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Spectroscopic Analysis of Some Food Dyes by Infrared and Laser

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Abstract

Most food dyes are used to color confectionery and beverages. Children and adolescents are often the target group for such colored products. Their presence in everyday life can be used as a motivator. Given that sugary foods are often included in discussions about nutrition, a closer examination of their components may be suitable for scientific research. There is also an acceptable daily intake for most dyes. The popularity of colored supermarket products justifies quantitative and qualitative spectroscopic studies of these dyes to study their internal composition and their effects on human health in general. In university education, understanding the basic principles of spectroscopic techniques is often challenging due to the lack of connections to the real world. Therefore, the present contribution presents context-based applications of infrared spectroscopy for food color analyses through which researchers can improve their skills with regard to this method. The spectroscopic determination of food dyes appears to be a promising approach due to the long tradition and presence of dyes in food products. The required spectroscopic data for commonly used dyes are provided for educational use. Qualitative and quantitative analyses of food colorants from twenty different origins of food colorants were used to study their spectral and compositional properties using infrared spectroscopy (IR) in the range (400-4000) cm-1. A small detection system was designed that included an infrared laser source (IR) in the range (800-1100nm) and a spectrometer to measure the intensity of the absorbed radiation. The results showed that these techniques provide accurate and rapid methods for the analysis of dyes without the need for complicated sample preparations. This study contributes to improving the scientific understanding of these dyes and supporting their industrial and educational applications.

Keywords: laser, IR spectroscopy, food dyes

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التحليل الطيفي بعض الاصباغ الغذائية بالأشعة تحت الحمراء والليزر

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الخلاصة

تستخدم معظم الأصباغ الغذائية لتلوين الحلويات والمشروبات. غالبًا ما يكون الأطفال والمراهقون هم المجموعة المستهدفة لمثل هذه المنتجات الملونة. يمكن استخدام وجودهم في الحياة اليومية كمحفز(عامل الجذب). وبالنظر إلى أن الأطعمة السكرية غالبًا ما تكون متضمنة في المناقشات المتعلقة بالتغذية، فقد يكون الفحص الدقيق لمكوناتها مناسبًا للبحوث العلمية. هناك أيضًا كمية يومية مقبولة لمعظم الأصباغ. إن شعبية منتجات السوبر ماركت الملونة تبرر إجراء دراسات طيفية كمية ونوعية لهذه الملونات لدراسة تركيبها الداخلي وتأثيرها على صحة الانسان بشكل عام. في التعليم الجامعي، غالبًا ما يكون فهم المبادئ الأساسية للتقنيات الطيفية تحديًا بسبب فقدان الاتصالات بالعالم الحقيقي. لذلك، تقدم المساهمة الحالية تطبيقات قائمة على السياق للتحليل الطيفي للأشعة تحت الحمراء لتحليلات ألوان الطعام التي يمكن للباحث من خلالها تحسين مهاراتهم فيما يتعلق بهذه الطريقة. يبدو أن التحديد الطيفي للأصباغ الغذائية هو نهج واعد بسبب التقليد الطويل ووجود الأصباغ في المنتجات الغذائية. يتم توفير البيانات الطيفية المطلوبة للأصباغ شائعة الاستخدام للاستخدام التعليمي. تم استخدام التحليلات النوعية والكمية لملونات الطعام في عشرون نوع مختلف المنشأ من الألوان الغذائية لدراسة خواصها الطيفية والتركيبية باستخدام مطيافية الاشعة تحت الحمراء للمدى (400-4000) cm-1 . تم تصميم منظومة كشف صغيرة تحتوي على مصدر ليزر تحت الحمراء IR للمدى (800-nm1100) وسبيكتروميتر لقياس شدة الاشعاع الممتص. أظهرت النتائج أن هذه التقنيات توفر طرقًا دقيقة وسريعة لتحليل الأصباغ دون الحاجة

إلى تحضيرات معقدة للعينات. تسهم هذه الدراسة في تحسين الفهم العلمي لهذه الأصباغ ودعم تطبيقاتها الصناعية والتعليمية.

الكلمات المفتاحية: الليزر، مطيافية تحت الحمراء، الاصباغ الغذائية

Introduction

Understanding specific aspects of physical chemistry in general and contemporary spectroscopic techniques in particular are extremely difficult tasks in the field of scientific research. In conjunction with context-based experiments, introducing spectroscopic techniques on a phenomenological basis is one potential entrance strategy for students with relatively little prior knowledge [1]. Generally speaking, spectroscopic methods have been shown to be among the most effective means of resolving issues in both qualitative and quantitative analytical chemistry. Infrared spectroscopy, Raman spectroscopy, and inelastic neutron scattering are among the well-established and suitable methods for determining molecular structures that fall within the infrared range of electromagnetic radiation (wavelength from roughly 780 nm to 1 mm) [2].

Diminished overall reflectance Crocin levels in commercial saffron samples were determined using the Fourier transform infrared spectrometric method. Spectral wavenumbers with a correlation coefficient (r) higher than 0.99 were chosen for the quantification of crocin in the samples, and calibration models were constructed based on the peaks at the 1700–900 cm−1 spectral region. Analyzing samples quantitatively using attenuated total reflectance Infrared Fourier transform was compared to the reference UV-visible spectrophotometric method. [3]

To use both qualitative and quantitative techniques to ascertain whether food colors contain heavy metals (Pb, Cd, Co, and Ni). Use TLC to qualitatively evaluate the purity of food color samples. Determine functional groups using FTIR and quantitatively assess the amount of heavy metals using AAS. Due to the widespread use of artificial food coloring, including prohibited varieties, food adulteration is a global public health concern. By examining 15 samples from nearby markets for the presence of heavy metals in food coloring, the study sought to address this problem. Fifteen samples, including standard food color samples, sweets, sweet drops, juices, and gelatin, were gathered from local markets. The majority of samples had artificial food coloring, according to TLC analysis. AAS found metal in two of the fifteen samples, while FTIR identified functional groups in the samples. [4]

Food color, also known as food dyes, is an essential class of additives that includes pure substances that are either synthetically produced or naturally derived from raw materials. When it comes to food products, synthetic dyes are more stable than natural colorants. [5–7] Young children are drawn to foods and drinks with appealing colors. Snacks, baked goods, candies, and drinks are just a few of the unpackaged edibles that contain harmful chemicals and prohibited colors. 2. There is mounting evidence that excessive dye use may have negative effects [7-9]. Applying natural food coloring requires careful and knowledgeable use, which calls for accurate color substance characterization. Nearly every year, scientific communities update information about color based on research findings [8–10]. While natural food colors are exempt from FDA regulations, synthetic food colors must be certified [11,12]. Three red (Carmoisine, Ponceau 4R, Erythrosine), two yellow (Sunset yellow FCF, Tartrazine), two blue (Brilliant blue FCF, Indigo Carmine), and one green (Fast green FCF) color are among the colors allowed by the Food Adulteration Act (1954). However, food is illegally contaminated with adulterants like Sudan dyes, Orange G, Rhodamine B (RB), and Metanil yellow [13]. Thin layer chromatography, Fourier transform infrared spectroscopy, and atomic absorption spectroscopy are used to identify and measure food color additives. [14–16].

Food Colors

The purpose of adding synthetic dyes to products is to increase their appeal to consumers. Colored products draw more attention from consumers than non-colored ones, particularly when they are intended for children. Pharmaceutical products (pills and tablets) and processed foods (candy, desserts, beverages, etc.) are especially high in these dyes [17, 18].

In the food and pharmaceutical industries, organic coloring agents are denoted by the letter E. These are listed on the product's packaging under "ingredients" and may also include food additives like vitamin C [19]. The E132 is more harmful than the other members of the European Free Trade Association, which is ranked three [20]. In addition to the blue dye E132 (carmine, indigotine) used on the aforementioned samples, there is another application for this dye in medicine [21]. 500 mg/kg of indigo carmine is thought to be the safest dosage for human consumption. Waste can contain a dye that is frequently used in the textile industry.

Studies of Food Colorings, Background Information.

Eating is typically done with the eye first. As a result, since our ancestors lived thousands of years ago, food color has been significant. One of the primary characteristics used to determine whether food was toxic or edible in those days was color. Nowadays, the majority of people no longer need to make this choice. Adding extra or artificial coloring ensures that today's food looks as appealing to consumers as possible [11]. Food coloring, particularly candy coloring, has a long history that dates back to the ancient Egyptians circa 1500 BC. Plant extracts or natural products like saffron were used as dyes there [12]. Before industrialization, the general public could not afford this kind of natural food coloring.

Due to the undesirable change in colour during food processing, food had to be recoloured with dyes due to the lack of general regulations. The use of toxic inorganic salts such as lead chromate or copper sulphate was prevalent throughout the 19th century [12]. With the banning of harmful ingredients and colours in Europe (England: 1875, Germany: 1887) and the United States (1906), there was a great demand for new food dyes [13]. One notable milestone was the new synthesis technology based on the invention of the first synthetic dye "mauveine" by William Henry Perkin in 1856 which led to a wide range of synthetic coal tar colours [12]. These new synthetic food dyes replaced not only the dangerous inorganic salts but also the natural colourants due to their low manufacturing costs, high colouring properties and economical use in products [11].

It became necessary to standardize food colors as self-service supermarkets, mass production, and transparent packaging increased [13]. Furthermore, because food colorings have psychosocial effects like color-flavor interactions (cf., e.g., [14]), food manufacturers realized the enormous economic influence of food colorings. As a result, synthetic dyes became widely used in food during the 20th century. But since the start of the twenty-first century, food producers have been under pressure because of the growing debate about artificial dyes' potential for harm [15]. The McCann et al. study from Southampton was a turning point in the movement to ban artificial food coloring [16].

which connected artificial colors to children's hyperactivity. As a result of the study, food that contains certain artificial dyes has been required to bear a warning label in the EU since July 2010 [15].

In the EU today, the dyes from the Southampton study "have been virtually eliminated" [[17], p. 81], and food manufacturers face the difficult challenge of substituting natural dyes for artificial ones without sacrificing quality.

Classification and Chemical Properties of Food Colorings

Each country regulates the use of food dyes, resulting in somewhat disparate definitions, approvals, and nomenclature. Every authorized color additive in the EU is listed and designated with an E-number. 40

color additives with E-numbers ranging from E100 to E180 are listed. On the other hand, color additives in the US are either exempt from the certification process or certified by the Federal Food, Drug and Cosmetic Act (FD&C) [22]. Despite the differences between the two regulations, there is a lot of overlap regarding the dyes that are used. Based on their origin and chemical characteristics, the dyes can be divided into three groups:

1. Plants or animals are the source of natural dyes. However, neither the US nor the EU offer a definition of "natural" that is widely agreed upon [22, 23]. Many of these are manufactured synthetically, which goes against what most sensible consumers would expect. In this contribution, we looked at food's curcumin, carotenes, and chlorophylls. The most significant natural dyes are carotenes, which are tetraterpenes with nine to eleven conjugated double bonds. The same plant can frequently contain multiple dye pigments, resulting in natural dyes and complex colorant mixtures [24].

2. Artificial dyes: on the other hand, they can be produced with high chemical purity. Their high and consistent color intensity is their primary characteristic. Azo dyes, such as tartrazine or allura red, make up the majority of artificial colorings. They all have the distinctive −N=N− azo group. The remaining synthetic dyes fall into one of two categories: quinoline dyes (like indigo carmine) or triphenylmethane dyes (like brilliant blue)[24].

3. Compared to natural or synthetic dyes, inorganic pigments, such as titanium dioxide, or metals, such as silver or gold, are less common. Nonetheless, titanium dioxide is occasionally used to produce bleaching effects, particularly in candies. An interactive table containing the structures of all food colorings examined in this contribution is available [25].

Method

Food colorants are one type of food additive that is commonly added to food and beverages to provide a particular purpose. Food colorants are divided into two categories—natural and synthetic—based on the sources. Although both natural and synthetic food coloring are frequently used in various food and beverage products, synthetic colorants are more popular in the market due to their accessibility and simple application techniques. Furthermore, the food and beverage industries use synthetic dyes extensively to reduce production costs because they are more stable and less costly than natural dyes. Some unethical producers replace permitted food coloring agents with prohibited ones in order to make economical profits because of the price difference between permitted and prohibited food coloring. Because of its toxicity, the substitution acts may pose serious health risks. The health of consumers is obviously at high risk due to the high toxicity and side effects of synthetic dyes, which can include teratogenic, carcinogenic, and mutagenic effects.

In this research, infrared spectroscopy is used to study the composition of food dyes for the range. Twenty food dyes of different origins were used. The spectral properties of the dye were also studied using an infrared source (halogen lamp) for the range (800-1100) nm, IR Laser source and spectrophotometer. A low-cost spectrometer was design to measure electrical properties by using fast photo transistors.

Devise and materials

FTIR (Fourier transform infrared) spectroscopy plays an important role in the field of medicinal plant analysis due to its accuracy, repeatability, identification of chemical components, functional group and chemical structure of components, which makes the use of infrared analysis almost limitless. The use of infrared absorption region in spectroscopy is (4000-400 cm-1) as absorption radiation for most organic and inorganic compounds within this region. The use of infrared laser and spectroscopic methods in analysis provides extensive information about the composition of the basic components of the model.

1- ATR-FTIR spectrophotometer

Bruker Alpha ATR FT-IR spectrometer technique was used to analyze food colors as shown in figure (1) with its specifications in table (1)

Fig (1): ATR-FTIR spectrometer (BRUKER ALPHA)

Table (1) ATR-FTIR spectrometer (BRUKER ALPHA) Specifications

Properties	**values**	**Components**
Spectral range	375 – 7,500 cm-1	IR laser sources
KBr beam splitter	500 – 6,000 cm-1	Detectors
measurement time	1 min,	Fourier transform
spectral resolution	4 cm-1	

ATR-FTIR is based on attenuated total reflection which generates a wave that can penetrate the sample for a few micrometers, then the sample absorbs part of this radiation and attenuates it, so that the device detects when it has been absorbed (or transmitted) and provides a spectrum. Figure (2) shows the process that takes place on the ATR crystal. Absorption is related to the vibrations of the sample molecules, and the spectra provide compositional information for the analyzed sample in terms of vibration signals.

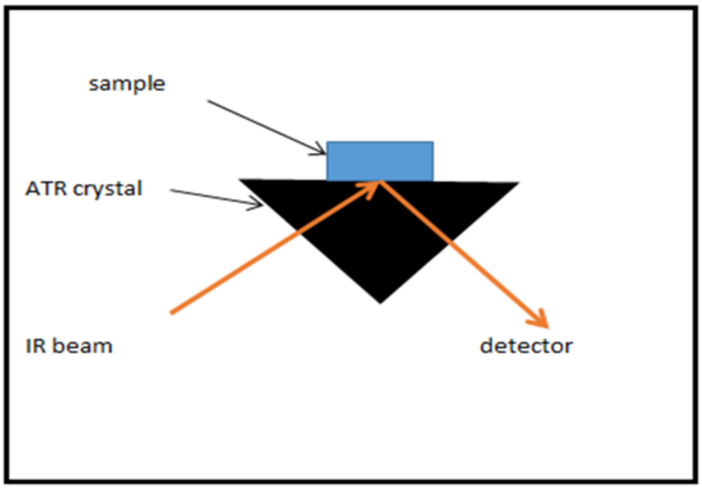

Fig (2): ATR crystal in spectral acquisition for FTIR spectrometer.

2. Halogen lamp with HR 4000

Detector experimental set up

In this experimental arrangement, a halogen lamp was used for the range (800-1100) nanometers with a fast sensitive spectrometer (HR 4000 Ocean) for the range (190-1100) nanometers, a cuvette holder was used to carry the dyes, and an optical laboratory discriminator was used to prevent vibration, as well as an optical fiber (Ocean) for the range (400-1100) nm. to transmit the optical signal to the detector as in figure(3).

Fig (3): Halogen lamp with HR 4000 Detector experimental

3- Low cost locally manufactured optical spectrometer

In this experimental arrangement, an experimental spectrometer system figure (4) was manufactured that included an infrared source and a fast infrared detector. A continuous power supply of about (10) watts was used, and a digital mustimeter was used for measurement.

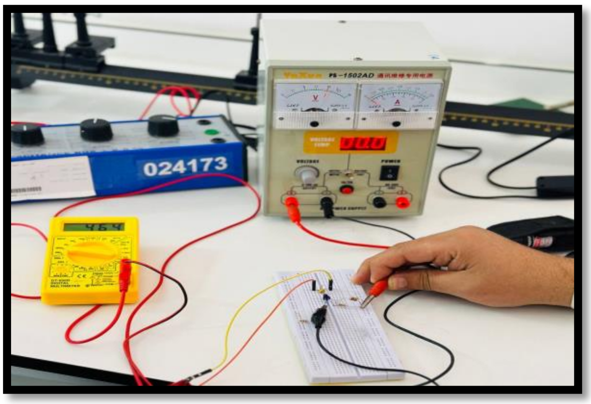

Fig (4): Low cost locally manufactured optical spectrometer

In this experiment, a laboratory spectrophotometer is used to measure the absorption rate of the near-infrared spectrum, where the wavelength is chosen around (1000) nm and its absorbance is recorded for each dye. The characteristics of this spectrometer are shown in the table (2) below and figure (5).

SPECTRUM 22 ED Spectrophotometer
• Screen: digital, 3-inch LCD • Spectral slit width: 10 nm • Optical system (nm): letro type, single beam, grating system 1200 lines/mm • Wavelength range: 360-1000 nm • Wavelength accuracy: ±4 nm • Wavelength repeatability: ±2 nm • Stray light: 2%T at 400nm • Optical range: 0-100%T, 0-1.99A • Optical measurement accuracy: ±3%T

- Drift: 1%T/h after warm-up
- Auto zero: Yes
- Data output: analog
- Power requirements: 120V, 50-60Hz, automatic
- Dimensions: 12.4"W x 10.4"D x 7.3"H (316 x 265 x 185 mm)
- Weight: 9.9 lbs (4.5 kg)

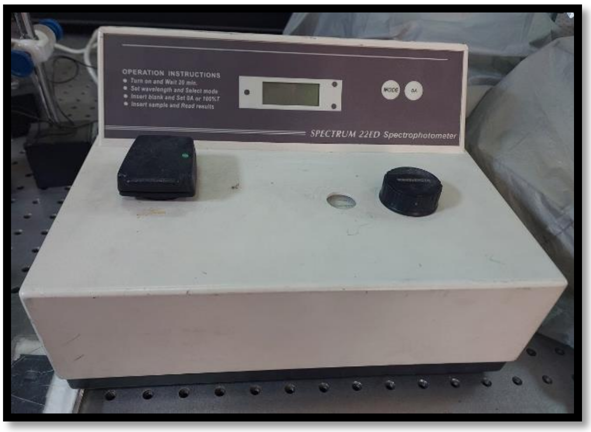

Fig (5): SPECTRUM 22 ED spectrophotometer

5- IR Laser with HR 4000 Detector experimental set up

In this experimental arrangement, an IR Laser (800 nm) with DC voltage (2.25 v) was used for the with a fast sensitive spectrometer (HR 4000 Ocean) for the range (190-1100) nanometers, a cuvette holder was used to carry the dyes, and an optical laboratory discriminator was used to prevent vibration.as shown in figure (6).

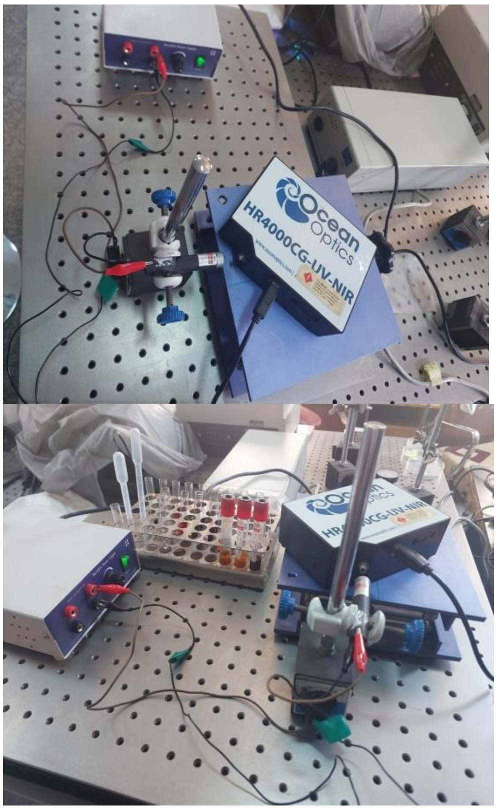

Figure (6) IR laser with HR 4000 Detector experiment

6-Sample preparation

In this examination, laboratory models of food colorings form different origin were prepared, and they were used in the liquid and solid state after drying them on laboratory slides using a laboratory incubator oven at temperatures (25-65) C as shown in figure(7).

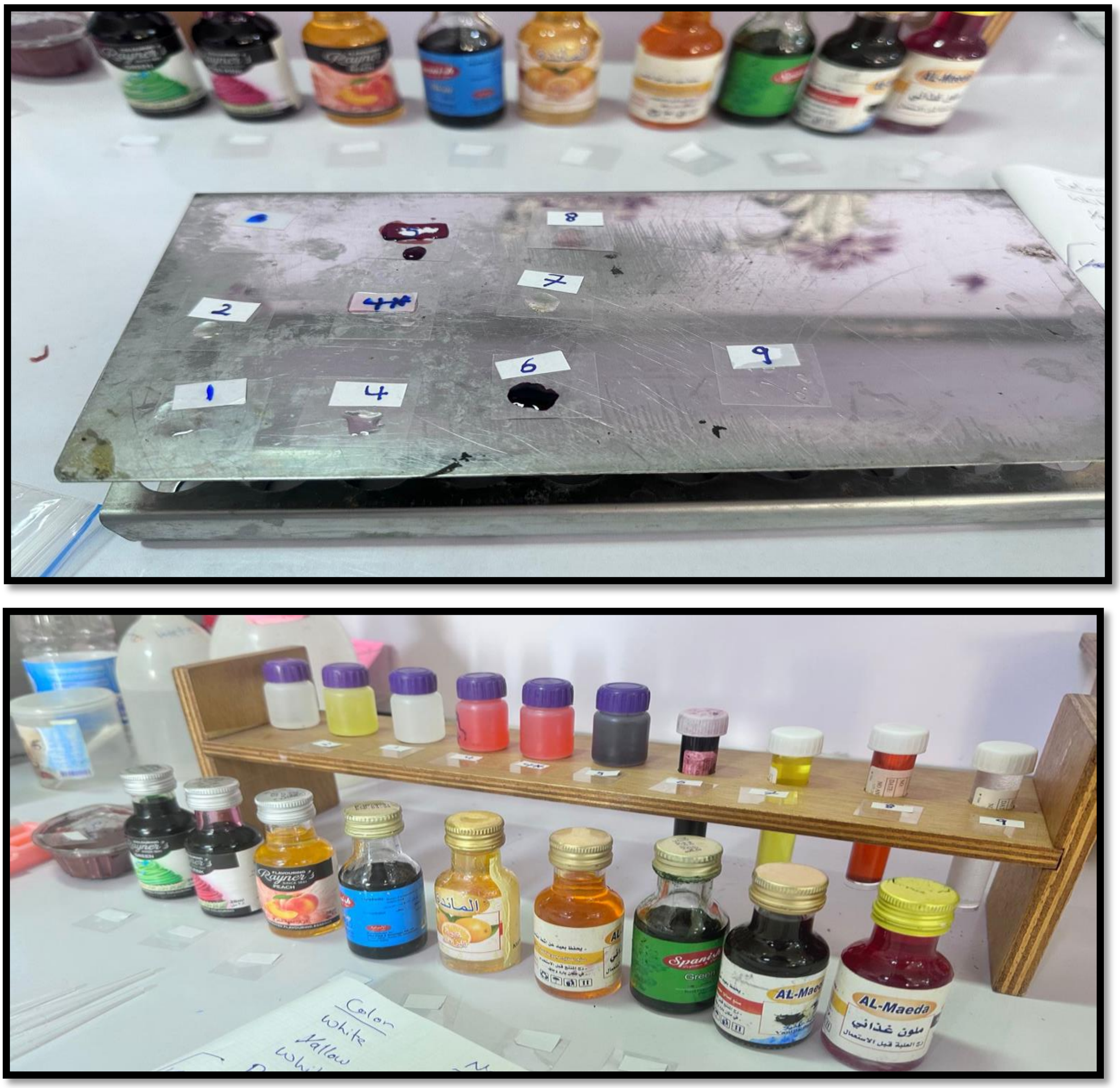

Fig (7): food dye samples

Results

In this research, infrared spectroscopy is used for the spectral range (4000-4000) cm-1 to study the composition of the food dyes of the group. Twenty-three food dyes (artificial and natural) of different origins were used for the purpose of studying their molecular structure. The spectral properties of the dye were also studied using an infrared source (halogen lamp) in the range (800-1100) nm to measure the absorption spectrum of each of them, and an infrared laser source (800) nm.

The spectrophotometer calculates the optical intensity of each dye and the absorbance percentage. A low-cost spectrometer is designed to measure electrical properties using fast phototransistors in which the value of the voltage coming from the detector is measured with each dye. The results for all previous experiments were as follows:

1-ATR-FTIR spectrophotometer

An attenuated total reflectance FTIR scan of samples was performed at wavenumbers ranging from mid-infrared region (4000-400 cm-1).In this measurement, FTIR spectra used to define structure properties to food colors. Results shows a strong and sharp absorption bands at the range (1400-400) cm-1This is corresponding function group to alkane ,olefin and halogen compound . as in figure (8).

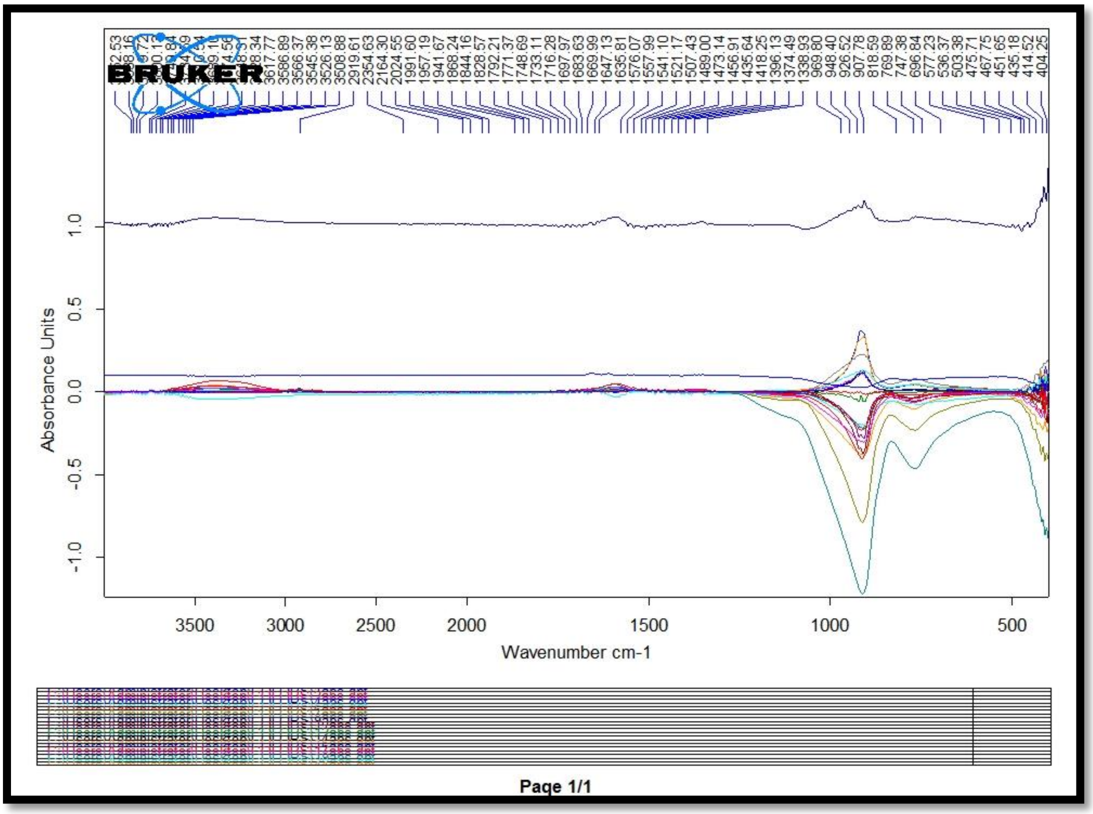

Fig (8): FTIR spectra for food dyes

2- Halogen lamp (800-1100) nm

The spectral properties of the dye were also studied using an infrared source (halogen lamp) in the range (800-1100) figure (9) .Food dye samples showed distinct absorption peaks in these ranges, with differences in absorption ratio between different dyes..In table (3) food dyes samples with its absorption max. Peaks for (3, 6, 13) sample

Table (3) food dyes samples with its absorption max. peaks

sample	company	color	Wave length nm	Absorption A%
1	Aromatic	white	900	0.078
2	Aromatic	Yellow	917	0.099
3	**Aromatic**	**white**	**905**	**0.87**
4	Aromatic	rosy	904	0.088
4*	Aromatic	rosy	906	0.042
5	Aromatic	red	800	0.092
6	**Aromatic**	**Dark red**	**800**	**2.374**
7	Aromatic	yellow	918	0.0056
8	Aromatic	Light orange	1064	0.087
9	Aromatic	white	904	0.082
10	UK-Rayners-coloring	Green	800	0.383
11	UK-Rayners-coloring	Dark red	801	0.111
12	UK-Rayners-coloring	Light orange	905	0.126
13	**Spanish vitaz food &Berevaged**	**blue**	**800**	**0.514**
14	Al-Attar Group/Iraqi from the local market	Dark orange	802	0.066
15	Spanish vitaz food &Berevaged	green	805	0.122
16	Al-Attar Group/Iraqi from the local market	brown	800	0.255
17	Al-Attar Group/Iraqi from the local market	pink	909	0.096

18	Al-Attar Group/Iraqi from the local market	Raisin	800	0.141
19	Al-Attar Group/Iraqi from the local market	orange	900	0.123

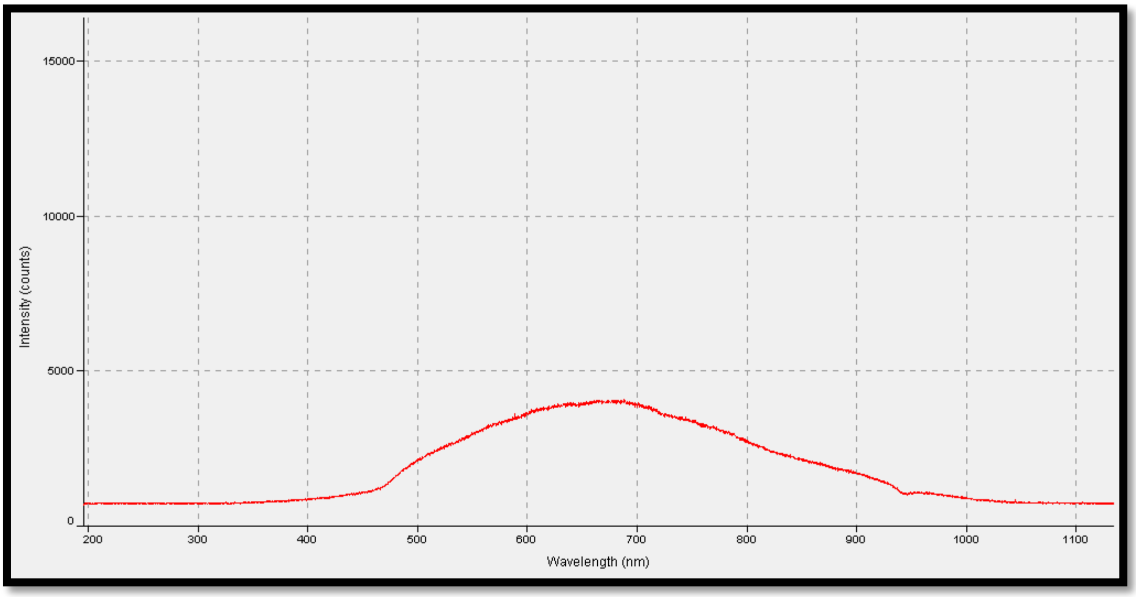

Fig (9): Halogen lamp spectrum

3- IR Laser with HR 4000 Detector experimental set up

In this experimental arrangement, an IR Laser (800 nm) as in figure (3) with DC voltage (2.25 v) was used for the spectrometer (HR 4000 Ocean) (190-1100) nm, Intensity for food colors as shown in figure (10). dyes showed high absorption peaks when an 800 nm laser source was used, demonstrating the high sensitivity of this technique in determining chemical composition. Max. Peak was get for (7,14,22) dyes ,figure (11).

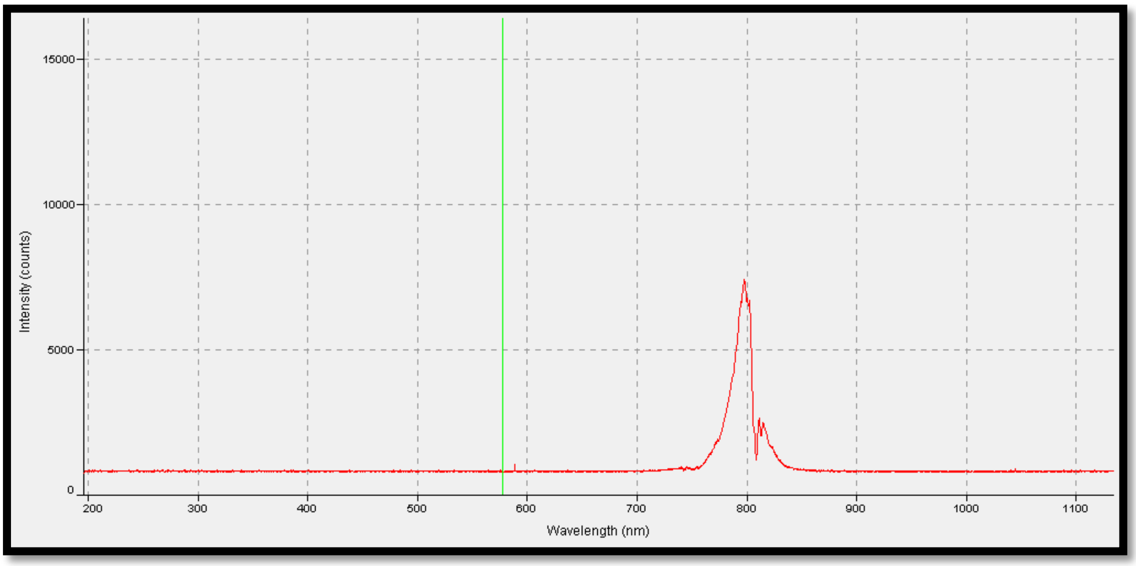

Fig (10): IR Laser (800 nm)

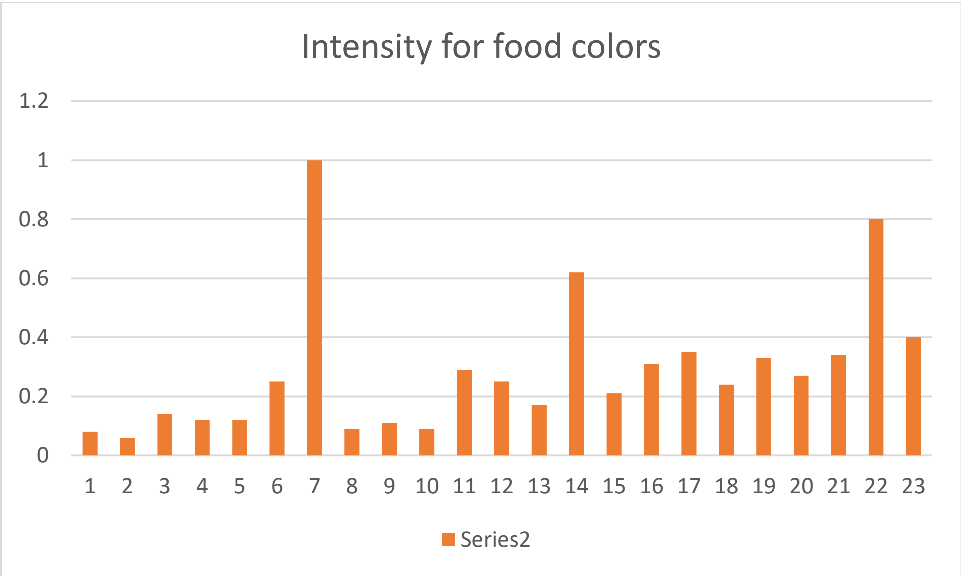

Fig (11): intensity with food colors samples

4- Laboratory spectrophotometer (360-1000 nm)

In this experiment, a laboratory spectrophotometer is used to measure the absorption rate of the near-infrared spectrum, where the wavelength is (1000) nm and its absorbance is recorded for each dye figure (12). Max. Peak was get for sample (6).

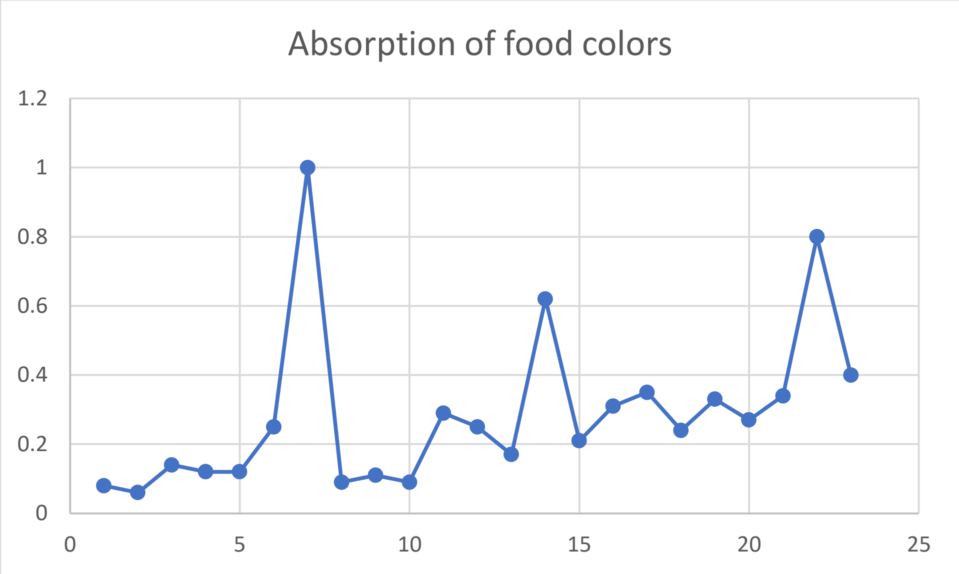

Fig (12): Absorption spectrum to different food colors

5- Low cost locally manufactured optical spectrometer

In this experimental arrangement, an experimental spectrometer system was manufactured that included an infrared source and a fast detector. A phototransistor's operating range is determined by the intensity of the applied light because the base input determines its operating range. The results showed good sensitivity and accurate results for determining the intensity of radiation absorbed by different dyes. Max. dc voltage for (7,14,19) samples. As shown in table (4).

Table (4) phototransistor DC voltage with different food colors

Sample No.	Sample color	DC (V)
1	white	467
2	yellow	466
3	white	472
4	rosy	455
4*	rosy	455
5	red	466
6	Dark red	388
7	yellow	470
8	Light orange	463
9	white	469
10	green	463
11	Dark red	460

12	Light orange	465
13	blue	459
14	Dark orange	474
15	green	463

Conclusions

This study was successfully carried out using fast and easy analysis methods, infrared spectroscopy, halogen, laser, photoelectron spectroscopy, the results revealed the following features:

- High light sensitivity: It can detect even a very small amount of light.
- It has a high gain.
- The small current generated by the photodiode can be amplified to a larger current that can be easily measured or processed.
- Very cheap and readily available.
- Simple and small
- Very fast and immediate outputs are obtained.
- Directly without sample preparation
- Can be used for different samples

The study also has applied analytical dimensions such as:

16	brown	459
17	pink	458
18	Raisin	464
19	orange	472

1. Development of technology in food analysis:

The use of laser and infrared spectroscopy has shown great development in food analysis techniques, providing accurate and rapid tools for determining the chemical components in food dyes.

2. Efficiency and accuracy:

The results confirmed that infrared spectroscopy is capable of determining the chemical compounds in food dyes with high accuracy, especially when used in conjunction with laser techniques to improve sensitivity.

3. Practical applications:

This approach is particularly useful for the food industry, as it can be used to detect synthetic or natural dyes in products, supporting efforts to comply with health standards.

4. Environment and safety:

The use of this technology reduces the need for traditional chemical reagents that may be harmful to the environment or humans, making it a safer and more sustainable solution.

5. Challenges and recommendations:

Despite the clear benefits, the application of these technologies may face challenges related to cost or availability. Therefore, further research is recommended to develop affordable tools and enhance their spread in the markets.

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