processes

MDPI

Article

Characteristics of Resveratrol Tablets Stored Under Stress Conditions by Total Hemispherical Reflectance and Selected Pharmacopoeial Parameters †

Beata Szulc-Musioł [1,*] and Beata Sarecka-Hujar [2]

[1] Department of Pharmaceutical Technology, Faculty of Pharmaceutical Sciences in Sosnowiec, Medical University of Silesia in Katowice, 8 B Jedności Str, 41-200 Sosnowiec, Poland
[2] Department of Basic Biomedical Science, Faculty of Pharmaceutical Sciences in Sosnowiec, Medical University of Silesia in Katowice, 8 B Jedności Str, 41-200 Sosnowiec, Poland; bsarecka-hujar@sum.edu.pl
* Correspondence: bszulc@sum.edu.pl
† Presented at the 3rd International Electronic Conference on Processes—Green and Sustainable Process Engineering and Process Systems Engineering, Online, 29–31 May 2024 (ECP 2024).

Abstract: The introduction of medicine into the pharmaceutical market must be preceded by a stability study. One of the most important reasons for the instability of a drug preparation is improper storage by the patient, which can accelerate the degradation process. In this study, the novel directional-hemispherical reflectance (THR) and traditional (hardness and friability) methods of drug quality control were used in the characteristics of resveratrol supplemental tablets exposed to light and elevated temperatures. The tablets were stored in an aging chamber at two different temperatures (25 °C, 45 °C) over different time intervals (1 h, 3 h, 1 day, 5 days), yielding seven storage conditions. The 410-Solar Reflectometer allowed us to determine the THR values for seven spectral ranges: 335–380, 400–540, 480–600, 590–720, 700–1100, 1000–1700, and 1700–2500 nm. At each time point, tablets exposed to stress conditions were characterized by lower reflectance values for all spectral ranges, compared to the values on day 0. Compared to day 0, significant differences in THR values were observed at temperatures of 25 °C and 45 °C on day 1 and at a temperature of 25 °C on day 5 across the entire spectrum studied. The change in THR on day 5 of the experiment at 45 °C, compared to 25 °C, was significantly higher only in the UVA 335–380 nm range. In addition, significant changes in the strength parameters of the tablets, i.e., an increase in hardness and a decrease in friability were found on days 1 and 5 of the study, irrespective of temperature. Such significant differences after UV and heat exposure are probably due to changes in the homogeneity of the tablet matrix and may indicate possible physical and chemical changes occurring on the surface or inside the tablet.

Keywords: tablets; resveratrol; photostability; hemispherical-directional reflectance; food supplement; shelf life; heat; UV radiation

check for updates

Academic Editor: Ibrahim M. Abu-Reidah

Received: 27 January 2025
Revised: 12 February 2025
Accepted: 20 February 2025
Published: 24 February 2025

Citation: Szulc-Musioł, B.; Sarecka-Hujar, B. Characteristics of Resveratrol Tablets Stored Under Stress Conditions by Total Hemispherical Reflectance and Selected Pharmacopoeial Parameters. *Processes* **2025**, *13*, 638. https://doi.org/10.3390/pr13030638

Copyright: © 2025 by the authors. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (https://creativecommons.org/licenses/by/4.0/).

1. Introduction

Resveratrol is a plant bioactive polyphenol belonging to the stilbene group and comprises two phenolic rings connected by an ethylene bridge. It is found in a variety of plants, including grape skins and seeds, legumes, blueberries, mulberries, cranberries, peanuts, Itadori root (*Polygonum cuspidatum*) Ko-jo-kon, and hops [1,2].

This natural compound is a phytoalexin produced by plants in response to infections caused by plant pathogens, UV radiation, and other harmful agents [3]. Data have demon-

strated that for daily supplementation in the range of 700–1000 mg/kg body weight, it is well tolerated and shows no toxic effects [4–7].

The chemical structure of resveratrol allows interactions with enzymes and cell receptors, which translates into biological activity. As an antioxidant whose activity is linked to three hydroxyl groups, it increases the activity of antioxidant enzymes and plays an important role in inhibiting free radicals [8–10].

In recent decades, this phytopharmaceutical has attracted attention due to its potential use in the treatment of diseases caused by oxidative stress [11].

Several studies have shown its anti-cancer, cardioprotective [12], anti-neurodegenerative [13,14], anti-osteoporosis [15], regenerative [16] and anti-aging properties, antiproliferative, anti-inflammatory, anti-diabetic [17], anti-ischemic, and antioxidant effects [18,19]. A significant contribution of resveratrol to the treatment of various kinds of cancer has been confirmed [20,21].

It is also called a phytoestrogen, due to its ability to regulate the activity of estrogen receptors α and β, which translates into beneficial effects on the cardiovascular system, central nervous system, and bone tissue [22]. A randomized study involving postmenopausal women with osteopenia showed an increase in bone, and a decrease in CTX (a marker of bone resorption) in plasma, after 12 months of resveratrol supplementation (75 mg twice daily) [23]. Based on network pharmacology, its potential multi-pathway molecular mechanism of action promoting diabetic wound healing was indicated [24]. When combined with hypoglycemic drugs, this compound can reduce diabetes-related complications [25,26]. It is also a natural antimicrobial agent that can be used as a stand-alone alternative therapy or as a co-adjuvant to current antibiotic therapy [27–29].

Resveratrol occurs in two isomeric forms: *cis* and *trans*. The *trans* form has higher biological activity and stability [30–32]. When exposed to heat, ultraviolet, or visible light, the trans form can isomerize into the *cis* isomer [32,33].

Drug stability studies are mandatory before a drug is released to the pharmaceutical market and should be performed under ICH guidelines and, in the case of preparations containing photolabile medicinal substances, following the ICH Q1B. Photostability studies are designed to confirm that the recommended storage conditions and drug packaging have been appropriately chosen to protect the medicinal product and can be carried out at any stage of medicinal product manufacture and development.

Solar radiation (in the ultraviolet and visible range) can lead to physicochemical changes in the drug product, causing adverse pharmacological effects and sometimes adverse reactions. The stability of medicines is closely related to their storage conditions, and the manufacturer indicates these on the packaging and leaflets. Adherence to these guidelines guarantees that the properties of the therapeutic substances in medicines, dietary supplements, and other preparations in our possession will be preserved.

According to available data, patients do not always follow these recommendations, storing drugs in places where they may be exposed to sunlight, elevated temperatures, or moisture [34–36]. This problem particularly affects the elderly [36].

This study innovatively applies the directional-hemispherical reflectance (THR) technique to assess the stability of resveratrol tablets under stress conditions, providing a novel perspective on drug stability analysis.

Each form of the drug at the stage of production and storage is exposed to the influence of electromagnetic radiation emitted from natural or artificial sources. The rate of degradation of a drug is linked to the intensity of light. Solar radiation reaches the earth's surface as an electromagnetic wave with a wavelength of 100–10,000 nm. The rest of the spectrum is reflected and absorbed by the Earth's atmosphere. The largest amount of energy is carried by visible light and thermal/infrared radiation. The rest is ultraviolet/UV

radiation. Measurement of directional reflectance (THR) provides information about the amount of sunlight absorbed and reflected from the tablet surface. Based on this information, its stability can be inferred, and the manufacturing process, formulation, and storage conditions can be designed. Another critical factor in maintaining the stability of a drug formulation is temperature.

In our work, we analyzed how THR values changed over time in different spectral ranges for resveratrol tablets (dietary supplement) exposed to UV radiation and different temperatures. In addition, changes in selected pharmacopoeial parameters (hardness, friability, tablet mass uniformity) during this storage were also assessed.

2. Materials and Methods

2.1. Analyzed Tablets

Resveratrol tablets used in the study are available on the Polish market and have been produced by a Polish manufacturer. The preparation is classified as a dietary supplement. The composition of the tablets includes Japanese knotweed root extract *fallopia japonica* (250 mg including 62.5 mg trans-resveratrol), microcrystalline cellulose, calcium carbonate, starch, magnesium salts of fatty acids, and silicon dioxide. All analyses were carried out within the shelf life of the products.

2.2. Quality Control of the Tablets

2.2.1. Weight Uniformity, Thickness, and Diameter

A total of 20 tablets were randomly selected and weighed on an analytical balance (HR60, A&D Weighing Company, Tokyo, Japan). The mean weight and standard deviation were calculated. The thickness and diameter of the tablets were measured using a tablet hardness tester.

2.2.2. Hardness and Friability

Tablet hardness and friability were measured using a Pharmatron hardness tester (Pharmatron Dr. Schleuniger, Thun, Switzerland) and an EF-2 friability tester (ELECTRO-LAB INDIA PVT. LTD. Mumbai, India), respectively. The tensile strengths (σ) of the tablets were calculated using the formula:

$$\sigma = 2F/\pi dt$$

where σ is the tensile strength of the tablet (Nm^{-2}), F is the crushing strength (N), d is the tablet diameter (m), and t is the thickness (m).

Friability was expressed as the percentage weight loss of tablets that were subjected to tumbling actions at 25 rpm for 4 min.

2.3. Photodegradation Experiments

Aging of the tablets was conducted in a Solarbox 1500 chamber (Co.fo.me.gra, Milano, Italy) with the simulating solar irradiance produced by a 1500 W xenon arc lamp. External UV filters were fitted to limit the transmission of light of wavelengths below 290 nm.

In the experiment, the effect of two temperatures, i.e., room temperature of 25 °C and elevated temperature of 45 °C, on the change in their reflectance characteristics was assessed (Figure 1). The resveratrol tablets on day 0 were stored before an experiment at ambient temperature, away from the sunlight, and with relative humidity below 65%. Tablets stored at 25 °C were taken from the chamber for assessment at the following time intervals: after 1 and 3 h of UV exposure, and after 1 and 5 days of UV exposure. In contrast, tablets stored at 45 °C were taken after 1 and 5 days of UV exposure. At each time point, 30 tablets were analyzed.

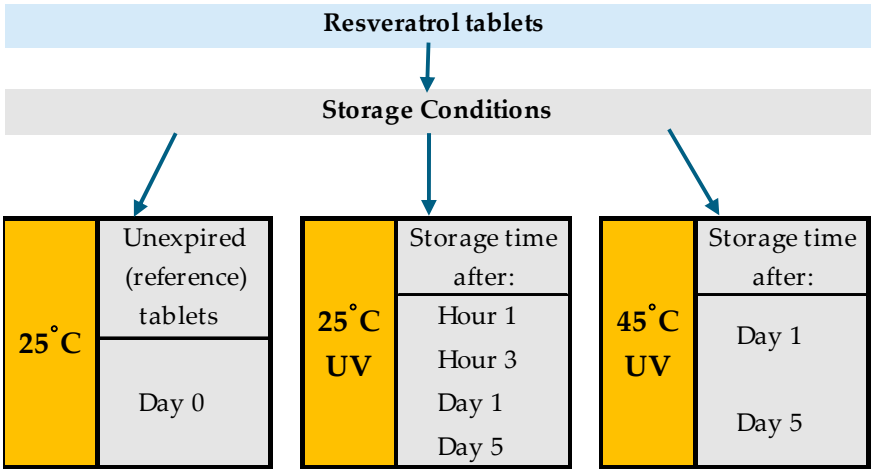


Figure 1. Diagram of the course and conditions of the experiment.

2.4. Directional-Hemispherical Reflectance

A portable 410-Solar Reflectometer (Surface Optics Corporation, San Diego, CA, USA) was utilized in this study to measure reflectance properties. The instrument employs a modified integrating sphere to measure total, diffuse, and specular reflectance across seven spectral sub-bands: 335–380 nm, 400–540 nm, 480–600 nm, 590–720 nm, 700–1100 nm, 1000–1700 nm, and 1700–2500 nm, with a directional illumination angle of 20°. The focus of this study was on total hemispherical reflectance (THR). Reflectance data were collected under solar energy distributions corresponding to an air mass of 1.5 (solar zenith angle of 48°), achieving a measurement accuracy of ±0.02 and repeatability of ±0.001. Each measurement session began with calibration using two calibration coupons. The device generated 21 data points during each acquisition cycle, with three measurements performed per spectral band for each sample.

2.5. Statistical Analysis

Statistica 13 (StatSoft, Tulsa, OK, USA) and Microsoft Excel 2019 (Office 365, Microsoft Corporation, Redmond, WA, USA) were used for statistical evaluation. Data were presented as mean ± standard deviation (M ± SD). The p values less than 0.05 were considered significant. Continuous variables were assessed in terms of normality with the Shapiro–Wilk W test and then compared. For multiple groups of tablets, variables with normal distribution were compared with the ANOVA, while variables deviating from normal distribution were compared using the non-parametric Kruskal–Wallis test.

3. Results

Overall, the findings revealed that tablets exposed to UV radiation and elevated temperatures exhibited lower reflectance values across all wavelength ranges compared to the reference samples. The extent of reflectance differences among the tested tablet groups varied based on wavelength, storage duration, and temperature conditions. Furthermore, simultaneous exposure to UV radiation and elevated temperatures amplified this trend.

The observed changes in total reflectance (THR) values were closely linked to alterations in tablet strength parameters, specifically hardness and friability. These two parameters are standard measures in routine tablet quality control. Tablets subjected to stress conditions demonstrated statistically significant ($p < 0.001$) increases in hardness and reductions in friability compared to the control group. Such changes in hardness parameters can influence the release profile of the active ingredient, ultimately impacting its bioavailability in vivo.

3.1. Characteristics of Treated Tablets Containing Resveratrol

Storage of the analyzed resveratrol tablets under stress conditions did not result in significant physical changes, except for the tablets stored at 45 °C for 5 days, which exhibited a slight color change. Regardless of the experimental conditions for all measuring points, no significant differences in weight, thickness, or diameter of the tested tablets were found (Table 1).

Table 1. Summary of the traditional parameters of the resveratrol tablets depending to the storage conditions.

Stability Conditions	Weight [g] M ± SD, *n* = 20	Thickness [mm] M ± SD, *n* = 7	Diameter [mm] M ± SD, *n* = 7
Day 0	0.988 ± 0.006	5.793 ± 0.049	9.234 ± 0.078
Hour 1 (25 °C)	0.984 ± 0.007	5.804 ± 0.111	9.206 ± 0.053
Hour 3 (25 °C)	0.986 ± 0.005	5.760 ± 0.101	9.189 ± 0.071
Day 1 (25 °C)	0.986 ± 0.008	5.746 ± 0.104	9.181 ± 0.035
Day 5 (25 °C)	0.987 ± 0.008	5.726 ± 0.054	9.181 ± 0.013
Day 1 (45 °C)	0.984 ± 0.009	5.729 ± 0.083	9.191 ± 0.077
Day 5 (45 °C)	0.988 ± 0.010	5.709 ± 0.046	9.211 ± 0.082
p	0.332	0.190	0.212

M—mean; SD—standard deviation.

The tablet weights followed the requirements of the Ph. Eur. guidelines, which stipulate a permissible deviation of 5% from the mean weight [37]. The diameter and thickness of the tablets also did not exceed the acceptable 5% deviation from the mean value of these parameters.

Table 2 shows the values of the mechanical parameters of the tablets before and after UV and heat aging at different times. It can be seen that the force required to crush the tablet gradually increases with aging time and increasing temperature. At 25 °C, this increase was 4.1% (after 1 h), 7.23% (after 3 h), 9.79% (after 1 day), and 12.63% (after 5 days, $p < 0.05$) compared to the reference tablets on day 0. Similarly, increasing the temperature from 25 °C to 45 °C resulted in an additional increase in this parameter of 25.47% ($p < 0.001$) after 1 day and 30.1% ($p < 0.001$) after 5 days of testing, respectively, compared to day 0 tablets.

Table 2. Summary of parameters describing the mechanical strength of resveratrol tablets without and with UV and thermal ageing, determined over different time periods.

Stability Conditions	Force Needed to Crush the Tablet [N] M ± SD, *n* = 7	Hardness Factor [N/m^2] M ± SD, *n* = 7	Friability [%] M ± SD, *n* = 7
Day 0	306.386 ± 33.019	$573.093 \times 10^4 \pm 64.590 \times 10^4$	0.708 ± 0.014
Hour 1 (25 °C)	318.957 ± 10.396	$596.859 \times 10^4 \pm 11.480 \times 10^4$	0.652 ± 0.047
Hour 3 (25 °C)	328.529 ± 12.449	$620.725 \times 10^4 \pm 20.476 \times 10^4$	0.644 ± 0.064
Day 1 (25 °C)	336.386 ±17.6998	$637.550 \times 10^4 \pm 29.192 \times 10^4$	0.491 ±0.038
Day 5 (25 °C)	345.071 ± 17.624	$656.466 \times 10^4 \pm 34.449 \times 10^4$	0.364 ± 0.012
Day 1 (45 °C)	384.414 ± 28.381	$730.922 \times 10^4 \pm 64.089 \times 10^4$	0.253 ± 0.023
Day 5 (45 °C)	398.329 ± 15.890	$757.662 \times 10^4 \pm 33.313 \times 10^4$	0.207 ± 0.013
p	**<0.001**	**<0.001**	**<0.001**

M—mean; SD—standard deviation. Significant differences are in bold.

The opposite trend was observed for mechanical resistance to friability. At 25 °C, this parameter decreased by 7.951% (after 1 h), 9.04% (after 3 h), 30.64% (after 1 day, $p < 0.01$), and 48.66% (after 5 days, $p < 0.001$), compared to the day 0. For a temperature of 45 °C, the decrease in friability was 64.28% ($p < 0.001$) after 1 day and 70.78% ($p < 0.001$) after 5 days of storage, respectively, compared to day 0 tablets.

3.2. Analysis of Changes in THR Values

Within all spectral ranges, mean THR values were highest for tablets on day 0 and lowest for tablets on day 5 regardless of the temperature used. Tablets on day 0 showed the lowest THR value in the range of 335–380 nm and the highest in the range of 1000–1700 nm.

Table 3 presents the exact values of mean THR for all spectral bands in all determined resveratrol tablets stored under UV at 25 °C. In all wavelength ranges, THR differed significantly between the time points of the experiment ($p < 0.001$ each).

Table 3. Mean THR values assessed for all the wavelength ranges in resveratrol tablets exposed to UV at a temperature of 25 °C compared to reference tablets on day 0.

Type of the Tablets	THR Values for Tablets Under UV and 25 °C, M ± SD					*p*
Spectral Bands [nm]	Day 0	Hour 1	Hour 3	Day 1	Day 5	
335–380	0.104 ± 0.004	0.099 ± 0.004	0.100 ± 0.005	0.086 ± 0.007	0.085 ± 0.017	**<0.001**
400–540	0.306 ± 0.007	0.301 ± 0.005	0.295 ± 0.024	0.287 ± 0.008	0.253 ± 0.034	**<0.001**
480–600	0.362 ± 0.012	0.352 ± 0.008	0.343 ± 0.031	0.324 ± 0.010	0.285 ± 0.038	**<0.001**
590–720	0.465 ± 0.012	0.460 ± 0.008	0.446 ± 0.038	0.447 ± 0.011	0.393 ± 0.051	**<0.001**
700–1100	0.650 ± 0.010	0.637 ± 0.045	0.653 ± 0.010	0.654 ± 0.012	0.587 ± 0.072	**<0.001**
1000–1700	0.714 ± 0.008	0.701 ± 0.049	0.716 ± 0.011	0.715 ± 0.011	0.643 ±0.071	**<0.001**
1700–2500	0.528 ± 0.013	0.515 ± 0.041	0.529 ± 0.013	0.524 ± 0.016	0.457 ± 0.066	**<0.001**

THR—total hemispherical reflectance, M—mean, SD—standard deviation. Significant differences are in bold.

In Table 4, the exact values of mean THR for all spectral bands in all determined resveratrol tablets stored under UV at 45 °C are presented. In all wavelength ranges, THR differed significantly on the day of the experiment ($p < 0.001$ each).

Table 4. Mean THR values for resveratrol tablets exposed to UV and temperature of 45 °C compared to reference tablets on day 0.

Type of the Tablets	THR Values for Tablets Under UV and 45 °C, M ± SD			*p*
Spectral Bands [nm]	Day 0	Day 1	Day 5	
335–380	0.104 ± 0.004	0.077 ± 0.004	0.076 ± 0.013	**<0.001**
400–540	0.306 ± 0.007	0.266 ± 0.014	0.246 ± 0.034	**<0.001**
480–600	0.362 ± 0.012	0.308 ± 0.018	0.276 ± 0.042	**<0.001**
590–720	0.465 ± 0.012	0.432 ± 0.025	0.393 ± 0.057	**<0.001**
700–1100	0.650 ± 0.010	0.633 ± 0.027	0.592 ± 0.076	**<0.001**
1000–1700	0.714 ± 0.008	0.693 ± 0.027	0.638 ± 0.079	**<0.001**
1700–2500	0.528 ±0.013	0.513 ± 0.024	0.462 ± 0.059	**<0.001**

THR—total hemispherical reflectance, M—mean, SD—standard deviation. Significant differences are in bold.

Figure 2 shows mean THR values along min.–max. for resveratrol tablets exposed to direct UV radiation at 25 °C and 45 °C in seven discrete spectral ranges. A trend of decreasing THR was observed during the experiment at both tested temperatures for the.

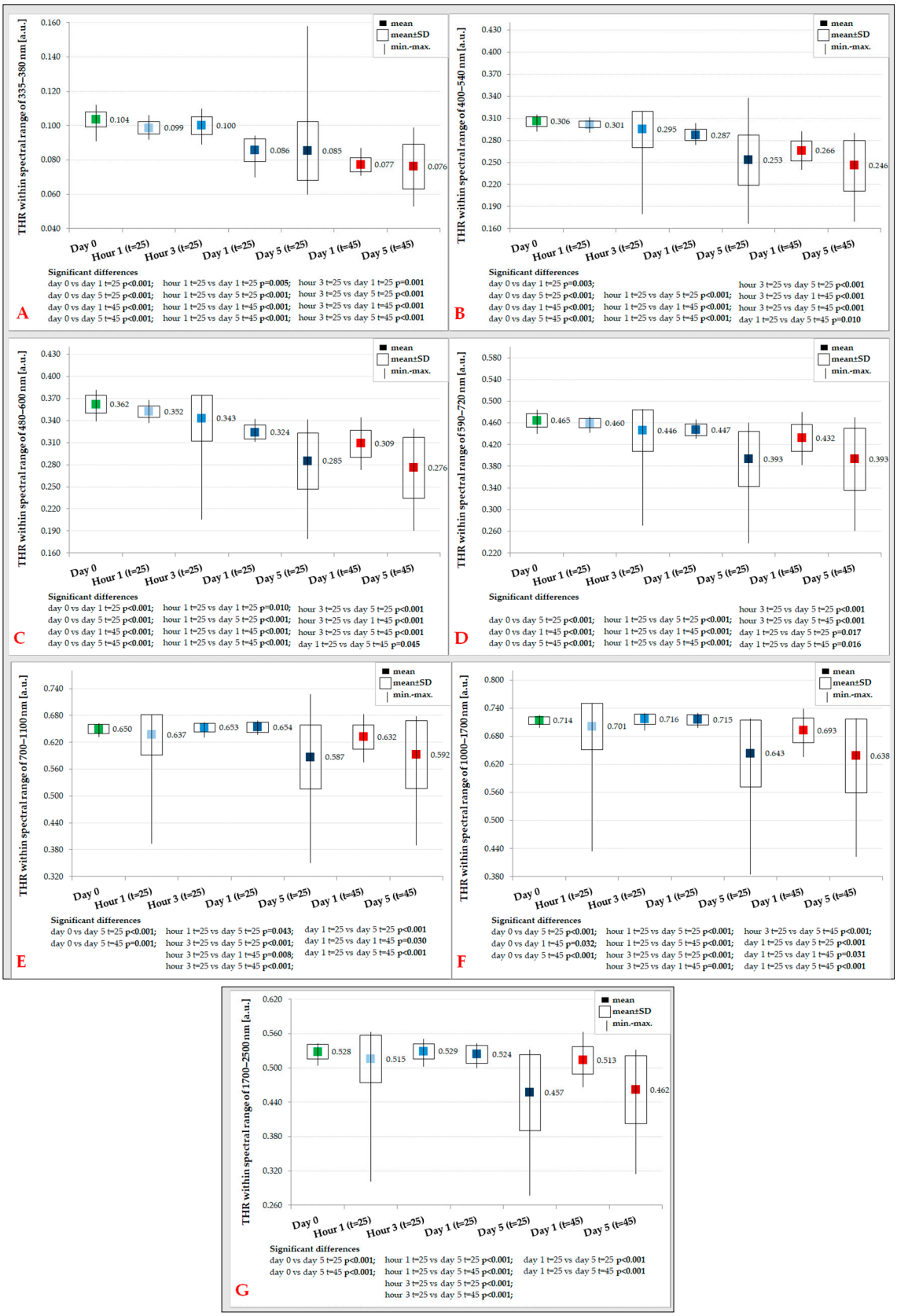


Figure 2. Diagrams showing mean THR values along with SD and min.–max. for resveratrol tablets exposed to direct UV radiation at 25 °C and 45 °C in seven discrete spectral ranges. (**A**) 335–380 nm, (**B**) 400–540 nm, (**C**) 480–600 nm, (**D**) 590–720 nm, (**E**) 700–1100 nm, (**F**) 1000–1700 nm, (**G**) 1700–2500 nm. THR—total hemispherical reflectance, SD—standard deviation. Significant differences are in bold.

UV light range (335–380 nm) and in the visible light spectral ranges (400–540 nm, 480–620 nm, 590–720 nm). In the IR light range (700–1100 nm, 1000–1700 nm, 1700–2500 nm), a decreasing trend in THR values was visible for both time points at 45 °C and, interestingly, in the first hour of tablet storage at 25 °C and on day 5 at 25 °C (Figure 2).

In the UVA light range (i.e., spectral range 335–380 nm), the THR value was significantly higher on day 0 than on days 1 and 5. No difference was found between days 1 and 5. In visible light, for each analyzed spectral range, THR had the highest value on day 0 and significantly lower on the following days of the study (Figure 2). Differences were found for all comparisons between each analyzed day of the experiment (i.e., day 0 vs. day 1, day 0 vs. day 5, and day 1 vs. day 5), except for the day 1 vs. day 5 comparison in the range of 480–600 nm, where the difference was on the boundary of significance. Similarly to the UV range, in the infrared light bands (i.e., 700–1100, 1000–1700, and 1700–2500 nm), the THR value was found to be significantly lower than on days 0 and 5 ($p < 0.001$ each) but there was no difference between day 0 and day 1.

3.3. Changes in THR Values Between Day 0 and Day 5 of the Experiment

In the study, we also analyzed the magnitude of the change in the THR value, i.e., the THR value on day 5 was subtracted from the THR value on day 0 of the experiment both at 25 °C and 45 °C and compared these changes with the temperatures determined in the study in each spectral band.

For a temperature of 45 °C, the change in THR during the study was significantly higher than at a temperature of 25 °C only in the 335–380 nm UVA range, although there is a tendency for a higher decrease in THR on the 5th day of the experiment at a temperature of 45 °C than at 25 °C for the visible light ranges of 400–540 nm, 480–600 nm, and one of the infrared light ranges of 1000–1700 nm. In turn, for the remaining ranges, the change in THR between day 0 and day 5 is at a similar level regardless of the storage temperature used (Figure 3).

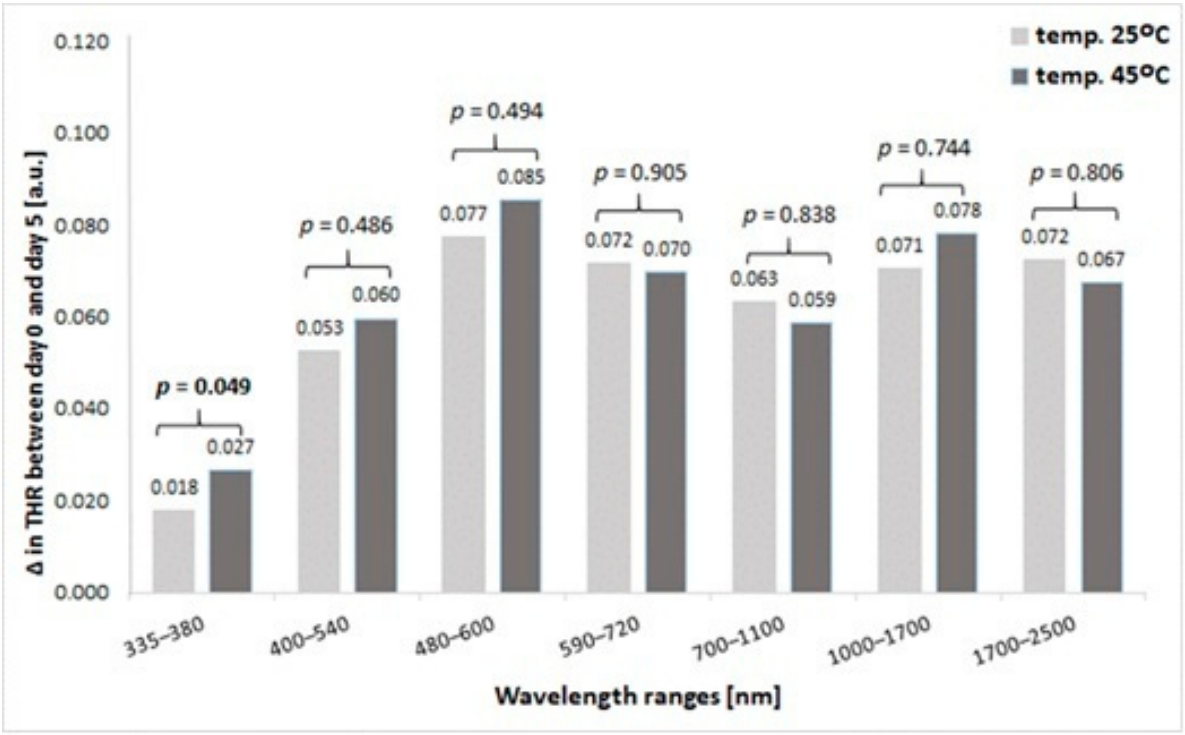


Figure 3. Comparison of changes in THR values between day 0 and day 5 of the experiment in all analyzed spectral bands. THR-total hemispherical reflectance. The significant difference is in bold.

4. Discussion

Available reports indicate that the exposure of pharmaceutical formulations to light may affect many of their parameters, including their overall quality, pharmacokinetic activity, and the formation of toxic photoproducts. It also affects the physical parameters of the drug, such as reflectance.

A significant change in the release profile of nifedipine was found for irradiated matrix tablets prepared from polyethylene oxide, resulting from an increase in release rate during the first 30 min, compared to tablets with a hydroxypropylmethylcellulose matrix [38]. Another study demonstrated that of the three coating polymers used (hypromellose, polyvinyl alcohol, Kollicoat IR) containing TiO_2, only the coating made of hypromellose changed color after 28 days of tablet exposure. At the same time, no significant change in API content was found in the tablets after this time, irrespective of the type of coating used [39].

Resveratrol is a bioactive polyphenol known for its numerous pharmacological activities. However, its biological activity after oral administration is influenced by many factors, including its solubility and stability, particularly its photostability. Experimental data show that resveratrol can decompose or isomerize when exposed to light, temperature, or pH changes, and the rate of this process depends on experimental conditions such as time, concentration, light source, physical form of the *trans*-resveratrol, or the carrier in which it was dissolved or suspended [32,33,40–44].

In recent years, research has revealed that various common pharmaceutical and cosmetic products contribute to environmental pollution. Resveratrol, a compound found in these products, is one such pollutant. To address this issue, photocatalysis has emerged as a cost-effective alternative to traditional advanced oxidation processes for removing resveratrol from water.

A study by Silva et al. [40] examined the photochemical degradation of trans-resveratrol, which exhibits an absorption maximum of 310 nm. The primary intermediate product of this degradation was identified as the cis-resveratrol isomer, with maximum absorption at 286 nm. The researchers observed that irradiation using the full UV–Vis spectral range resulted in a more rapid conversion of trans-resveratrol compared to UV or near-UV to visible irradiation alone. Analysis of the degradation process revealed that it followed first-order kinetics. The degradation rate constant, k, was found to increase in the following order: UV < Vis < UV–Vis. These findings suggest that the use of a broader spectrum of light can enhance the efficiency of resveratrol removal from water through photocatalysis.

In vitro studies have shown high stability of *trans*-resveratrol in acidic medium but exponentially increasing degradation in alkaline medium in the pH range 6–9 [32]. In addition, higher temperatures accelerate the rate of *trans*-resveratrol degradation. Hydro-alcoholic solvents of *trans*-resveratrol are stable in the dark. After an 8 h exposure to the light of a 100 µM aqueous solution of *trans*-resveratrol, a decrease in absorbance at 304 nm of more than 45% was observed [41]. Transformation of the *trans* to *cis* isomer increases with solvent polarity. Photoactivated resveratrol can convert to 2,4,6-trihydroxyphenanthrene [40] or produce singlet oxygen by acting as a photosensitizer [42] and showing antimicrobial activity [43]. It has been shown that in aqueous and ethanol solutions at room temperature, irradiation causes rapid isomerization of *trans*-resveratrol to *cis*-resveratrol. Additionally, a strong fluorescent compound (resveratron) was detected in ethanol solutions, regardless of the irradiation wavelength, which was not detected in aqueous solutions [44]. In the oil samples with the exogenous addition of resveratrol, which were heated in the oven at 60 °C and additionally fried at 180 °C, seven non-volatile oxidation products and two volatile oxidation products were shown [45].

The stability of *trans*-resveratrol can be improved by formulating solid drug forms or forming inclusion complexes and/or its encapsulation into nanoparticles and microparticles [46,47]. Encapsulation does not always prevent resveratrol degradation but significantly slows the rate of this process. The incorporation of *trans*-resveratrol into the microemulsion increased its physical stability. After 4 h UVB irradiation, its concentration decreased by 39.1% and was about 3.32 higher compared to the ethanolic solution [48].

There is little data on the photostability of preparations of this natural stilbene in solid drug form, such as tablets. On the basis of accelerated ageing tests (40 °C) and long-term tests (25 and 30 °C), Biagini et al. [49] showed that the compound was stable, and that the decomposition kinetics of the API was temperature dependent.

Our study analyzed changes in THR values for nutraceutical tablets containing resveratrol, exposed to UV radiation, as a function of storage time and temperature. The reflectometer we used has seven detectors built into the device, which allows for the measurement of the optical properties of the sample surface by electromagnetic wave reflection in the corresponding wavelength ranges from 335 to 2500 nm. The method used is characterized by its non-invasiveness, environmental friendliness, low operating cost, speed of analysis, and flexibility for the analysis of different pharmaceutical preparations. This state-of-the-art analysis technique can find applications both on the production line and in the field.

Like NIR hyperspectral imaging, which is widely used in pharmaceutical technology, it enables the detection of abnormal changes in the API molecule and/or excipients that make up the drug formulation. França et al. [50] assessed the degradation of captopril in tablets from hyperspectral imaging and, based on the model developed, calculated an expiry date with an error of 120 days. In contrast, another paper [51] discussed the development trend and prospects for robots based on hyperspectral imaging technology in the field of pharmaceutical quality control.

THR provides a single value of reflectance from the sample surface for each wavelength range measured, while NIR hyperspectral imaging captures spatial changes on the sample surface, usually in the near-infrared range. THR measurements are relatively straightforward technically, whereas NIR imaging generates large, multidimensional data sets that require advanced processing techniques [52,53].

Previous publications have described the use of THRs for, among other things, the detection of counterfeit drugs [54,55], and the effect of packaging on the photostability of tablets with cefuroxime [56].

The methods of hyperspectral near-infrared (NIR) spectroscopic imaging and UV imaging were used by Klukkert et al. to analyze changes on the surface of trypsin tablets of identical composition but obtained by compaction at five different compression pressures (from 0.3 MPa to 5.6 MPa) [57]. The data obtained were subjected to multivariate analysis. No significant differences were found in the shape of the spectra; but, for all six wavelengths considered (254, 280, 300, 313, 334, and 365 nm), a significant increase in absorbance was shown with increasing tablet mass compaction force. The application of greater compression force during tablet formation led to increased surface density and reduced surface roughness. These changes altered the tablet's light absorption characteristics. When comparing near-infrared (NIR) and ultraviolet (UV) spectroscopy techniques, UV spectroscopy demonstrates a higher scattering coefficient. This property makes UV spectroscopy more sensitive to variations in tablet surface texture. Consequently, UV spectroscopy can more readily detect subtle changes in the physical properties of tablet surfaces resulting from different compression forces [58,59].

We confirmed that day 5 tablets which were stored under UV, regardless of the applied temperature, had a significantly lower THR value in all tested wavelength ranges, compared to the values determined at the beginning of the test (0 days). Furthermore, the highest THR was observed for the near-infrared spectral range (1000–1700 nm), while the lowest was observed for two ranges: ultraviolet (335–380 nm) and visible light (400–540 nm). For tests carried out at 25 °C, the differences in THR values relative to the control after 1 day of UV irradiation were: 17.31% (for 335–380 nm) and 6.21% (for 400–540 nm), and after 5 days: 18.27% (for 335–380 nm) and 17.32% (for 400–540 nm). Increasing the temperature to 45 °C further increased the above mentioned differences in values after 1 day of UV irradiation, respectively: 25.96% (for 335–380 nm) and 13.07% (for 400–540 nm) and after 5 days: 26.92% (for 335–380 nm) and 19.61% (for 400–540 nm).

After these study times (i.e., 1 and 5 days), there was also a significant increase in hardness and decrease in friability of the analyzed tablets, compared to the control tablets (day 0). Analogous to the study by Klukkert et al. [57], a similar reflectance spectrum of the tablets under study was observed across the entire spectral range studied for the control tablets. Storing the tablets under stress conditions resulted in a shift of their spectra towards lower reflectance values. The results obtained correspond with our previous studies. Based on the findings of reflectance measurements, a decrease in THR values was demonstrated for expired effervescent tablets (containing magnesium and vitamin B6), compared to unexpired tablets [60]. Similarly, effervescent tablets stored for 10 days under conditions of high temperature (45 °C) UV exposure had significantly lower reflectance values (in the range from visible to near-infrared light). In addition, an increase in density and porosity (measured by the x-ray microtomography analyses) as well as hardness coefficient was observed [61].

Our study has some limitations since we analyzed only selected physical parameters (temperature and UV radiation, as well as storage time) without evaluating resveratrol levels at the beginning and end of the experiment. However, many other physical factors may also affect the observed differences in reflectance spectra. Notwithstanding, the demonstrated significant change in hardness and friability of tablets subjected to stress conditions allows us to suggest their instability.

5. Conclusions

THR is a rapid, non-destructive analysis technique that should find practical application in assessing the stability of medical preparations. It serves as a screening method that enables the detection of changes in the reflectance of analyzed drug forms across a wide range of wavelengths. This method has not been used so far in pharmacy, while it is common in the construction industry, aviation, astronomy, among others. The portable refractometer used in the work allows in situ optical surface inspection at ambient temperature, comparable to laboratory spectrophotometers [62]. When combined with other techniques, it can become a valuable tool in pharmaceutical development and manufacturing.

The THR measurement method used provides new information on the optical properties of the surface of the tablets under study. The decrease in the value of TRH for tablets subjected to stress conditions, observed in our work, is due to the transfer of energy to the interior of the matrix, which in turn can initiate the photodegradation processes. A protection against this phenomenon could include coating the matrix of the tablets under study. Physical changes (reflectance, hardness, and friability) due to stress conditions, demonstrated in the study, could affect the degradation time, bioavailability, and, consequently, the pharmacological effect of the drug.

Thus, the significant changes in reflectance recorded after treatment with light and elevated temperatures for all seven spectral bands may be an attribute of tablet quality and reflect adverse physical and chemical changes on the surface or inside tablets exposed to stressful conditions or stored by patients in a manner inconsistent with the manufacturer's recommendations.

Author Contributions: Conceptualization, B.S.-M. methodology, B.S.-M. and B.S.-H. software, B.S.-M. and B.S.-H. validation, B.S.-M. and B.S.-H. formal analysis, B.S.-M. and B.S.-H. investigation B.S.-M. and B.S.-H. resources, B.S-M.; data curation, B.S.-M. and B.S.-H. writing—original draft preparation, B.S.-M. and B.S.-H. writing—review and editing, B.S.-M. and B.S.-H. visualization, B.S.-M. and B.S.-H. supervision, B.S.-M.; project administration, B.S.-M.; funding acquisition, B.S.-M. All authors have read and agreed to the published version of the manuscript.

Funding: The experimental part of this study, as well as the APC, were funded by the Medical University of Silesia in Katowice (Poland) within the projects: PCN-1-059/K/2/F and BNW-1-140/K/3/F.

Data Availability Statement: The data presented in this study are available on request from the Department of Pharmaceutical Technology, Medical University of Silesia in Katowice (Poland).

Conflicts of Interest: The authors declare no conflicts of interest.

References

1. Tian, B.; Liu, J. Resveratrol: A review of plant sources, synthesis, stability, modification and food application. *J. Sci. Food Agric.* **2020**, *100*, 1392–1404. [CrossRef] [PubMed]
2. Burns, J.; Yokota, T.; Ashihara, H.; Lean, M.E.J.; Crozier, A. Plant foods and herbal sources of resveratrol. *J. Agric. Food Chem.* **2002**, *50*, 3337–3340. [CrossRef]
3. Ko, J.H.; Sethi, G.; Um, J.Y.; Shanmugam, M.K.; Arfuso, F.; Kumar, A.P.; Bishayee, A.; Ahn, K.S. The role of resveratrol in cancer therapy. *Int. J. Mol. Sci.* **2017**, *18*, 2589. [CrossRef] [PubMed]
4. Zhang, L.X.; Li, C.X.; Kakar, M.U.; Khan, M.S.; Wu, P.F.; Amir, R.M.; Dai, D.F.; Naveed, M.; Li, Q.Y.; Saeed, M.; et al. Resveratrol (RV): A pharmacological review and call for further research. *Biomed. Pharmacother.* **2021**, *143*, 112164. [CrossRef] [PubMed]
5. Williams, L.D.; Burdock, G.A.; Edwards, J.A.; Beck, M.; Bausch, J. Safety studies conducted on high-purity trans-resveratrol in experimental animals. *Food Chem. Toxicol.* **2009**, *47*, 2170–2182. [CrossRef]
6. Vang, O. What is new for resveratrol? Is a new set of recommendations necessary? *Ann. N. Y. Acad. Sci.* **2013**, *1290*, 1–11. [CrossRef] [PubMed]
7. Patel, K.R.; Scott, E.; Brown, V.A.; Gescher, A.J.; Steward, W.P.; Brown, K. Clinical trials of resveratrol. *Ann. N. Y. Acad. Sci.* **2011**, *1215*, 161–169. [CrossRef]
8. Li, S.; Yin, S.; Ding, H.; Shao, Y.; Zhou, S.; Pu, W.; Han, L.; Wang, T.; Yu, H. Polyphenols as potential metabolism mechanisms regulators in liver protection and liver cancer prevention. *Cell Prolif.* **2023**, *56*, e13346. [CrossRef]
9. Morris, G.Z.; Williams, R.L.; Elliott, M.S.; Beebe, S.J. Resveratrol induces apoptosis in LNCaP cells and requires hydroxyl groups to decrease viability in LNCaP and DU 145 cells. *Prostate* **2002**, *52*, 319–329. [CrossRef]
10. Takizawa, Y.; Nakata, R.; Fukuhara, K.; Yamashita, H.; Kubodera, H.; Inoue, H. The 4′-hydroxyl group of resveratrol is functionally important for direct activation of PPARα. *PLoS ONE* **2015**, *10*, e0120865. [CrossRef]
11. Galiniak, S.; Aebisher, D.; Bartusik-Aebisher, D. Health benefits of resveratrol administration. *Acta Biochim. Pol.* **2019**, *66*, 13–21. [CrossRef]
12. Bostancıeri, N.; Elbe, H.; Eşrefoğlu, M.; Vardı, N. Cardioprotective potential of melatonin, quercetin and resveratrol in an experimental model of diabetes. *Biotech. Histochem.* **2022**, *97*, 152–157. [CrossRef] [PubMed]
13. Andrade, S.; Ramalho, M.J.; Pereira, M.D.C.; Loureiro, J.A. Resveratrol Brain Delivery for Neurological Disorders Prevention and Treatment. *Front. Pharmacol.* **2018**, *9*, 1261. [CrossRef]
14. Komorowska, J.; Wątroba, M.; Szukiewicz, D. Review of beneficial effects of resveratrol in neurodegenerative diseases such as Alzheimer's disease. *Adv. Med. Sci.* **2020**, *65*, 415–423. [CrossRef] [PubMed]
15. Feng, Y.L.; Jiang, X.T.; Ma, F.F.; Han, J.; Tang, X.L. Resveratrol prevents osteoporosis s by upregulating FoxO1 transcriptional, activity. *Int. J. Mol. Med.* **2018**, *41*, 202–212. [CrossRef]
16. Hu, C.; Li, L. The application of resveratrol to mesenchymal stromal cell-based regenerative medicine. *Stem Cell Res. Ther.* **2019**, *10*, 307. [CrossRef] [PubMed]

17. Michno, A.; Grużewska, K.; Ronowska, A.; Gul-Hinc, S.; Zyśk, M.; Jankowska-Kulawy, A. Resveratrol Inhibits Metabolism and Affects Blood Platelet Function in Type 2 Diabetes. *Nutrients.* **2022**, *14*, 1633. [CrossRef] [PubMed] [PubMed Central]
18. Hecker, A.; Schellnegger, M.; Hofmann, E.; Luze, H.; Nischwitz, S.P.; Kamolz, L.P.; Kotzbeck, P. The impact of resveratrol on skin wound healing, scarring, and aging. *Int. Wound J.* **2022**, *19*, 9–28. [CrossRef] [PubMed]
19. Meng, T.; Xiao, D.; Muhammed, A.; Deng, J.; Chen, L.; He, J. Anti-Inflammatory Action and Mechanisms of Resveratrol. *Molecules* **2021**, *26*, 229. [CrossRef] [PubMed]
20. Almatroodi, S.A.; Alsahli, M.S.M.A.; Aljohani, A.; Alhumaydhi, F.A.; Babiker, A.Y.; Khan, A.A.; Rahmani, A.H. Potential Therapeutic Targets of Resveratrol, a Plant Polyphenol, and Its Role in the Therapy of Various Types of Cancer. *Molecules* **2022**, *27*, 2665. [CrossRef] [PubMed]
21. Banaszak, M.; Górna, I.; Woźniak, D.; Przysławski, J.; Drzymała-Czyż, S. The Impact of Curcumin, Resveratrol, and Cinnamon on Modulating Oxidative Stress and Antioxidant Activity in Type 2 Diabetes: Moving beyond an Anti-Hyperglycaemic Evaluation. *Antioxidants* **2024**, *13*, 510. [CrossRef]
22. Bowers, J.L.; Tyulmenkov, V.V.; Jernigan, S.C.; Klinge, C.M. Resveratrol Acts as a Mixed Agonist/Antagonist for Estrogen Receptors α and β*. *Endocrinology* **2000**, *141*, 3657–3667. [CrossRef]
23. Wong, R.H.; Thaung Zaw, J.J.; Xian, C.J.; Howe, P.R. Regular Supplementation With Resveratrol Improves Bone Mineral Density in Postmenopausal Women: A Randomized, Placebo-Controlled Trial. *J. Bone Miner. Res.* **2020**, *35*, 2121–2131. [CrossRef]
24. Youjun, D.; Huang, Y.; Lai, Y.; Ma, Z.; Wang, X.; Chen, B.; Ding, X.; Tan, Q. Mechanisms of resveratrol against diabetic wound by network pharmacology and experimental validation. *Ann. Med.* **2023**, *55*, 2280811. [CrossRef] [PubMed]
25. Qu, B.; Zeng, Z.; Yang, H.; He, J.; Jiang, T.; Xu, X.; Liu, J.; Li, Y.; Xiang, D.; Pan, X. Resveratrol reversed rosiglitazone administration induced bone loss in rats with type 2 diabetes mellitus. *Biomed. Pharmacother.* **2024**, *178*, 117208. [CrossRef] [PubMed]
26. Mahjabeen, W.; Khan, D.A.; Mirza, S.A. Role of resveratrol supplementation in regulation of glucose hemostasis, inflammation and oxidative stress in patients with diabetes mellitus type 2: A randomized, placebo-controlled trial. *Complement. Ther. Med.* **2022**, *66*, 102819. [CrossRef] [PubMed]
27. Ma, D.S.L.; Tan, L.T.; Chan, K.G.; Yap, W.H.; Pusparajah, P.; Chuah, L.H.; Ming, L.C.; Khan, T.M.; Lee, L.H.; Goh, B.H. Resveratrol-Potential Antibacterial Agent against Foodborne Pathogens. *Front. Pharmacol.* **2018**, *9*, 102. [CrossRef] [PubMed]
28. Cui, W.; Wang, Y.; Zhang, L.; Liu, F.; Duan, G.; Chen, S.; Long, J.; Jin, Y.; Yang, H. Recent advances in the use of resveratrol against *Staphylococcus aureus* infections (Review). *Med. Int.* **2024**, *4*, 67. [CrossRef]
29. Cardile, V.; Chillemi, R.; Lombardo, L.; Sciuto, S.; Spatafora, C.; Tringali, C. Antiproliferative activity of methylated analogues of E- and Z-resveratrol. Z. Naturforsch. C. *J. Biosci.* **2007**, *62*, 189–195. [CrossRef]
30. Weiskirchen, S.; Weiskirchen, R. Resveratrol: How Much Wine Do You Have to Drink to Stay Healthy? *Adv. Nutr.* **2016**, *7*, 706–718. [CrossRef] [PubMed]
31. Leischner, C.; Burkard, M.; Michel, A.; Berchtold, S.; Niessner, H.; Marongiu, L.; Busch, C.; Frank, J.; Lauer, U.M.; Venturelli, S. Comparative Analysis of the Antitumor Activity of Cis- and Trans-Resveratrol in Human Cancer Cells with Different p53 Status. *Molecules.* **2021**, *26*, 5586. [CrossRef] [PubMed] [PubMed Central]
32. Zupančič, Š.; Lavrič, Z.; Kristl, J. Stability and solubility of trans-resveratrol are strongly influenced by pH and temperature. *Eur. J. Pharm. Biopharm.* **2015**, *93*, 196–204. [CrossRef] [PubMed]
33. Neves, A.R.; Lucio, M.; Lima, J.L.; Reis, S. Resveratrol in medicinal chemistry: A critical review of its pharmacokinetics, drug-delivery, and membrane interactions. *Curr. Med. Chem.* **2012**, *19*, 1663–1681. [CrossRef]
34. Dijkstra, N.E.; Sino, C.G.M.; Schuurmans, M.J.; Schoonhoven, L.; Heerdink, E.R. Medication self-management: Considerations and decisions by older people living at home. *Res. Social. Adm. Pharm.* **2022**, *18*, 2410–2423. [CrossRef]
35. Funk, O.G.; Yung, R.; Arrighi, S.; Lee, S. Medication Storage Appropriateness in US Households. *Innov. Pharm.* **2021**, *12*, 10. [CrossRef] [PubMed]
36. Hewson, C.; Shen, C.C.; Strachan, C.; Norris, P. Personal medicines storage in New Zealand. *J. Prim. Health Care* **2013**, *5*, 146–150. [CrossRef] [PubMed]
37. *European Pharmacopoeia*, 10th ed.; EDQM Council of Europe: Strasbourg, France, 2022.
38. Maggi, L.; Ochoa Machiste, E.; Fasani, E.; Albini, A.; Segale, L.; Conte, U. Photostability of extended-release matrix formulations. *Eur. J. Pharm. Biopharm.* **2003**, *55*, 99–105. [CrossRef]
39. Matsushima, Y.; Hattori, M.; Tanaka, A.; Furubayashi, T.; Sakane, T. Changes in Tablet Color Due to Light Irradiation: Photodegradation of the Coating Polymer, Hypromellose, by Titanium Dioxide. *AAPS Pharm. Sci. Tech.* **2024**, *25*, 26. [CrossRef]
40. Silva, C.G.; Monteiro, J.; Marques, R.R.; Silva, A.M.; Martínez, C.; Canle, M.; Faria, J.L. Photochemical and photocatalytic degradation of trans-resveratrol. *Photochem. Photobiol. Sci.* **2013**, *12*, 638–644. [CrossRef] [PubMed]
41. Camont, L.; Cottart, C.H.; Rhayem, Y.; Nivet-Antoine, V.; Djelidi, R.; Collin, F.; Beaudeux, J.L.; Bonnefont-Rousselot, D. Simple spectrophotometric assessment of the trans-/cis-resveratrol ratio in aqueous solutions. *Anal. Chim. Acta.* **2009**, *634*, 121–128. [CrossRef] [PubMed]

42. Yoshinaga, M.; Toldo, J.M.; Rocha, W.R.; Barbatti, M. Photoisomerization pathways of trans-resveratrol. *Phys. Chem. Chem. Phys.* **2024**, *26*, 24179–24188. [CrossRef]
43. Zhao, Y.; Shi, M.; Ye, J.H.; Zheng, X.Q.; Lu, J.L.; Liang, Y.R. Photo-induced chemical reaction of trans-resveratrol. *Food Chem.* **2015**, *171*, 137–143. [CrossRef] [PubMed]
44. Tosato, M.G.; Vicendo, P.; Thomas, A.H.; Lorente, C. Clearing up the photochemistry of resveratrol: Effect of the solvent. *J. Photochem. Photobiol. A Chem.* **2018**, *367*, 327–331. [CrossRef]
45. Yao, Y.; Yuan, H.; Chen, C.; Liang, J.; Li, C. Study of the Antioxidant Capacity and Oxidation Products of Resveratrol in Soybean Oil. *Foods* **2023**, *13*, 29. [CrossRef] [PubMed]
46. Dos Santos, D.P.; Soares Lopes, D.P.; de Moraes Junior, R.C.; Vieira Gonçalves, C.; Pereira Rosa, L.; da Silva Rosa, F.C.; da Silva, R.A.A. Photoactivated resveratrol against Staphylococcus aureus infection in mice. *Photodiagnosis Photodyn. Ther.* **2019**, *25*, 227–236. [CrossRef] [PubMed]
47. Szulc-Musioł, B.; Sarecka-Hujar, B. The Use of Micro- and Nanocarriers for Resveratrol Delivery into and across the Skin in Different Skin Diseases-A Literature Review. *Pharmaceutics.* **2021**, *13*, 451. [CrossRef]
48. Juškaitė, V.; Ramanauskienė, K.; Briedis, V. Testing of resveratrol microemulsion photostability and protective effect against UV induced oxidative stress. *Acta Pharm.* **2017**, *67*, 247–256. [CrossRef] [PubMed]
49. Biagini, A.; Refrigeri, N.; Caglioti, C.; Sabbatini, P.; Ticconi, S.; Ceccarelli, G.; Iannitti, R.G.; Palazzetti, F.; Fioretti, B. Accelerated Stability Testing in Food Supplements Underestimates Shelf Life Prediction of Resveratrol with Super-Arrhenius Behavior. *Symmetry* **2024**, *16*, 493. [CrossRef]
50. França, L.d.M.; Pimentel, M.F.; Simões, S.d.S.; Grangeiro, S.; Prats-Montalbán, J.M.; Ferrer, A. NIR hyperspectral imaging to evaluate degradation in captopril commercial tablets. *Eur. J. Pharm. Biopharm.* **2016**, *104*, 180–188. [CrossRef] [PubMed]
51. Su, X.; Wang, Y.; Mao, J.; Chen, Y.; Yin, A.; Zhao, B.; Zhang, H.; Liu, M. A Review of Pharmaceutical Robot based on Hyperspectral Technology. *J. Intell. Robot. Syst.* **2022**, *105*, 75. [CrossRef] [PubMed]
52. Nishii, T.; Matsuzaki, K.; Morita, S. Real-time determination and visualization of two independent quantities during a manufacturing process of pharmaceutical tablets by near-infrared hyperspectral imaging combined with multivariate analysis. *Int. J. Pharm.* **2020**, *590*, 119871. [CrossRef] [PubMed]
53. Kandpal, L.M.; Tewari, J.; Gopinathan, N.; Boulas, P.; Cho, B.K. In-Process Control Assay of Pharmaceutical Microtablets Using Hyperspectral Imaging Coupled with Multivariate. *Analysis. Anal. Chem.* **2016**, *88*, 11055–11061. [CrossRef] [PubMed]
54. Shinde, S.R.; Bhavsar, K.; Kimbahune, S.; Khandelwal, S.; Ghose, A.; Pal, A. Detection of Counterfeit Medicines Using Hyperspectral Sensing. *Annu. Int. Conf. IEEE Eng. Med. Biol. Soc.* **2020**, *2020*, 6155–6158. [CrossRef] [PubMed]
55. Wilczyński, S.; Deda, A.; Koprowski, R.; Banyś, A.; Błońska-Fajfrowska, B. The Use of Directional Reflectance Measurement for in vivo Assessment of Protective Properties of Cosmetics in the Infrared Radiation Range. *Photochem. Photobiol.* **2017**, *93*, 1303–1311. [CrossRef] [PubMed]
56. Meisner, M.; Sarecka-Hujar, B. Assessment of Directional-Hemispherical Reflectance of Tablets with Cefuroxime during Storage under Elevated Temperature and Ultraviolet Radiation. *Sensors* **2024**, *24*, 630. [CrossRef] [PubMed]
57. Klukkert, M.; Wu, J.X.; Rantanen, J.; Carstensen, J.M.; Rades, T.; Leopold, C.S. Multispectral UV imaging for fast and non-destructive quality control of chemical and physical tab-let attributes. *Eur. J. Pharm. Sci.* **2016**, *90*, 85–95. [CrossRef]
58. França-Silva, F.; Rego, C.H.Q.; Gomes-Junior, F.G.; Moraes, M.H.D.; Medeiros, A.D.; Silva, C.B.D. Detection of Drechslera avenae (Eidam) Sharif [Helminthosporium avenae (Eidam)] in Black Oat Seeds (Avena strigosa Schreb) Using Multispectral Imaging. *Sensors* **2020**, *20*, 3343. [CrossRef]
59. Kessler, R.W. Sensitivity and selectivity in optical spectroscopy and imaging: A molecular approach. In *OCM 2015—Optical Characterization of Materials, Conference Proceedings*; Beyerer, J., Ed.; KIT Scientific Publishing: Karlsruhe, Germany, 2015; pp. 89–102.
60. Meisner, M.; Duda, P.; Szulc-Musioł, B.; Sarecka-Hujar, B. Characteristics of Commercial Effervescent Tablets Using Selected Pharmacopeial and Novel Analytical Methods. *Appl. Sci.* **2023**, *13*, 3171. [CrossRef]
61. Szulc-Musioł, B.; Duda, P.; Meisner, M.; Sarecka-Hujar, B. Hyperspectral and Microtomo-graphic Analyses to Evaluate the Stability of Quercetin and Calcium Effervescent Tablets Exposed to Heat and Ultraviolet Radiation. *Processes* **2024**, *12*, 531. [CrossRef]
62. Caron, S.; Herding, L.; Binyamin, Y.; Baidossi, M.; Vinetsky, Y.; Morales, A.; Hildebrandt, C.; Reoyo-Prats, R.; Faugeroux, O.; Agüero, A.; et al. A laboratory intercomparison of solar absorptance and thermal emittance measurements at room temperature. *Sol. Energy Mater. Sol. Cells* **2022**, *238*, 111579. [CrossRef]

Disclaimer/Publisher's Note: The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of MDPI and/or the editor(s). MDPI and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.