www.ThePharmaJournal.com
The Pharma Innovation

ISSN (E): 2277-7695
ISSN (P): 2349-8242
NAAS Rating: 5.23
TPI 2022; SP-11(7): 4717-4723

www.thepharmajournal.com
Received: 25-05-2022
Accepted: 27-06-2022

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Laser labeling on dragon fruit with different codes and their impact on surface characteristics

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Abstract
The currently popular adhesive stickers on freshly consumed produce like fruits and vegetables are not a reliable as they are simple to remove, not permanent, and easily counterfeited. Using laser technology agricultural produce can have engravings made directly on the surface, which could offer environmentally friendly and sustainable labeling. To observe the effects of the laser on the fruit, a variety of codes were used. A diversity of codes, including QR codes, DM codes, barcodes, alphanumeric codes, logos, and personalized codes, were engraved on the surface of the exotic dragon fruit. Laser etched fine and clear markings irrespective of the codes that can be used for a wide range of engraving. Laser treatment is a surface treatment, so this paper focused mostly on the surface morphology of the fruit using stereo zoom microscope and scanning electron microscope. The depth of penetration of the markings, skin strength, weight loss and shrinkage of the fruit after laser engraving were minimal and did not significantly differ between various types of codes. Therefore, depending on the purpose, any type of code can be used while still utilizing the benefits of laser labeling.

Keywords: Laser engraving, green labeling, traceability, codes, dragon fruit

1. Introduction

With the change in time, people's perspectives have evolved and shifted toward higher-quality foods. Concerns over high-quality food have escalated due to the global Covid-19 epidemic. Traceability is a crucial factor in building consumer trust. Traceability is defined as "The ability to access any or all information relating to that which is under consideration, throughout its entire life cycle, by means of recorded identifications" (Olsen & Borit, 2013) [10]. It is challenging to trace and track freshly consumed fruits and vegetables, but once done, most foodborne outbreaks can be controlled, food catastrophes can be managed successfully, counterfeiting and fraud can be reined in, and food adulteration can be avoided (Dabbene *et al*., 2014) [2]. Adhesive stickers are frequently used for fruits and vegetables and can contain information about price, location, date of harvest, and other important product information. These stickers, often known as price look-up stickers, are simple to remove and counterfeit, casting doubt on the accuracy of the data. The currently utilized traceability techniques, such as RFID tags and holograms, cannot be easily countered, but can be easily tampered with and removed from labels on which they are printed and are not cost-effective. So, directly marking the surface of the commodities comes into the picture. Laser engraving is an effective solution to address these problems and provides reliable information. The principles of stimulated absorption, spontaneous emission, and emission of electrons underline the operation of light amplification by stimulated emission of radiation, otherwise called laser. Narrow line width, coherence, monochromaticity, and high directivity, intensity, and stability of the laser beam make it fit for direct part marking on the fruit or vegetable surface. Besides engraving, lasers can also be used for cutting, ablation, processing, preservation, irradiation, laser-assisted packaging, and non-destructive analysis such as biospeckle imaging and NIR laser image analysis (Abhirami P, 2021) [1]. Due to its contactless working, which produces clean and hygienic environments, the laser has its unique significance in food and agro-processing.

The current study made use of the dragon fruit, *Hylocereus undatus*. It was a highly valued exotic fruit, commonly known as pitaya or pitahaya, which belongs to the family of Cactaceae and climbing vine cactus species. Highly valued for its nutraceutical properties with high water content and rich in bioactive phytochemicals, which are known to curb cancer, obesity and type-2 diabetes and other metabolic syndromes (Jiang *et al*., 2021) [8]. Due to the growing demand for fresh dragon fruit, the dragon fruit market is expanding swiftly; it was estimated to Compound annual growth rate (CAGR) of 3.9% for the years 2022-2027 (Dragon fruit market-growth, trends, covid-19 impact, and forecasts (2022 - 2027), 2022. Several types of codes can be engraved on biological materials with a laser. It is possible to engrave alphabets, letters, alphanumeric codes, brand logos, personalized text, one-dimensional barcodes, two-dimensional barcodes like quick response (QR) codes, data matrix (DM) codes, etc. The impact of various markings on dragon fruit has not been the subject of any studies yet. Therefore, this study aims to determine the impact of various types of codes on surface characterization of dragon fruit and recommend the most effective ones.

2. Materials and Methods

2.1 Plant materials

The dragon fruits were purchased from the local market of Thanjavur, Tamil Nadu, India. The fruits were harvested from the same region and had the same level of maturity they were washed under running water, wiped and stored at a temperature of 10 ℃ until further analysis. (Jadhav, 2018) [7].

2.2 Laser setup

CO_2 laser (continuous wave) engraving setup that produced infrared light with an operating voltage of 220V and a wavelength of 10,600 nm (Model EVA 43, Mehta CAD-CAM systems Pvt. Ltd, India) was employed. The least input power required to leave a mark on the fruit surface was chosen. Preliminary research revealed that at least 12% of 130W input power was required to etch the fruit's surface. Below this input power, no mark was obtained. Therefore, the current study used a 15.6 W input power for different engraving codes.

2.3 Readability of the code

The QR, DM and bar codes needed to be scanned to retrieve information. They are scanned with the mobile phone reader and code reader (DS2200 handheld imagers).

2.4 Visibility of the mark

The laser labels were etched for different codes. The clarity of the different marks after the storage life of 14 days of dragon fruit was determined by visual inspection and divided into two classes, namely clear markings and unclear markings (Sood *et al*., 2008) [11].

2.5 Depth of penetration

The peels were sliced longitudinally using a surgical blade before being positioned vertically beneath a Leica stereo zoom microscope (Leica S8AP0, CMS GmbH stereo-zoom microscope LAS version 3.8.0). To measure penetration depth, the images were examined using AutoCAD (version: S.51.0.0 AutoCAD 2022, 2021 Autodesk, Inc.). The penetration depth was determined by scaling up the stereomicroscope images, which had fixed dimensions of 13.10 x 9.83 mm, and measuring the average length of the mark.

2.6 Skin strength

The Texture Profile Analyser (TPA) (Stable Micro System Ltd., UK) was used to measure the skin strength at a strain of 5% of a 30-kg load cell using a 2-mm needle probe (P/2N). The skin strength was measured at the etched area and non-etched area of the fruit.

2.7 Weight loss

The weight of fruits was taken before they were marked (initial weight), and the final weight was measured after 14 days of storage. Weight loss was calculated using the formula:

$$\text{Weight loss (\%)} = \frac{\text{Initial weight (g)} - \text{Final weight (g)}}{\text{Initial wight (g)}} \times 100 \quad (1)$$

2.8 Shrinkage

Using the water displacement method, the volume change ratio was used to calculate the volumetric macroscopic shrinkage (ASTM D6683-14). At the beginning and end of two weeks, the volume of the treated and control samples was acquired to calculate shrinkage using the equation below.

$$\text{Shrinkage (\%)} = \left(\frac{v_0 - v}{v_0}\right) \times 100 \quad (2)$$

Where, v_0 is the initial volume of the sample, and v is the volume after a week.

2.9 Stereo micrographs

Leica stereo zoom microscope (Leica S8AP0, CMS GmbH stereo-zoom microscope LAS version 3.8.0) was employed for acquiring images. Images were taken to observe the effects of laser ablation on the surface and compare it with the untreated area.

2.10 Scanning electron micrographs

To understand the surface morphology at the microstructure level, a scanning electron microscope (SEM) (EVO-18, Carel Zeiss, Germany) at different magnifications with high electron tension of 10 kV at a working distance of around 10 mm was employed. The comparison of the treated region to the untreated area was given the most consideration.

3. Results and Discussion

3.1 Readability of the code

To obtain the information, the two-dimensional and one-dimensional codes should be decoded. Good contrast between the code and the surface and a clear mark and surface were essential for improved code readability (Eyahanyo & Rath, 2021) [5]. Although the mark was clear and the surface was clean, a good contrast could not be produced because the mark and the dragon fruit were dark in color. The region of interest in the case of QR and DM codes was visible to the human eye, but the scanner could not distinguish it from the fruit surface due to insufficient contrast. In order to clearly distinguish the code layers from the fruit, more research on the lines of developing software was required to address the problem. Colored dyes can be used to make the codes brighter and thus increasing contrast. Sood *et al.* (2008) [11] used a fruit-based black color dye to make the engraved code on tangerines easier to read.

Direct reading by consumers was done for logos and personalized text. The logos offer branding for the makers as well as information. These days, personalized things are getting much attention. Such endeavors attract a sizable public. On first reading, the alphanumeric code "HYD 08-11-2021" provides information on the location and date of harvest. The data may be fed to a website, and the code could be followed to obtain detailed information. With the restriction of information limit, because 1D or 2D can store large amounts of data, alphanumeric logos and personalized codes were preferred for direct and simple reading of the codes without requiring specialized technology or equipment.

3.2 Visibility of the mark
The least amount of laser power was used for engraving each code. The fruit appeared to have sustained only minor damage and shows up to be finely engraved. For engraving, each code had a different set of dimensions. The size of codes: QR code- 15×15 mm, DM code 15×15 mm, barcode 23×10 mm, alphanumeric code- 15×9.5 mm, logo 15×20 mm, and personalized code- 15×7 mm. BMP image format was used for particular engraving codes like QR and DM for clear markings. The images were visually screened following Sood *et al*. (2008) [11]. All markings were deemed clear on the first day and even the fourteenth day. Figure 1 depicts the images of each type of code used in the current study.

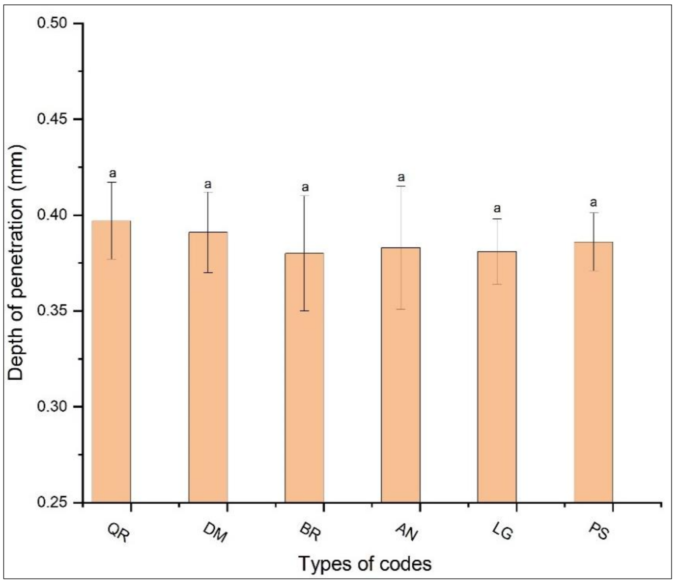
Fig 1: Types of codes engraved on the dragon fruit

3.3 Depth of penetration
For various types of codes, there were no appreciable differences in the depth of mark penetration ($p<0.5$). According to studies, the average depth of penetration was 0.39 mm. QR codes had the largest observed depth (0.40 mm), whereas barcodes had the lowest depth (0.38 mm). This 0.2 mm difference might be related to the slight difference in the fruits. The values of all the different types of codes are given in table 1. The laser energy attempts to melt the surface of the fruit when it comes into contact with the laser beam. The successive layers of fruit will seek to melt under the heated, molten surface further. Therefore, if higher-intensity laser beams were used, they would have sufficient energy to pierce deeper into the fruit's skin. The depth of penetration for different types of codes is represented in figure 2. According to Etxeberria *et al*. (2009) [4], avocado and tomato skin can be affected by laser marking up to five layers deep when a pulsed CO_2 laser with an energy level of 0.000752 W/dot was used.

Table 1: Average depth of penetration on laser markings when different codes were engraved

Factor	Mean	St. Dev
QR Code	0.40	0.02
DM Code	0.39	0.02
Barcode	0.38	0.03
Alpha-numeric	0.38	0.03
Logo	0.38	0.02
Personalised	0.39	0.02

*St. Dev- standard deviation



*QR- QR code, DM-DM code, BR- barcode, AN-alphanumeric code, LG- logo, PS- personalized code

Fig 2: Depth of penetration of laser markings on fruit surface by engraving different types of codes

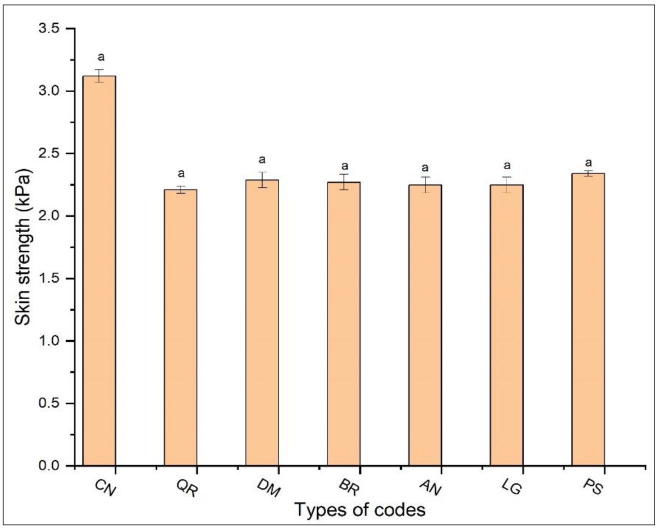
3.4 Skin strength
There were no discernible differences in the skin strength for different types of codes ($p<0.5$). The skin strength of the peel without laser treatment was found to be 3.121 kPa. Around 2.27 kPa was found to be the average peel strength at the locations of marks with various code types. That demonstrates how a laser beam affected the surface of the fruit. Skin

strength of dragon fruit by engraving different types of codes was represented in figure 3, and their corresponding average values with standard deviation were given in table 2. The fruit's surface was exposed to a laser beam, which slightly damaged or ablated the surface and decreased the skin strength. Due to the thick peel of the dragon fruit and the low intensity of the laser beam, there was no visible damage to the pulp inside. During ripening, fruits may be exposed to several negative mechanical, environmental, and biological variables. The structural and chemical integrity of the cuticle needed to be preserved throughout fruit development and expansion to preserve fruit characteristics (physical, chemical and sensory). Cuticles also protect against various biotic and abiotic stress factors (Zarrouk *et al*., 2018) [12]. The cuticle of the fruit, which was exposed to the laser during the laser treatment and may have suffered minor damage, may have contributed to the decrease in skin strength. The epidermis layers of cavendish bananas were damaged by laser treatment, according to the report by Indera Sakti & Thomas (2017) [6], which also noted a decrease in skin strength.

Table 2: Average skin strength of the fruit due to different types of laser markings

Factor	Mean	St. Dev
Control	3.12	0.05
QR Code	2.21	0.03
DM Code	2.29	0.06
Barcode	2.27	0.06
Alpha-numeric	2.25	0.06
Logo	2.25	0.06
Personalised	2.34	0.02

*St. Dev- standard deviation



*CN-control, QR-QR code, DM-DM code, BR-barcode, AN-alphanumeric code, LG-logo, PS-personalized code [a] Same letter indicating statistical significance between groups

Fig 3: Skin strength of dragon fruit by engraving different types of codes

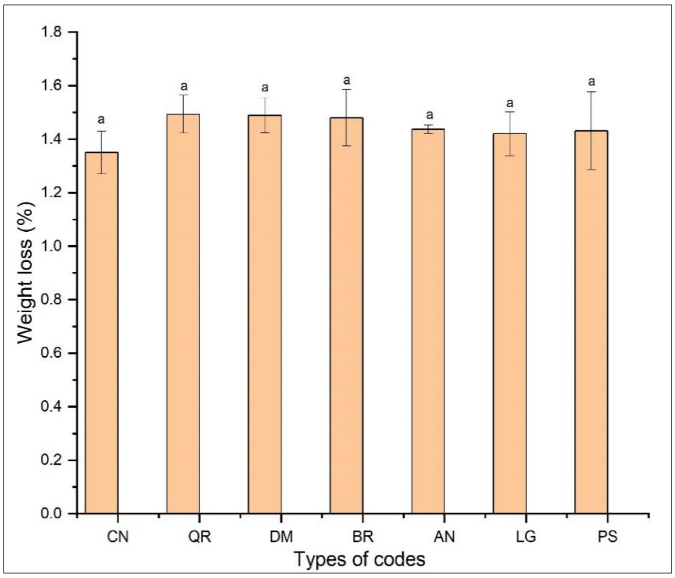
3.5 Weight loss

For various types of codes, the weight loss did not differ significantly (p<0.5). After 14 days, an average weight loss was 1.46%. The weight loss of all the samples with different types of codes was represented in figure 4, and their average values with standard deviation were given in table 3. The cuticle layer damage, which was the cause of the abovementioned factor, also contributed to moisture loss. It is possible that the laser's ablation of the fruit's surface made room for fluid loss. The control sample, which underwent no laser ablation, also experienced a 1.35% weight loss. It was clear that there was little difference between the treated and control samples. When biological material is exposed to a laser, the laser photons penetrate the material and transform it into thermal energy, which burns the tissues on the fruit's surface. The vaporization of the burned tissues and water loss were contributing variables in weight loss (Indera Sakti & Thomas, 2017) [6].

Table 3: Average weight loss of the fruit due to different types of laser markings

Factor	Mean	St. Dev
Control	1.35	0.08
QR Code	1.49	0.07
DM Code	1.49	0.07
Barcode	1.48	0.11
Alpha-numeric	1.44	0.02
Logo	1.42	0.08
Personalised	1.43	0.15

*St. Dev- standard deviation



*CN-control, QR-QR code, DM-DM code, BR-barcode, AN-alphanumeric code, LG-logo, PS-personalized code
[a] Same letter indicating statistical significance between group

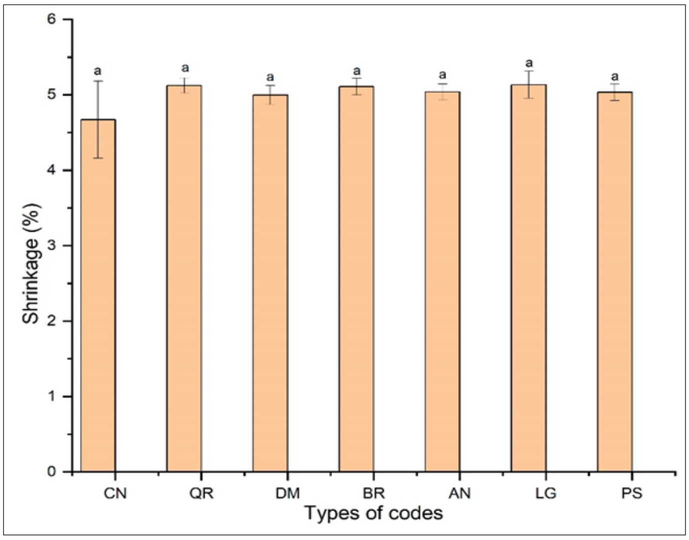
Fig 4: Weight loss of dragon fruit by engraving different types of codes

3.6 Shrinkage

Table 4: Average shrinkage of the fruit due to different types of laser markings

Factor	Mean	St. Dev
Control	4.67	0.51
QR Code	5.12	0.10
DM Code	4.99	0.13
Barcode	5.11	0.11
Alpha-numeric	5.04	0.11
Logo	5.10	0.18
Personalised	5.03	0.11

*St. Dev- standard deviation



*CN-control, QR-QR code, DM-DM code, BR-barcode, AN-alphanumeric code, LG-logo, PS-personalized code [a] same letter indicating statistical significance between groups

Fig 5: Shrinkage of dragon fruit by engraving different types of codes

There were no significant differences in the shrinkage for different types of codes ($p<0.5$). The average shrinkage of samples with different types of codes was recorded to be 5.07% (table 4). The shrinkage of the sample without laser treatment was 4.67%. The shrinkage of 5.12% was recorded for the case of QR codes, which might be due to the highest exposure area. Shrinkage of dragon fruit by engraving different types of codes is represented in figure 5. If more area was exposed, then more chances of water loss, but the results had not varied much, indicating the lesser impact of the laser. The fruit's surface was heated due to the exothermic reaction caused by the laser beam, which then caused the peel to melt and begin to evaporate. As it descends and interacts with the unmolten layer, the melted liquid creates a cavity and accelerates component melting. The major cause of shrinkage was water loss. Tangerine fruit shrinkage was measured by Sood *et al*. (2008) [11] to be less than 5%. Similar results were found for the dragon fruit in the current study.

3.7 Stereo micrographs

The microscopic images were represented in figure 6. It clearly shows the surface of the fruit sample was ablated. To show the impact of the laser branding, the letter H was focused and magnified (figure 6(a)). When a laser beam of sufficient strength tries to heat a surface, the heated surface melts and evaporates, leaving a depression in the fruit's surface that was plainly visible in stereo microscope photos. Carbonization of the fruit tissues can be clearly observed in figure 6(b).

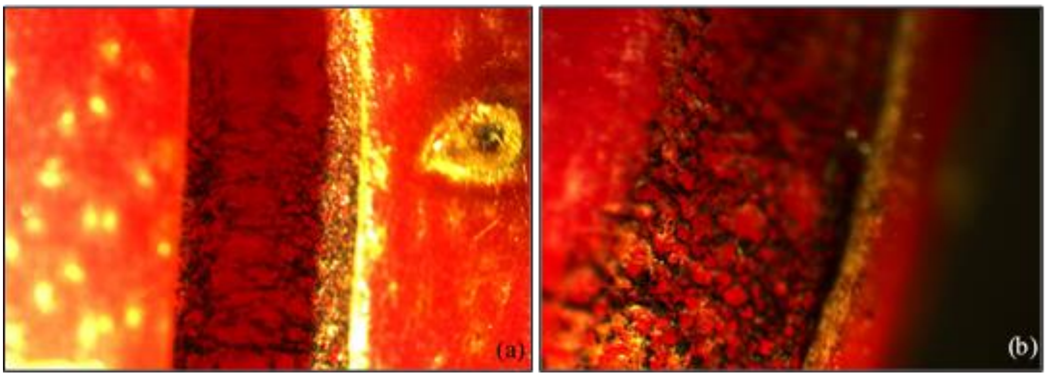


Fig 6: (a) Part of alphanumeric code (H) under stereo microscope, (b) magnified image of the letter H

When captured at different magnification settings, the numerous photos demonstrate that the dragon fruit's surface has comparable ablation. When compared, the laser ablation's extent was remarkably similar. The microscope pictures also revealed another factor that may have contributed to the inability to read barcode data: a potential problem with the spacing between the codes (figure 7). The brownish color of the engraving might be due to the burning of fruit cell wall components like cellulose and pectin (Etxeberria *et al*., 2006) [4].

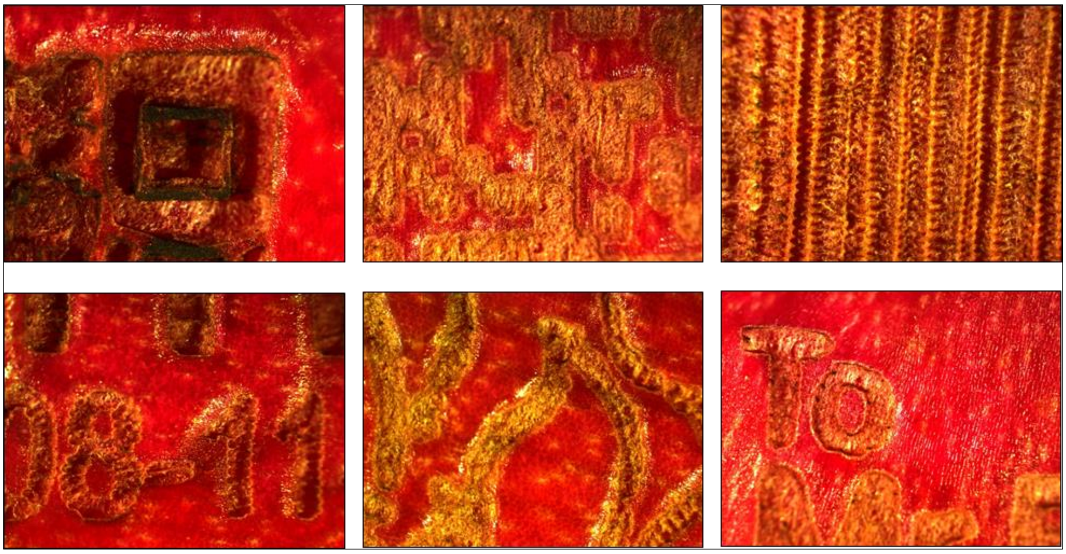


Fig 7: Different types of codes engraved on dragon fruit with laser were magnified under stereo microscope

The figure 8 depicts the sequential zooming picture of the DM code. The skin's appearance following laser treatment was seen in the zoomed image (figure 8 (e)). Etxeberria *et al.* (2009) [4] used a transmission electron microscope and SEM images to comprehend the surface-level nature of the laser-engraved pinholes in the citrus.

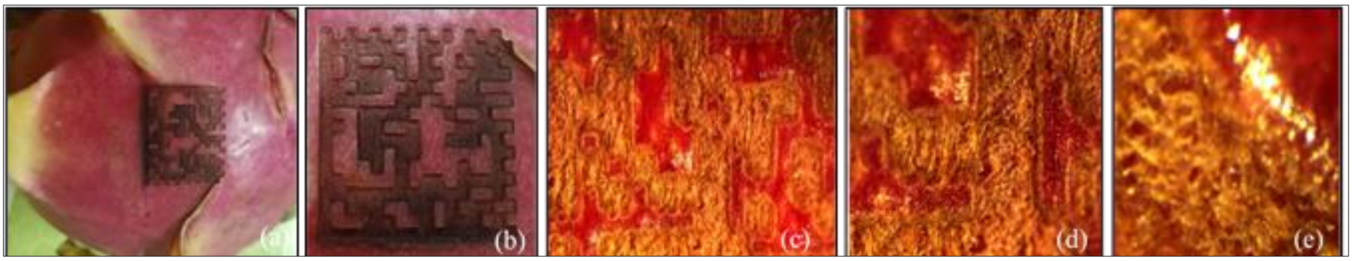


Fig 8: Sequentially magnified image of DM code engraved on the dragon fruit (a) and (b) with the camera and (c), (d) and (e) under stereo microscope

3.8 Scanning electron micrographs

Figure 9(a) displays a portion of the alpha-numeric code under SEM at a 60X magnification. The distinction between the treated and untreated areas was clear. In the treated section, depressions were seen, looked smooth due to burns and a rugged texture of the dragon fruit peel was observed in the untreated area. Despite the conventional belief that lasers provide precise cutting and engraving, Figure 9(b), which was taken at 243X magnification, illustrates very little unevenness in the engraving. Neither a stereo microscope nor the human eye could see the corrugations; these were seen as they worked on the biological substance, and the energy was transferred from the top surface to the subsequent layers. Marx *et al.*, (2013) [9], also stated that the quality of laser marking depends on the intensity of the laser beam, surface pigmentation, sub-surface water content and any other irregularities like mechanical damage, old wounds.

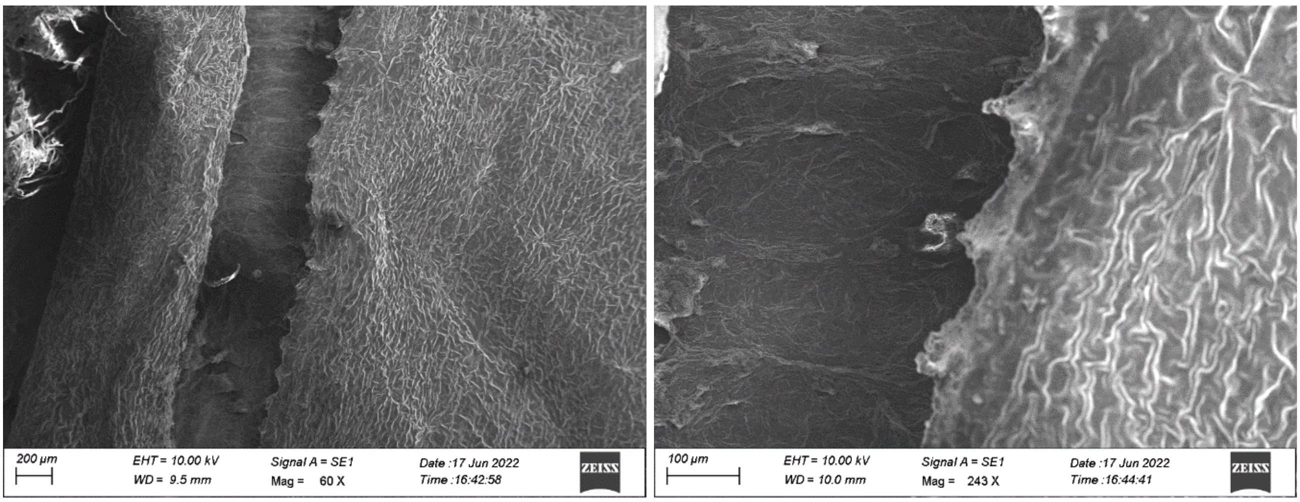


Fig 9: (a) Part of alpha-numeric code (H) under SEM at 60X magnification. (b) 243X magnified image of letter H, distinguishing laser etched surface from untreated surface.

Conclusion

Different types of codes like QR code, DM code, barcode, alphanumeric code, logo and personalized code were engraved directly on the surface of the dragon fruit at the least possible input power of the laser. Since every code was clearly engraved, it can be concluded that a laser can fetch a variety of markings. Although QR, DM, and barcodes require additional setup to retrieve data, they can collect much information. Depending on the context, alphanumeric, logo, and personalized codes can be chosen. Logos are useful for commercial purposes because they provide distinct branding and identification. Personalized codes can be a novel strategy for premium purposes. Consumers can choose fruits with the aid of alphanumeric codes for the location and date of harvest. As a result, the codes had to be chosen based on the need since changing the codes did not seem to make much of a difference to the fruit. The average depth of penetration of markings into the peel surface was 0.39 mm, skin strength of the peel after laser marking was 2.27 kPa and suffered a weight loss of 1.46% after 14 days with shrinkage of 5.07%. Stereo micrographs and scanning electron micrographs of the surface revealed the effects of laser on the surface even at microstructure. Even though the fruits' breed, location, and level of maturity were the same, there may have been slight variations in each fruit that contributed to small variations in the parameters being studied. It was clear that laser engraving technology has no restrictions on what information can be engraved on fruit surfaces and that doing so causes little to no harm to the produce. As a result, laser engraving stands out as a clean, non-contact, hygienic, and green traceability alternative. It was environmentally friendly, sustainable and anti-counterfeiting technology**.**

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