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Infrared Thermographic Investigation of the Use of Microcrystalline Wax to Preserve Apples from Thermal Shocks

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***Abstract*— This paper aims to prove the feasibility and effectiveness of using microcrystalline wax in order to preserve fruit from thermal shocks due to temperature changes or thermal excursions during food supply chain. Wax is a natural substance which covers the surface of some species of fruits such as the apples. This wax layer protects the fruit against parasites, atmospheric agents, thermal excursions, moisture loss, mechanical damage and microbiological infections. These singular features are currently object of studies and research activities aimed to develop new synthetic substances obtained by natural extracts or essences.**

Active infrared thermography has been used in this work to study the thermal response of apples to ambient temperature changes. The experimentation has been performed on the Golden Delicious variety. Two different apple sets have been considered. The first set was composed of apples covered by their own natural wax layer. The second set was composed of apples coated with an additional artificial microcrystalline wax layer. Their thermal responses have been put in comparison after a cooling process inside a climatic chamber. Measurements have been performed under controlled environmental conditions to assure the repeatability and reproducibility of data. By using an infrared camera, the thermal response of the two apple sets has been recorded and the heating rates have been compared. The wax coated apples have showed a slower heating rate due to the thicker wax layer. As a consequence, the coated apples have shown a reduced influence to external temperature variations. The final aim of this study is to reproduce artificially bio-wax films in order to cover and protect fruits during their life cycle from the tree to the table.

***Index Terms* — apple wax, microcrystalline wax, active thermography, emissivity, thermal response analysis, infrared thermal imaging.**

I. INTRODUCTION

With the increase of the demand for biological agriculture, new solutions have been developed to allow the diffusion of biological farms. The biological farming is based on new concepts and approaches to encourage the production of food of high quality in agriculture. The aim is to promote the natural processes in the farm, so to produce natural products without renouncing to their organoleptic properties. This new environmental sustainable approach is based on the use of methods of ecological agriculture which are free from toxic and artificial substances. So, only substances coming from soil and nature are permitted avoiding any kind of pesticides, chemical substances and artificial products [1].

At the present time, the approach to environmental preservation is drastically changed. Governmental organizations and international institutions are paying more attention to the definition of new regulations to safeguard the environment and the natural ecosystem balance. In addition, the increase of diseases, such as cancer and metabolic disorders, and even the soil/water contamination and the environmental changes have persuaded several countries to get more care to the environment by means of an ecologist vision. Therefore, as an example, the past agriculture practices and the conventional chemical farming become unsustainable and unprofitable. In this new scenario, researchers and agronomists are jointly working on developing modern technologies and novel methods to reduce any impact on the ecosystem. Biological fertilisers, biological antiparasitics products, natural nutrients, etc… [2] are taking place in the agriculture. Farmers are today more responsive to such issues. In addition, studies and crop analyses prove the effectiveness of these new fertilisers and antiparasitics. Biological farms have good productivity, food is more nutrient and healthy, and no side-effects are present for fauna and flora. So this new approach is becoming increasingly accepted by worldwide.

Although the effectiveness of these biological substances has been demonstrated, the management processes and the costs are more time-consuming and expensive, respectively. As a consequence, the definition of alternative means or methods is encouraged in order to prevent fungi, parasites, bacteria and microbiological infections. In addition, atmospheric agents, thermal excursions and mechanical damages are further issues to be faced.

The new paradigm and approach of biological farming are based on a simple assumption: any solution has to come from nature. The solution has to focus on the problem rather than on the symptoms. In this way, it is possible to address specifically the cause of the problem. In this view, the present work aims to provide a possible solution to protect fruits during their life cycle from the tree to the table. In particular, attention is focused on thermal shock issue. By observing the nature, it is known that the apples are naturally covered with a wax layer, which protects the fruit from external agents [3], [4]. In addition, this wax layer contributes to preserve the organoleptic properties and quality of the apple. The production of artificial and biological waxes is today an interesting challenge, which involves different research disciplines [5]. In fact, after the synthetisation of the wax by chemical or extraction process, it is required to characterize the features of the natural wax in terms of thermal, chemical, mechanical and organoleptic properties. Several techniques are used for this aim [6]. In this context, the authors propose an investigation of the use of microcrystalline wax to preserve apples from thermal shocks. Microcrystalline wax is today used in food industry for fresh-food storage. For example, some cheese varieties are wax-coated to preserve organoleptic properties and avoid mould formation. The aim of the present study is to characterize the thermal response of artificially coated apples to ambient temperature changes in order to define the thermal properties of the wax. At the same time, this research intends to describe the potentialities of the active thermography as a contactless and non-destructive tool. Due to its non-invasive property, thermography is today widely used for several applications, such as for environmental monitoring [7]-[10], in biomedical field to assess specific pathologies [11]-[13], to characterize materials cracks [14]-[17], in the field of archaeology [18], [19], and in agricultural field and food industry [20]-[26]. It is an image-based technique, which transforms the thermal IR energy emitted by an object into temperature values. A thermal camera is able to capture a scene and to reproduce it into a thermographic or thermometric image. Pixel by pixel, the image shows, by a colour scale, the temperature distribution of the objects surface in the scene. It is expected that changes of the apple layer thickness (by means of artificial wax addition) are cause of changes of the apple thermal response to external stimuli or thermal excitation. The thermography has been used in a comparative study for analysing the apple response to thermal shocks avoiding any damage for the investigated object.

The paper is organized as follows. In Section II, the theory of active thermography is described. Section III reports the description of the used measurement procedure and setup. Experimental results are showed in Section IV. Finally, conclusions are outlined in Section V.

II. ACTIVE THERMOGRAPHY THEORY

Any object with temperature over the absolute zero is able to exchange thermal energy or heat with the surrounding ambient. Depending on the object and the ambient temperature, the object can absorb or emit energy in the IR range within the interval 0.78 μm – 1 mm of the electromagnetic spectrum. In detail, it is possible to evaluate the radiance W by means of the Planck's Radiation Law:

$$W(\lambda, T) = \frac{2\pi hc^2}{\lambda^5}\left[\exp\left(\frac{hc}{\lambda kT}\right) - 1\right]^{-1} \tag{1}$$

where T is the thermodynamic temperature of the object, λ the wavelength of radiation, h is the Planck constant, c is the velocity of light in vacuum and k is the Boltzmann constant. This equation describes the mathematical relation existing between the radiance and the object temperature.

By using detector-based systems, it is possible to measure the object radiance. An infrared thermal camera is able to measure the electromagnetic radiation emitted by the object in the infrared spectrum. The emitted infrared energy is correlated with the superficial temperature. Modern thermal cameras have high accuracy and resolution. As a consequence, changes and temperature differences can be detected with a sensitivity less than 15 m°C.

Atoms and molecules movements allow infrared energy to be emitted or absorbed by the object. Molecules can move according to specific directions and, depending on the number of atoms, can even vibrate, rotate or twist along an axis. With the increase of object temperature, the interactions among molecules increase, consequently the object exchanges a greater amount of thermal energy. The thermal exchange with the ambient can happen by three mechanisms: emission, transmission and reflection. Therefore, no all thermal energy is emitted by the object. As a consequence, in order to evaluate the right amount of radiated energy, the emissivity ε_λ of the observed object has to be known. This important parameter can be evaluated by the Kirchhoff's Law:

$$\varepsilon_\lambda = 1 - \tau_\lambda - \rho_\lambda \tag{2}$$

where τ_λ is the transmittance and ρ_λ is the reflectance of the object. A further parameter to be considered is the reflected temperature, a wrong estimation of its value can be cause of errors influencing the temperature measurement. Consequently, these two parameters must be very accurately estimated and set in the setting utility of the thermal camera. In this way, the thermal camera detects the object radiance in (1) pixel by pixel. Then, by the embedded algorithms, the radiance value of each pixel is converted into temperature value. By using a colour palette, an infrared image is generated according to the temperature range of the observed scene. Each pixel is depicted by a specific colour shade depending on the specific palette. Each colour shade matches with a temperature value according to the colour bar.

Depending on the specific application and scope, different thermographic techniques have been defined in literature. Passive and active thermography are the two basic techniques. In the first case, the radiance of the object is measured by means of a thermal camera without using any external excitation system. This technique is used to study the surface temperature distribution of an object so to characterize zones with higher temperature values. In the second case, an external thermal excitation system is typically used to stress thermally the object by increasing or decreasing its temperature. Consequently, the dynamical thermal response is observed over time. This technique is frequently used to find out the presence of irregularities in the object structure or uneven thickness [27]. This is made possible because different materials or different compositions have a different thermal response.

Lastly, pulsed-thermography, lock-in IR thermography, laser-thermography, vibration-thermography and spectral thermography are further advanced techniques of active thermography, which allow to extract detailed information about the object properties by means of external excitation systems and spectral filters [28]. Today, thermography is used in several application fields: building diagnostics, medical imaging, surveillance and security, non-destructive testing etc…

III. THE MEASUREMENT PROCEDURE

The microcrystalline wax is a derived petroleum product. It is a synthetic wax, tasteless, colourless (sometime white), composed of a complex mixture of hydrocarbons. It is used as food additive to coat fresh fruit or vegetables to make their appearance brighter and to protect them from deterioration during transportation. Paraffin should be non-toxic even if ingested although it cannot be digested by humans. It is commonly used in food industry and is known with the code E 905. About its use in Europe, the Panel on *Food Additives and Nutrient Sources added to Food* (ANS) has the task to introduce/remove additives in/from the authorised list and to define the specific use of each one. The European Commission regulates and inspects the ANS Panel activities. According to the Panel opinion, the microcrystalline wax (E 905), when used as a food additive, has to be considered a surface treatment agent which can be used on non-chocolate confectionery, chewing gum and decorations, coatings and fillings, except fruit based fillings. It is also permitted as a surface treatment of melons, papaya, mango and avocado. In a report, the Panel concluded that there is no concern for genotoxicity from microcrystalline wax (E 905). The Panel also considered that the available toxicity studies with mineral hydrocarbons, closely related from a chemical point of view with microcrystalline waxes, consistently reported no effects of concern associated with the intake of microcrystalline wax. Therefore, the use microcrystalline wax (E 905) as a food additive (following *quantum satis* rule) is not of safety concern [29].

A comparative study between apples with its natural wax layer and apples coated by microcrystalline wax is described in the following. The present investigation will focus the attention on the use of the active thermography technique to measure and compare the dynamical thermal response of the two apples sets. The aim of this study is to demonstrate that the use of artificial wax can improve the apple resistance to thermal shocks and moisture loss. The same coating technique could be even used on other fruit species. The used measurement instrumentation includes: a climatic chamber *Angelantoni Discovery DY-250* used as external thermal excitation system; and a thermal IR camera *FLIR x8400sc* for recording the thermal response over time, see Figure 1.

Fig. 1. Measurement instrumentation.

In detail, the used thermal infrared camera has an *Indium Antimonide* (InSb) detector with a resolution of 1280x1024 pixels, a frame rate up to 106 Hz, a temperature range [-20 3000] °C, a spectral range of [1.5 5.1] µm, and a sensitivity (NEDT) smaller than 18 m°C. The used climatic chamber has a temperature range of [-40 180] °C, a relative humidity range of [10% 98%], a dew point range of [2 94] °C, and a temperature fluctuation up to ±0.3 °C. The whole experimentation has been carried out under controlled environmental conditions in order to assure the repeatability and reproducibility of the experiment. The measurement procedure can be divided in four steps:

- *Step A*: each apple has been weighed, their diameter has been measured, and the thermal emissivity of the apple peel has been evaluated at start of experiment;
- *Step B*: apple has been coated with about 3 mm layer of microcrystalline wax, then the thermal emissivity of the wax coat has been evaluated before the cooling process;
- *Step C*: the apples have been cooled at a temperature of 5 °C for 48 hours by means of the climatic chamber (cooling process);
- *Step D*: the thermal emissivity of both apples has been measured once more, then the thermal response of the apples has been recorded during a time interval of 120 minutes. In detail, each apple began a natural heating process starting from an initial temperature equal to 5 °C and then reaching the ambient temperature of 28 °C. (heating process).

During the entire measurement process, the ambient temperature T_{AMB} was continuously monitored and kept constant at 28 °C in order to assure the repeatability and reproducibility of the *Step D*. The ambient relative humidity $U_{AMB}\%$ was equal to 38%.

A. Apple Cultivars and Spectral Emissivity

The experimentation has been performed on *Golden Delicious* apples, see Figure 2 [21], [26], [30]. The apple on the left is labelled as apple #1, the apple on the right is labelled as apple #2. This apple cultivar is widely produced and consumed due to its organoleptic characteristics. This variety has a yellow colour and a thinner superficial wax layer compared to the other cultivars, such as the red variety. In fact, the red variety is typically characterized by a major resistance to changing weather conditions, thermal excursions and external agents [30].

Fig. 2. Apples under test.

For each apple, the thermal emissivity has been estimated for assuring an accurate temperature evaluation from the measured radiation [27]. This parameter can be cause of errors of the temperature measurements if it is incorrectly estimated. To this aim, a standardized procedure has been used. In detail, a little piece of *Scotch™ Brand 88* black vinyl electrical tape with known emissivity of 0.96 has been glued on a portion of each apple skin waiting for thermal equilibrium. By setting the emissivity parameter of the thermal camera to that of the known material, the absolute temperatures of both materials (Scotch tape and apple peel) have been put in comparison. The surface emissivity value of each apple is estimated by making equal the acquired temperature values of the tape and of the apple surface near it [27]. The emissivity of the peel of both apples was equal to 0.98. Table I reports the main features of the two examined apples.

TABLE I. APPLE FEATURES

Apple Cultivar	**Apple Features**				
Golden Delicius	***Mass [g]***	***Diameter [cm]***	***Colour***	***Emissivity pre-coating***	***Emissivity post-coating***
#1	216	24	yellow	0.98	0.85
#2	237	24.5	yellow	0.98	0.98

B. Microcrystalline wax coating

The apple #1 has been coated with about 3mm layer of microcrystalline wax, see Figure 3. Then, the thermal emissivity of the wax coat has been evaluated before the cooling process, see Figure 4. The above-described procedure has been used, and the evaluated emissivity of the wax coat was equal to 0.85, see Table I for further reference.

Fig. 3. Microcrystalline wax coating.

Fig. 4. Emissivity evaluation by black vinyl electrical tape.

C. Climatic Chamber setup and Thermal Conditioning

The thermal conditioning of the two apples has been performed by using the climatic chamber, see Figure 5. In detail, the chamber parameters have been set to 5 °C and 40 % of relative humidity. The apples have been placed inside the chamber and have been cooled starting from a temperature of 28 °C to 5 °C. The cooling process has taken about 48 hours. Before performing the thermographic measurements, the apples have been put at rest to ambient temperature for few minutes in order to avoid the formation of dew which could alter the thermographic measurements.

Fig. 5. Climatic chamber and cooling process.

D. Thermographic Measurements and ROI selection

The thermal emissivity of both apples has been measured once more in order to check the previous measurements, the emissivity values reported in Table I have been confirmed (refer to *“Emissivity post-coating”* column). The reflected temperature has been estimated by using a crumpled and re-flattened piece of aluminium foil. The used measurement procedure is standardized and is described in more detail in [27]. In particular, by assuming an emissivity equal to 1 and a distance of 0 m, the thermal infrared camera has measured the temperature of the aluminium piece. The measurement is repeated by using this temperature value as the reflected temperature. The resulting temperature value is the final and real reflected temperature T_{REFL}, it was equal to 32.8 °C. The two apples, after the cooling process, have been placed on a table with an antireflection surface at a distance of 0.4 m from the IR camera. The test bench is shown in Figure 6.

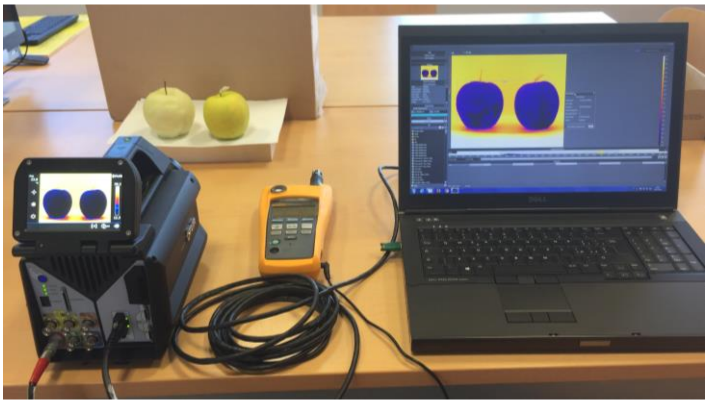

Fig. 6. Test bench.

Before starting the acquisition of the thermal response of the apples, the thermal camera parameters (ambient temperature, distance, emissivity and reflected temperature) have been set by means of the camera setting utility. Each apple began a natural heating process starting from an initial temperature equal to 5 °C and then reaching the ambient temperature of 28 °C. The heating process has been recorded over an interval of 120 minutes with a frame rate of 1/60 fps (one thermographic frame every 60 s). For each apple, 120 thermographic frames have been acquired. *Regions Of Interest* (ROIs) have been properly selected by considering the whole frontal area of each apple surface. Attention has been payed to remove from the analysis the area of the apple which is near to the edge in order to avoid to detect partially the emitted radiation.

IV. EXPERIMENTAL RESULTS

The *FLIR ResearchIR* software has been used to process the thermographic images. Figure 7 shows the first acquired thermographic frame of the two apples at the time instant t=1 s.

Fig. 7. Thermal response at the time instant t=1 s.

On the left of the image there is the coated apple, on the right the apple with natural wax. Two oval-shaped ROIs have been selected to evaluate the thermal response of each apple. In this way, it is possible to compensate possible irregularities of the superficial temperature distribution and possible reflection effects due to the external lightning or external heat sources. These ROIs allow to get information on the mean temperature of each apple. Figure 8 shows the last acquired thermographic frame of the two apples at the time instant t=120 s.

Fig. 8. Thermal response at the time instant t=120 s.

With more detail, Tables II and III report the statistic values for each oval-shaped ROIs for the first and the last frames, respectively. The Tables report the mean temperature value of the ROI area, the temperature standard deviation of the selected pixels, the temperature value of the central pixel, the maximum and minimum temperature values in the ROI area, the number of pixels of the ROI, the emissivity and finally the object distance. By a quick overview of the two thermal images and of their statistics, it is possible to observe the slow heating rate of the microcrystalline wax coated apple. In detail, both at the start and at the end of the measurement process, the apple #1 has shown a temperature lower than the apple #2 by considering the graduated colour scale. In fact, it is clearly visible that the apple #2 has a faster heating process, it can be imputed to the less thickness of its natural wax layer.

TABLE II. STATISTICS OF THE OVAL-SHAPED ROIS (FRAME #1).

ROI Statistics	**Apple**	
	#1	***#2***
Mean [°C]	6.4	11.0
Standard Deviation [°C]	0.9	0.5
Center Value [°C]	5.8	11.2
Maximum [°C]	9.5	12.8
Minimum [°C]	4.4	9.9
Number of Pixels	125648	128845
Emissivity	0.85	0.98
Distance [m]	0.4	0.4

TABLE III. STATISTICS OF THE OVAL-SHAPED ROIS (FRAME #120).

ROI Statistics	**Apple Cultivars**	
	Apple #1	***Apple #2***
Mean [°C]	24.5	26.1
Standard Deviation [°C]	0.7	0.4
Center Value [°C]	24.6	26.2
Maximum [°C]	25.9	27.1
Minimum [°C]	22.9	25.1
Number of Pixels	125648	128845
Emissivity	0.85	0.98
Distance [m]	0.4	0.4

These statics provide a clearer overview for each apple about their initial and the final stages of the heating process. More information can be obtained by Figure 9; it reports the temporal plot of the oval-shaped ROIs of the two apples. In the ordinate axis, the temperature values are reported in °C measurement unit. The abscissa axis reports the frame number with a sampling period of 60 s. So each frame amounts to 1 minute. After the cooling process in the climactic chamber at 5 °C, each apple has been put at the ambient temperature equal to 28 °C, so this plot shows the dynamical thermal response of both apples during the process of adaptation to the change of ambient temperature.

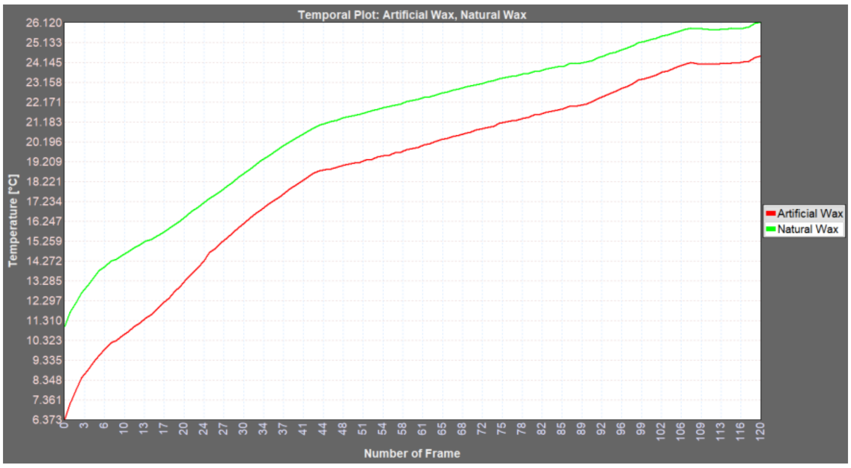

Fig. 9. The apples thermal response over time (oval-shaped ROIs).

The upper curve (depicted in green colour) represents the temperature temporal trend of the non-coated apple #2, it is named "*Natural Wax*". The lower curve (depicted in red colour) shows the temperature temporal trend of the microcrystalline wax coated apple #1, it is named "*Artificial Wax*". It is important to note that the temperature of both apples does not start from 5 °C. In fact, before starting the thermographic recording, the apples have been put at rest to ambient temperature for few minutes in order to avoid and remove the formation of dew which would alter the temperature measurements. According to the previous analysis, the temporal plot highlights the different thermal behaviour of the apples. In detail, the apple #2 shows a faster heating rate due to the heat exchange with the ambient. Such a behaviour can be explained by the thinner natural wax layer of the apple. By analysing the temperature plot reported in Figure 9 and comparing data included in the Tables II and III, the mean thermal excursion rate of the apple #1 is equal to 0.151 °C per minute. The apple #2 has shown a mean thermal excursion rate of 0.126 °C per minute. Figure 10 describes the temperature difference between the two apples frame by frame.

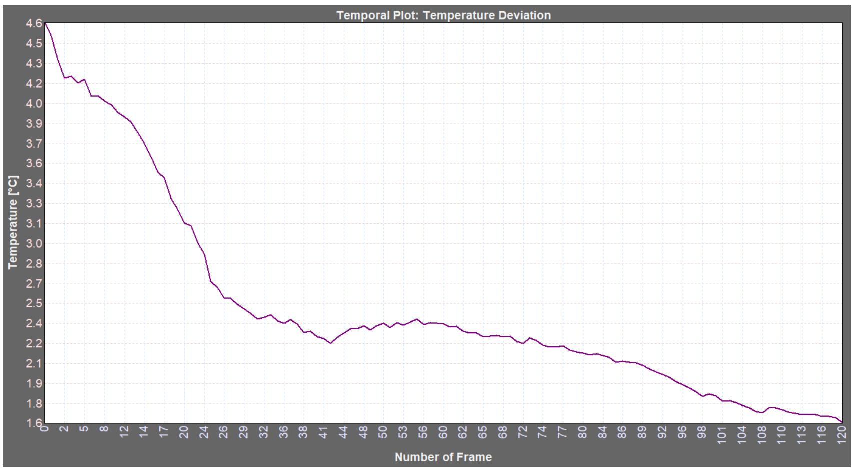

Fig. 10. Temperature Deviation frame by frame.

This plot can provide further information on the insulating capacity of the investigated wax. The best performances are shown during the first 40 minutes with a temperature deviation ranging from about 4.6 °C to 2.2 °C. Its efficacy continues up to

90 minutes with an insulating level of about 2 °C. After 2 hours, at the end of the experimentation, the temperature deviation was equal to 1.6 °C.

Since the above analysis provides information only on the superficial temperature of the two apples, additional data have been got by cutting the two apples in order to examine the temperature distribution of the inside, see Figure 11.

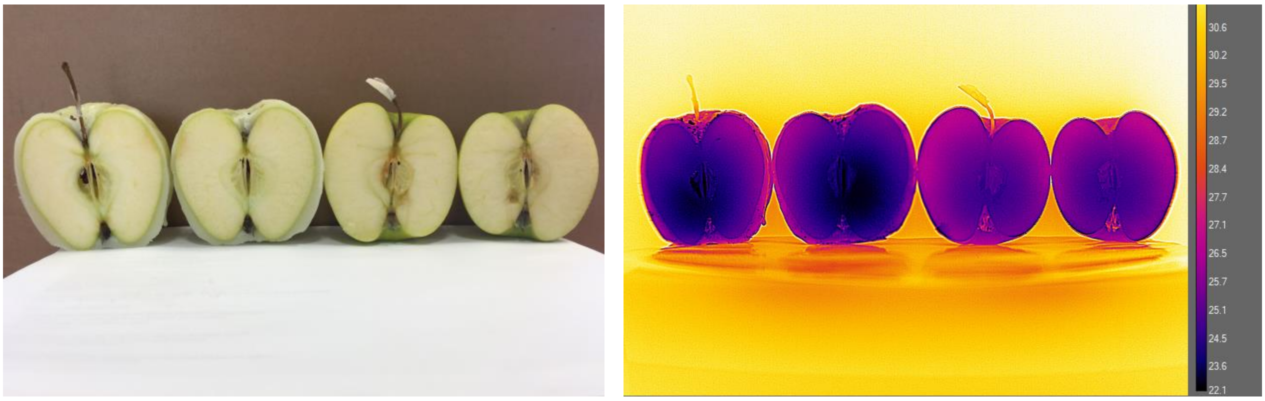

Fig. 11. Temperature distribution of the apple inside.

Before starting the measurement, the apples pulp has been manually dried in order to avoid any interference and measurement error due to possible reflection or evaporation effects. The emissivity of the apple inside has been estimated by using the measurement procedure above described. A piece of black vinyl electrical tape has been glued on the apple pulp, see Figure 12. The estimated emissivity was equal to 1 for both apples.

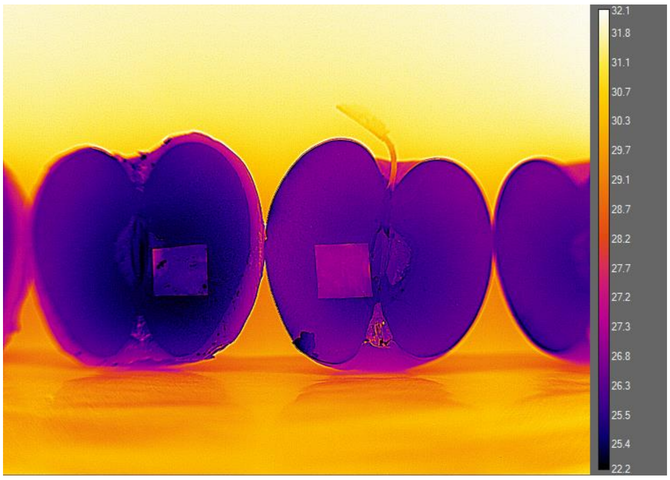

Fig. 12. Emissivity evaluation of the apple inside.

Two oval-shaped ROIs have been chosen to analyse the temperature values of the inside of the two apples, see Figure 13. The greater extension of the considered ROIs allows to compensate specific error contributions due mainly to a non-uniform superficial heating of the single apple caused by an irregular shape, and due to a possible thermal energy reflection due to the damp apple pulp. In detail, Tables IV reports the statistic values for each oval-shaped ROIs of the apple inside. Data show a mean temperature deviation between the two apples of about 1 °C and a maximum temperature deviation of about 1.5 °C.

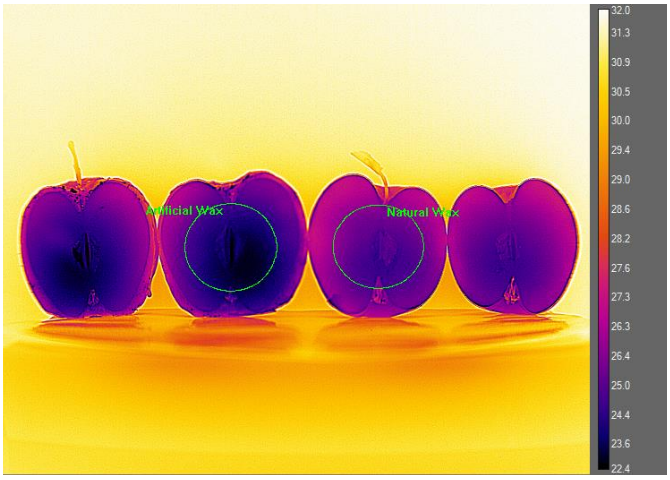

Fig. 13. The oval-shaped ROIs.

TABLE IV. STATISTICS OF THE OVAL-SHAPED ROIS (APPLE INSIDE).

ROI Statistics	Apple Cultivars	
	Apple #1	***Apple #2***
Mean [°C]	23.3	24.4
Standard Deviation [°C]	0.3	0.3
Center Value [°C]	22.9	24.2
Maximum [°C]	24.1	25.6
Minimum [°C]	22.6	23.8
Number of Pixels	25898	27628
Emissivity	1	1
Distance [m]	0.4	0.4

In order to improve the statistical basis of the results, the described procedure has been reproduced to test further 10 coated apples. The obtained mean of the temperature deviations (with respect to the uncoated apple) was equal to 2.6 °C, 2.2 °C and 1.4 °C after 30, 60 and 120 minutes, respectively. The calculated standard deviation was equal to about 0.2 °C. These additional results confirm the previous deductions on the insulating capacity of the microcrystalline wax.

V. CONCLUSIONS AND FUTURE WORK

The proposed investigation aims to prove the effectiveness of artificial wax coating to preserve fruits from thermal excursion and thermal shocks. The experimentation has been carried out on twelve apples by comparing their dynamical thermal response after a cooling process at 5 °C. One apple has been covered by using the microcrystalline wax. It is a food additive commonly used in food industry to increase storage time. The other apple has not undergone artificial coating, so its peel is covered by the only natural wax layer. The two thermal responses have been compared during the heating process induced by the gradient with the ambient temperature equal to 28 °C. The cooling and heating processes could simulate the thermal excursions and shocks occurring during the several phases of the supply chain from the tree to the table of the final user. The final results have shown a good insulating property of the microcrystalline wax. In fact, after 2 hours, the apple surfaces have shown a temperature difference of 1.6 °C, whereas the inside of the two apples has shown a difference of 1.1 °C.

The main contribution of the proposed investigation concerns the thermal characterization of the microcrystalline wax properties by using active thermography. At the present, food wax coating has been widely discussed and investigated in literature. However, most of the contributions concern the characterization of organoleptic properties preservation and the protection from parasites. This work aims to prove the thermal effects in using wax coating in order to preserve food from thermal shocks and excursions during the food supply chain. So, in detail, the present research activity has allowed us to define the main thermal features of the microcrystalline wax and its response to thermal stress. The wax coating process could be performed on any fruit or vegetable. The advantages concerning the wax use do not regard the only thermal feature. In addition, wax coating could improve the food resistance to external agents (parasites, atmospheric agents) or to prevent moisture loss, mechanical damages and microbiological infections. In addition, wax coating contributes to preserve the organoleptic properties and quality of food.

Future works aim to compare the insulating properties of several artificial and natural waxes reproduced in laboratory. At the present stage, the preliminary studies performed on using microcrystalline wax have shown that this artificial wax has a good response to thermal excursions. In an ecologist view, the main advantages in using wax coating do not concern the only preservation of the food organoleptic properties, in fact the use of artificial coating could permit in the next future to avoid the use of pesticides and chemical substances, and to preserve crops from weather and climatic changes.

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