Application of mobile fluorescence spectroscopy as a method for the analysis of representatives of different varieties of carrots (*Daucus carota*) during storage under uncontrolled conditions

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The present study aims to establish the application of mobile fluorescence spectroscopy as a method to determine varietal differences and water content during storage of carrots under uncontrolled conditions. The experimental studies were carried out on the farm where the carrots were grown and stored. Fluorescence analysis was performed with a source with an emission wavelength of 285 nm, using an author-developed mobile set up in a fiber-optic configuration generating fluorescence signals. Root crops from Nantes, Short`n Sweet, Touchon and Flakkee varieties were the subject of this study. They were measured after harvesting after 3 and 6 months of storage. The correlation between the emission wavelengths of the samples of different varieties, as well as those of the same variety at different storage intervals, was established. This fact allows mobile fluorescence spectroscopy to be successfully applied as a rapid tool in carrot breeding programs in establishing the origin of unknown root crops in the presence of a rich library of spectra, as well as in the sorting of carrots in warehouses of food chains and producers. The results of the experiment can be used to optimize the time for the analysis of varietal affiliation of different carrot genotypes during storage under uncontrolled conditions. Fluorescence spectroscopy in a fiber-optic configuration will support the process of determining the affiliation of a particular carrot variety to a given variety (even for samples of unknown origin when it is necessary to qualify and sort in a short time).

Keywords: carrot accessions, fluorescence spectroscopy, variety, emission wavelength, storage under uncontrolled conditions

INTRODUCTION

The carrot (*Daucus carota*) is a biennial, rarely annual or perennial herbaceous plant of the umbel family. It is grown mainly in the Mediterranean, but also in America, Africa, Australia, etc. [1]. The cultivated carrot is a biennial vegetable and fodder plant. It is grown for its root, which is fleshy and, depending on the variety, has a rounded, truncated-conical, spindle-shaped or other shape with a red, yellow-red, yellow or white color [2]. It forms a pale yellow to red-orange root crop in the first year. It forms seeds and flowers in the second year. It is used for food, fodder and as a medicinal agent [3].

The carrot contains an average of 88.8% water [4]. Carrots are a strong-tasting, useful, long-lasting and storable vegetable. It has been shown that during the first five months of storage after peeling, its vitamin A content increases, and if protected from heat or direct sunlight, it can preserve its nutrients for another two to three months [5].

A non-destructive method was developed for the determination of carotene content in carrots using Raman spectroscopy combined with chemometry. Raman spectra of carotene and carrots were collected to determine the Raman peaks of carotene in the Raman spectrum of carrot. According to the Raman peaks of carotene, the distribution of carotene content in carrots is discussed. The average Raman spectra of different parts of carrots were used to represent the carrot sample. The results of the study provide methodological support for the quantitative analysis of carotene content in carrots [6].

Various analytical techniques have been used to investigate the complex composition of carrots. Among them, fluorescence spectroscopy cannot be neglected in the development of rapid and non-invasive analytical methodologies. It is one of the most sensitive spectroscopic approaches used in the identification, classification, authentication, quantification and optimization of various parameters during food processing and storage. It uses various chemometric tools. Chemometrics helps extract useful information from spectral data used in the characterization of food samples. The potential of fluorescence spectroscopy in the analysis of various foods, such as dairy products, meat, fish, eggs, edible oil, cereals, fruits,

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vegetables, etc., has been demonstrated by qualitative and quantitative analysis with different chemometric approaches [7]. The potential application of front face fluorescence (FFF) to monitor the impact of the industrial process on carrot baby food was evaluated. The effect of using different raw materials, fresh carrots, frozen cubes or pasteurized puree, on the NFC content of the resulting sterilized puree was also tested. FFF is a hopeful tool for monitoring the fast and easy processing of vegetables in a quality control approach [8].

The optical, morphological, structural and compositional properties of water-soluble and blue-emitting carbon quantum dots (CQDs) have been confirmed by various characterization methods. As a fluorescent probe, CQDs showed a good linear response to picric acid (PA) with a limit of detection (LOD) of 18 nM. The sensing mechanism involves a combination of static cooling and fluorescence resonance energy transfer. Fresh carrots were used as a model sample [9].

Through the application of fluorescence spectroscopy, the binding mechanisms of purple corn, grape and black carrot anthocyanin extracts have been successfully investigated. A laser with a wavelength of 280 nm at 25 ◦C, 35 ◦C and 45 ◦C was used as the emission source. The fluorescence intensity decreased (up to 73%) and its λ_{max} increased (by ~5 nm) with increasing anthocyanin concentration (0–100 μM). This technique was applied to evaluate the color stability of anthocyanins, expanding the application of anthocyanins as food colorants that better withstand processing and storage [10].

In connection with the demands of consumers for high food quality, the conducted research can serve as a basis for the creation of mobile detecting devices, with which to carry out instant analysis of warehouse production of carrots stored in uncontrolled conditions, both in processing plants and in food retail outlets.

The present study aims to establish the function of fluorescence spectroscopy as a mobile method for the analysis of representatives of different varieties of carrots (*Daucus carota*) during storage under uncontrolled conditions. They will be compared in terms of determining the spectral distribution after harvesting and at different storage periods of 3 and 6 months. The accessions were stored under uncontrolled storage conditions.

This will permit the technique to be applied non-invasively in the quality control of carrot production in unspecified storage and outdoors.

MATERIALS AND METHODS

Materials

Accessions from four standard carrot varieties were investigated.

Nantes - An early (non-hybrid) variety suitable for both greenhouse and field production. They are used for fresh consumption, for processing, for pickles, winter salads, many dishes and natural juices. Their shape is cylindrical and smooth. The average length of Nantes carrots is about 15-16 cm. The root crops are extremely sweet, orange-red, crunchy and aromatic - with very good tasty qualities.

Short`n Sweet - Suitable for growing in soil conditions that are not ideal, such as heavy or poor soil that is rich in clay or difficult to work. This rich, sweet little root is easy to grow and full of vitamins. 'Short 'n Sweet' is a 'Chanetay' type that produces compact 4-inch roots with about 68 days to harvest.

Touchon - The variety is suitable for different types of soil, which is why it is grown both in the southern and northern regions. According to the description, if the crops are properly cared for, Touchon carrots bear fruit until the end of July, but the main harvest occurs in early autumn (early September). To be harvested in early June, sowing is done in mid-autumn (October-November).

Flakkee - An early variety. It forms a smooth, deep orange-red, cone-shaped root with a blunt tip, 20 cm long and weighing 200 - 250 g. High tolerance to diseases and high temperatures. An extremely suitable variety for early production. Vegetation period - about 105 days after sowing. The roots are cone-shaped, bright orange, sweet, 18-24 cm long. They do not tend to crack. Suitable for autumn harvest and winter storage. It grows best in cultivated, humus, unirrigated light clay or sandy soil. If the soil is heavy, germination is poor, root crops are short, branched and split.

Carrots are harvested in dry sunny weather in the morning. After they are washed, they are spread out on a linen cloth and left to dry well, being turned periodically. The carrots are dried for 2-3 hours in the sun and then for 7-10 days in a well-ventilated place. Their tops are cut in two stages. The first stage is to cut off just above the root crop, the second stage is to cut off the top of the carrot by 1 cm. Immediately before storage, the carrots are sorted and only healthy and undamaged root vegetables are set aside for long-term storage. They are stored in a dry warehouse at an average temperature of 4-7 ^{o}C.

Fluorescence spectroscopy

The mobile fiber-optical spectral installation for the study of fluorescence signals is designed specifically for the rapid analysis of plant biological samples. The mobile experimental setup used by fluorescence spectroscopy includes the following components:

- Laser diode (LED) with an emission radiation of 245 nm with a supply voltage in the range of 3 V. It is housed in a hermetically sealed TO39 metal housing. The emitter has a voltage drop of 1.9 to 2.4 V and a current consumption of 0.02 A. The minimum value of their reverse voltage is – 6 V.
- Rod lens of the achromatic doublet type. It is composed of two bonded lenses with different Schott and Corning dispersion coefficients with an anti-reflective coating. The radii of the two lenses are selected so that the chromatic aberration of one lens compensates that of the other. The tolerance of the diameter of the forming optics is -0.005 mm.
- The multimode optical fiber is FG200LEA. It has a core diameter of 200 μm and a step index of refraction.
- Quartz glass area of 4 cm^2. Its optical properties are to be transparent to visible light and to ultraviolet and infrared rays. This allows it to be free of inhomogeneities that scatter light. Its optical and thermal properties exceed those of other types of glass due to its purity. Light absorption in quartz glasses is weak.
- CMOS detector with photosensitive area of 1.9968×1.9968 mm. Its sensitivity ranges from 200 nm to 1100 nm. Its resolution is $\delta\lambda = 5$. The profile of the detector sensor projections along the X and Y axes is also designed for very small amounts of data, unlike widely used sensors.

The sample is irradiated by the LED, after which it fluoresces. The emission signal is registered at 45ºC by the rod lens which transmits it through the optical fiber to the detector.

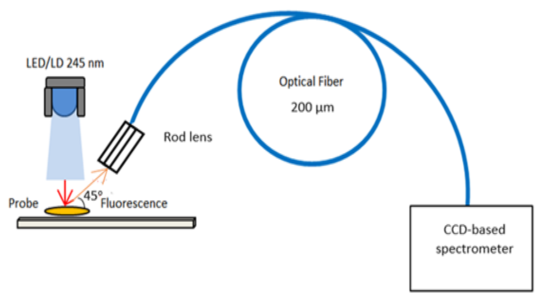

Fig. 1. Mobile experimental installation used by fluorescence spectroscopy

The three unique advantages of this scheme are:

- Inclusion of the HQ lenses in the construction of the system due to their increased light transmission efficiency by almost completely filling the air gaps between the individual lenses.
- Unique design of optical fiber coupling from a headquarters lens in a duralumin housing. In this way, the optimal design for compiling with optical fibers and forming images from laser diodes with low levels of intense losses is achieved.
- Registering of the emission signal at 45ºC.

RESULTS AND DISCUSSION

Prolonged storage under controlled conditions of carrot root crops leads to a decrease in their water content. This process is directly proportional to the duration of storage.

The optical properties of the carrot are determined by its energy structure, which includes both the occupied and free electronic energy levels, as well as the energy levels of the atomic vibrations of the molecules or the crystal lattice.

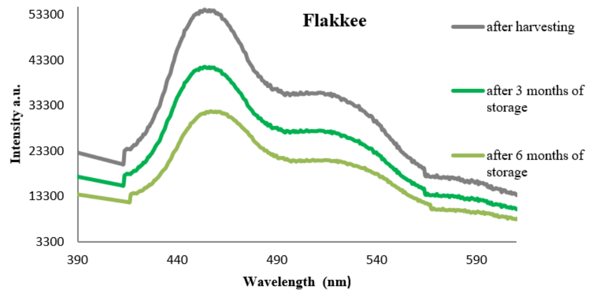

Fig. 2. Difference in emission wavelengths of Flakkee variety accessions of carrots after harvesting and storage for 3 and 6 months.

The possible transitions between these energy levels, as a function of photon energy, are specific to the carrot, resulting in spectra and optical properties unique to it. Carrots contain particles smaller than the wavelength of visible light. Particles in the turbid medium, such as the carrot, act as independent light sources, emitting incoherently, causing the samples to visibly fluoresce.

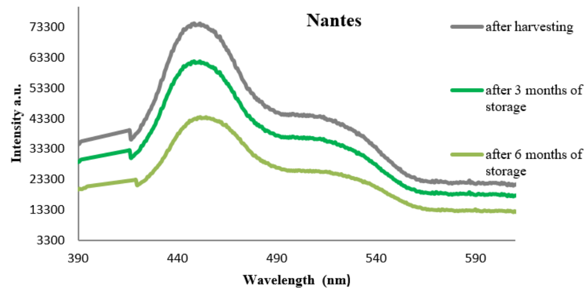

Fig. 3. Difference in emission wavelengths of Nantes variety accessions of carrots after harvesting and storage for 3 and 6 months.

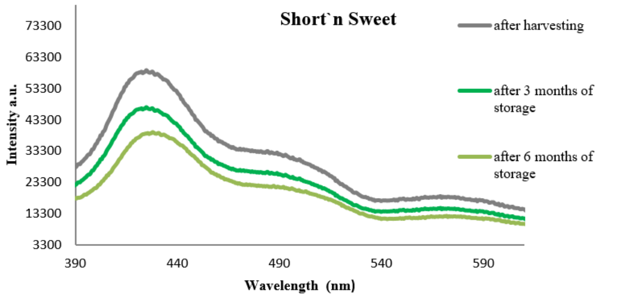

Fig. 4. Difference in emission wavelengths of Short'n Sweet variety accessions of carrots after harvesting and storage for 3 and 6 months.

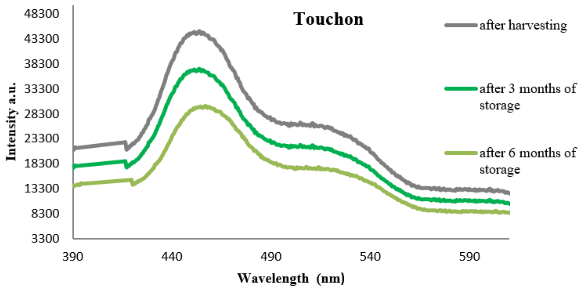

Fig. 5. Difference in emission wavelengths of Touchon variety accessions of carrots after harvesting and storage for 3 and 6 months.

Therefore, fluorescence spectroscopy finds application for analysis of this vegetable crop. The optical parameters and spectral properties also change as a function of temperature, pressure, external electric and magnetic fields, etc., which allows obtaining essential information about changes in the chemical and cellular morphological composition of the carrot.

The analysis of the graphs established the application of fluorescence spectroscopy for the analysis of root crops during storage in a warehouse under uncontrolled conditions for a period of 3 and 6 months (Figures 2, 3, 4 and 5). The decrease in signal intensity is directly proportional to the duration of storage (and it, in turn, is related with a decrease in root water content due to evaporation).

A literature survey was performed to conduct similar research. It turned out that until now the described experimental approach for the analysis of root crops has not been applied nationally and internationally. This gives us reason to claim that mobile fluorescence spectroscopy in a fiber optic configuration has been applied for the first time to analyze carrot samples for their water content and root stability during storage in a storage room under uncontrolled conditions. The three main advantages of fluorescence spectroscopy are that the method is fast, does not require consumables, and can be performed on-site in the warehouse. The decision for local measurements was made to avoid damage to the samples during transport and thus, to ensure fluorescence analysis with high sensitivity. The signal intensity is high enough at very low water content, which means that the method is applicable to controlling the quality of root crops during long-term storage of carrots in storage rooms under uncontrolled conditions. An essential point in fluorescence diagnostics regarding the comparison of accessions after harvesting and after a certain period of storage is that the method is highly sensitive in terms of determining the water content of root crops kept in a storage room under uncontrolled conditions. This fact allows fluorescence spectroscopy to be applied as a non-invasive method in quality analysis of carrot production kept in storage rooms of farms and commercial establishments.

CONCLUSIONS

- The method of mobile fluorescence spectroscopy is fast-acting in determining the water content of carrots during storage of the product.
- The method of mobile fluorescence spectroscopy is applicable in controlling the germination quality of root crops during storage.
- It was proven that mobile fluorescence spectroscopy will support the selection process and the control of stock production of carrots when it is necessary to qualify a large set of samples in a short time.
- A systematic engineering approach for the alignment (optical tuning) of a dedicated mobile fluorescence spectroscopy applied research facility was found to be applicable in the characterization of produced carrot during storage.

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