress is reduced to zero,(which occurs in nature after ripening), a large residual strain remains (creep), indicating a permanent increase of the skin area. At low strain tests (about 1%) the residual strain disappears at zero stress, indicating elastic behavior and the skin returns to its initial dimensions. This decrease is gradually due to internal friction in the tissues. The diagrams for "non separated" skins show lower creep values than the "skin separated" ones since those skins have a higher E value and appear to have suffered only small diurnal turgor (stress) fluctuations during the critical period prior to the *Rutab* stage. On the other hand, the "skin separated" curves show larger creep values and the skin has a much lower value of E. It may be therefore assumed that those dates were subjected to large diurnal turgor fluctuations. The right end of the diagrams shows the end point of the test and indicates the residual strain, It can be seen that the "skin separating" fruits have a larger residual strain than the "non skin separated" ones but both reach zero close to a test strain of about 1%. It may be therefore assumed that strain levels at or below this value during the diurnal turgor fluctuations before the *Rutab* stage will not cause skin separation as they stay in the elastic range and do not stretch it permanently. Although this test protocol does not match the slow sinusoidal changes of diurnal size fluctuations in nature, it is useful to separate the different stages of the process (expansion and contraction) and study them independently. It also allows the easy determination of the elastic limit of the skin and the susceptibility of the dates to skin separation. Therefore strains of that order, occurring during the diurnal fluctuation of the turgor pressure in the pre-ripening stages of the fruit should not cause skin separation after ripening. It can be probably suggested that skin separation in date fruits is caused by high values of turgor pressure peaks in the fruit from the beginning of the growing stage of the fruit (including the skin cells) till the end of the ripening stage (*Khalal*). Date fruits lose water by evaporation even at night although at a lower rate than in daytime[4] The amount of water that enters the fruit at night depends probably on the concentration of sugar in it, while the amount lost is a function of the difference between ambient vapor pressures in the air around the fruit and that of the skin. At nights, with a high relative humidity, water loss by evaporation is lower than during nights with a low relative humidity and it will cause the turgor pressure to rise. If the extension of the skin exceeds the elastic limit during turgor pressure peaks, non reversible changes will occur (creep), the modulus of elasticity (E) will decrease and the skin will slacken. These changes occur when the fruit ripens and the tissue connections within the mesocarp weakens. This is being the origin of skin separation[8]. Skins trait of irreversible extensions have a larger area than the underlying surface of the mesocarp and do not adhere to it when it shrinks, do not folding simultaneously with it and form air filled bubbles (skin separation). (Fig 7) On the other hand, when the skin extension during the *Khalal* stage does not exceed the elastic limit, the skin remains tight with a high E value and adheres to the shrinking mesocarp without separation. These considerations may explain the difference between "skin separated" and "non skin separated" fruits. Varying skin strains that cause creep can only occur during the *Khalal* stages growth of the fruit when it is still supplied with water from the tree and has turgor pressure. They stop in the *Rutab* stage when the water supply from the tree has been finally interrupted, the turgor pressure disappears and the mesocarp continues to shrink. Diameter changes of about 1 mm and linear strains of about 3 % have been measured in various cultivars (Data not presented here). The stage, at which the environmental factors can influence skin separation, occurs when the growth of the skin cells and the fruit totally ceases. It depends upon the evaporation rate of the date and on the flow of water to it when the relative humidity decreases. In the northern regions of Israel, where the climate is more humid, the *Khalal* stage, last longer than in the southern arid zone and consequently has more diurnal cycles of turgor fluctuations. Therefore cumulative large amounts of creep can be constructed to form skin separation. On the other hand, dates, grown in the arid south, where the relative humidity at night is low (desert climate), have only small diurnal diameter fluctuations and skin separation will be prevented. Additionally, the stage of sugar accumulation is also shorter when early ripening occur than in late ripening case, affecting the number of size fluctuations cycles and therefore decreasing "skin separation". Our study is an attempt to explain the origins of "skin separation" in dates by confirming the correlation between it and the mechanical properties of the skin: The modulus of elasticity (E) and creep which are mostly affected by the climatic conditions such as the diurnal variations of the ambient relative humidity. The information presented here might be the basis for the design of treatment procedure aimed at reducing or even eliminating "skin separation". For example, by reducing the difference of the vapor pressures of the fruit skin and the environment, such as increasing the air flow around the fruit (e.g. the use of rings, to enable optimal distribution of the fruits along the strands instead of shorting them etc.), increasing the water permeability of the skin (chemical treatments), restricting the water flow from the tree to the fruits or even use chemical treatments to alter the mechanical properties of the skin. Some of these treatments have been successfully tested during the current growing season and further tests are in progress.

‘A’ ‘B’ ‘C’

Figure 7. A Majhul Date ‘A’. Immediately after ripening, the skin does not adhere to the Mesocarp and It is about to be separated. ‘B’. A "non skin separating" fruit, ‘C’. A "skin separating" one

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