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Development of a Freshness Index for Fruit Quality Assessment—Using Bell Pepper as a Case Study

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Abstract: *(1) Background:* This special issue contains new developments in the field of fresh produce quality. Freshness provides the appeal for the consumer to purchase a particular horticultural produce. Freshness is a combination of size, colour, shape, flesh firmness, turgescence and glossiness without wilting, which imply that the produce has been picked only a short while ago and has not suffered any decay during harvest, transport or storage. *(2) Objective:* The objective of the present work was to develop potential freshness indices. The indices are based on non-invasive, real-time measurements, using changes in surface appearance after harvest, using Bell pepper as the most difficult model. *(3) Methods:* The selection criteria were a dramatic change in values over 14 days of storage at 17 °C, and either a consistent decrease or increase without peaks and troughs. Only two (out of five) non-invasive techniques were selected, i.e., surface glossiness, measured non-destructively using a luster sensor (type CZ-H72 from Keyence Co., Osaka, Japan) and light reflection spectra, recorded by a spectrometer, whereas the three techniques fruit firmness (penetrometer), colorimeter (e.g., Minolta) and false colour images (profilometer) were excluded. *(4) Results:* The first technique based on fruit glossiness provides luster values depending on fruit colour. Green Bell pepper fruit with a Fresh Index in excess of 463–490 a.i. can be classified as fresh, and similarly of 525–565 a.i. for yellow and 486–502 a.i. for red pepper fruit. This first Freshness index dropped, indicating a lesser freshness, to less than 100 a.i. after 14 days storage, irrespective of fruit colour, thereby providing a suitable wide, ca. 5-fold, range of parameterization. The second index is based on the difference between the light reflectance peaks at 630–633 nm and at 500 nm, also measured perpendicular to the convex fruit side. These percentage values decreased from >40% with fresh red and yellow Bell pepper to ca. 20% after 14 days storage; similarly, these percentages decreased from ca. 16% to ca. 8% in green pepper fruit, in both cases by a twofold factor. Overall, a third Freshness index could be a combination of luster values larger than 470 a.u. and >40% difference of the light reflectance between 630 nm and 500 nm. *(5) Conclusions:* Two viz three freshness indices are proposed and thresholds elaborated for Bell pepper fruit. The analysis showed that both indices viz technologies, luster and light reflection spectra, require colour differentiation, i.e., a specific index for yellow, red and green Bell pepper fruit.

Keywords: sweet pepper (*Capsicum annum* L.); consumer preference; freshness; fruit quality; glossiness; light reflection; non-invasive techniques; shrivel; sustainability; turgescence; wilting

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1. Introduction

This special issue of horticulturae aims to collect contributions on "Advances in improving fresh produce quality and postharvest shelf life". Fresh or Freshness is a term often used but rarely defined [1–3]. Freshness provides the appeal for the consumer to purchase a particular horticultural produce, being a combination of size, colour, shape, flesh firmness, turgescence and glossiness without wilting, which imply that the produce has been picked only a short while ago and has not suffered any decay during harvest, transport or storage [1–3]. Some of the previous work concentrated on wilting, e.g., in radish, horseradish, fennel and kohlrabi, as well as all kinds of lettuce (romana, endive, rucola), where the degree of wilting of the attached leaves served as an indicator of freshness

or produce quality and for the optimum for human nutrition. In other horticultural crops such as asparagus, chicory, celery or table grapes, the dryness of the cut stem serves as an indicator for freshness, but is subject to manipulation, i.e., it could be re-cut to simulate freshness.

In our previous work, we investigated five new approaches based on changes in product surface pattern. Five non-invasive and real-time, mostly opto-electronic methods were evaluated as to their potential in-situ use for the possibility of detecting the freshness using Bell pepper fruit as a case study stored up to 14 days with increasing fruit shrivel (Figure 1) [4]. Since previous studies and parameters based on changes in surface pattern of fresh produce may be sensitive to colour (Schüesseler et al. 2019 [5–7]), this issue was particularly addressed.

Figure 1. Bell pepper fruit employed for the present freshness index evaluation, in their fresh condition and the fresh specimen on the right and then stored for 14 days (left specimen).

The aim of this study was to elaborate suitable parameters and thresholds for an objective freshness assessment and develop a Freshness index using Bell pepper fruit of the three colours.

2. Materials and Methods

2.1. Source of Data and of Bell Pepper Fruit

The data in this contribution originate from sixty commercial Bell pepper fruit obtained from the local supermarket from a fresh Spanish delivery.

2.2. Measurement Position and d.o.s.

Shelf-life is presented as days from fresh (day 0) and as d.o.s.-degree of shriveling (Figure 2).

The same Bell pepper fruit and the same marked positions (Figure 3) were used for the measurements, i.e., 12 fruit per colour and shelf life and four positions on each fruit.

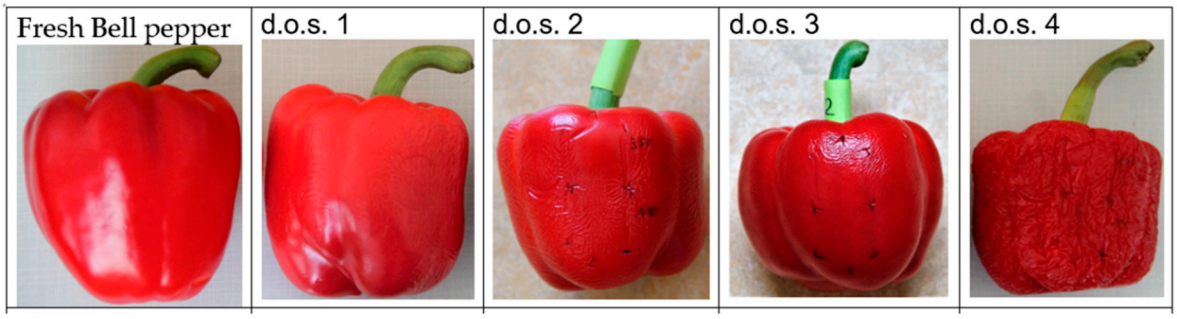
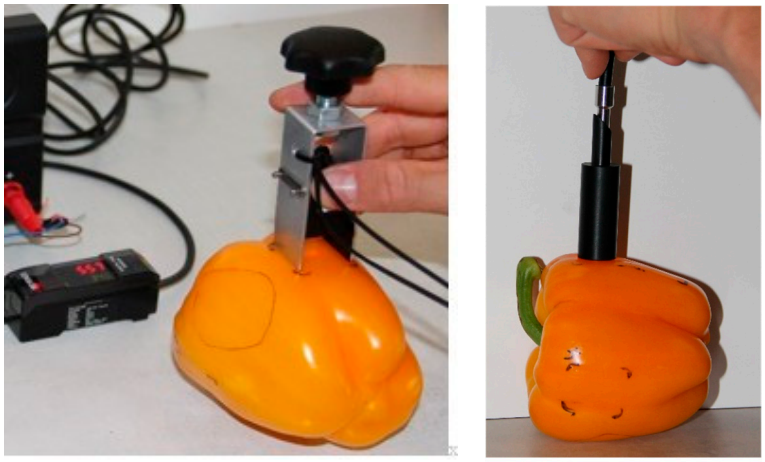


Figure 2. Shrivel development during shelf-life-designated as d.o.s.-degree of shriveling.



(**a**) (**b**)

Figure 3. Perpendicular gloss (**a**) and reflectance measurements (**b**) (0° from the normal) with a portable luster sensor and spectrometer with the measured spots marked on the specimen; the same marked spots and fruit were used for all measurements in this study.

2.3. Gloss Measurements

A CZ-H72 luster sensor (Keyence, Co., Osaka, Japan) was used to measure the surface glossiness of the Bell pepper fruit in a non-invasive way [8], which provides red LED light at 665 nm. The operating voltage was 14.8 V. The diameter of the measuring spot was 5 mm. In contrast to previous work, which had required a micromanipulator (Klemm et al., 2016) [9], a special holder (Figure 3a) was designed. This holder provides a 15 mm constant distance between the luster sensor and the fruit without the necessity of a micromanipulator and without moving the fruit and provides the luster values in real time.

2.4. Spectrometry

Spectral reflection of the pepper fruit with different degrees of freshness and shrivel was measured non-invasively with a portable miniature spectrometer (StellarNet Inc., Tampa, FL, USA) with data processing using SpectraWiz^{TM} supplied with the instrument. Measurements over 500–850 nm using the build-in halogen light source at 0° (from the normal) reflection angle (Figure 3b) with a resolution of 0.2–6.0 nm depending on wavelength and a flexible glass fiber cable to provide a measuring spot of 2 mm with a measuring time of less than 1 s. The instrument was calibrated with the supplied 5 cm O white barium sulfate disc as reference for 100% light reflection and data expressed as percentage later

2.5. Statistics

After testing the experimental data for normal distribution (Kolmogorov–Smirnov test and Shapiro–Wilk test) and for variance homogeneity (Levene test), they were statistically processed using one-factorial analysis of variance (ANOVA), using aging as group/factor

within one fruit colour or within all 60 Bell pepper fruit (Figure 4) in RStudio (Boston, MA, USA, version 1.3) at 95% probability.

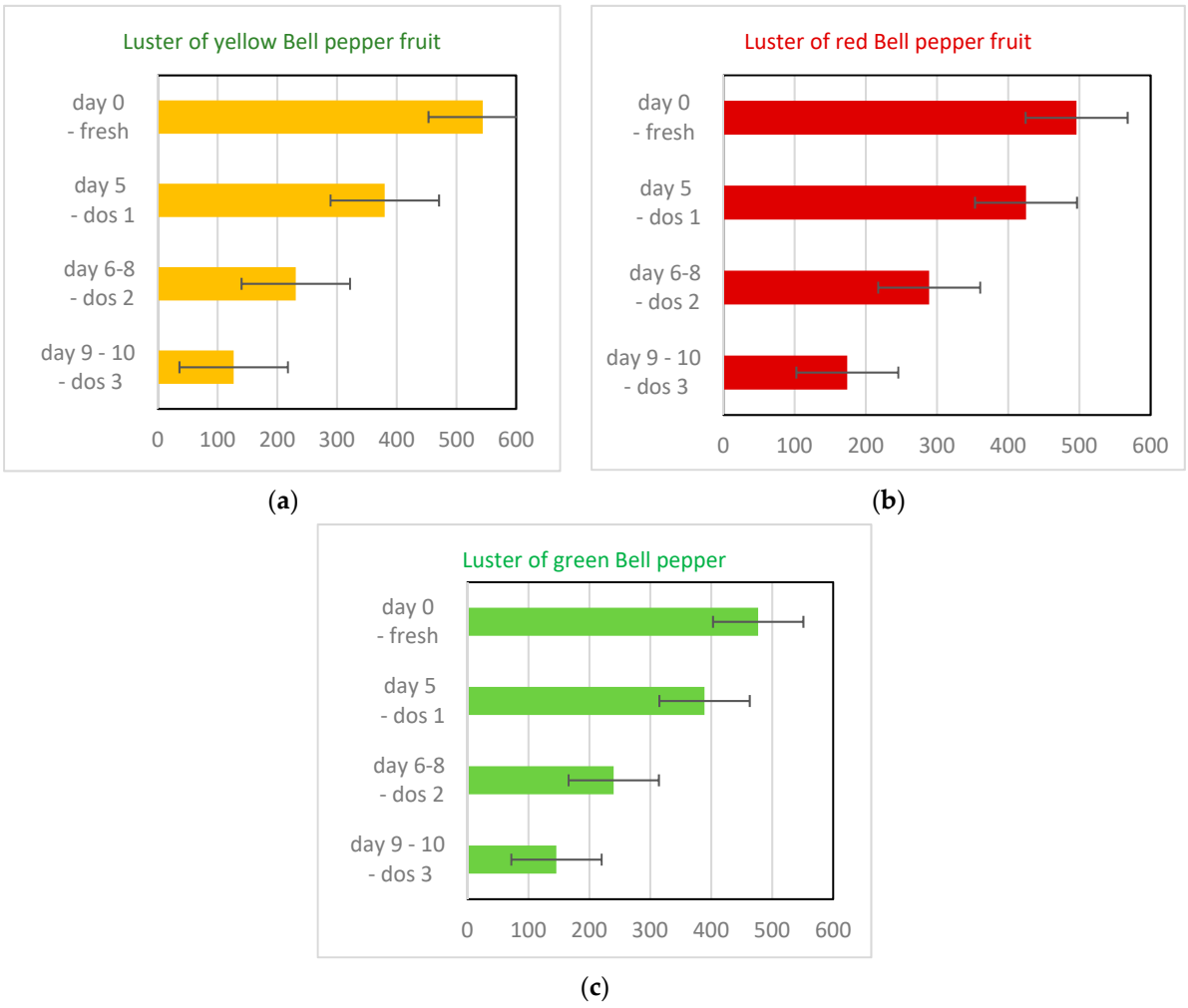


Figure 4. First Freshness index of Bell pepper fruit classified by fruit colour, yellow (**a** top-left), red (**b** middle) and green (**c** bottom), averaged gloss values, stored over 14 days with the degree of shrivel (d.o.s) (n = 60 pepper fruit per day; ± SD).

3. Results

3.1. Selection Criteria

Non-invasive measurements of fresh versus fruit stored over 14 days [4] were evaluated. Three sets of these measurements were discarded for the development of a Freshness index, i.e., (a) fruit firmness (assessed by a penetrometer), (b) colour measurements (Minolta; i1Pro, X-rite) and (c) false colour images from a profilometer, the latter for cost, time and effort.

Our selection criteria (Table 1) were a dramatic change in values (in excess of 2-fold) over the 14 days storage, and either a consistent decrease or increase without peaks and troughs. Only two non-invasive techniques fulfilled these criteria, luster/glossiness measurements and light reflection spectra.

Table 1. Selection criteria for the present study.

Criterium	Explanation
twofold increase or decrease in values	adequate differentiation of values
No peak, no trough	values do not appear twice
non-invasive, affordable	Real-time, in-situ

These two (out of five) techniques, however, responded to product colour, waiving the chance of a uniform Freshness index for pepper; such a uniform Freshness index could be developed e.g., for tomatoes or aubergine/eggplant fruit without the colour variation as in pepper fruit.

3.2. Gloss Disappearance of the Bell Pepper Fruit—A First Possible Freshness Indicator?

Product gloss represents the attractiveness of the fruit as perceived by the human eye [4]. The Bell pepper fruit lost its glossiness during two weeks of storage (Figure 4). Visual observation showed that fruit shriveling began on day 5 (Figure 1), i.e., after 6–8% weight loss.

The first technique based on fruit glossiness provides luster values depending on fruit colour. Green Bell pepper fruit with a Freshness Index in excess of 463–490 a.i. could be classified as fresh, and similarly of 525–565 a.i. for yellow and 486–502 a.i. for red pepper fruit (Table 2). These Freshness indices dropped to less than 100 a.i. after 14 days storage (Figure 3), irrespective of colour, thereby providing a suitable wide, ca 5fold scaling.

Table 2. Ranges of glossiness (luster) values for Bell pepper fruit of different colour (a.i.).

Colour of Bell Pepper	Day 0 (Fresh)	Day 5 (dos 1)	Day 6-8 (dos 2)	Day 9-10 (dos 3)
Yellow Bell pepper	524–564	422–502	231–260	105–171
Red Bell pepper	486–502	424–465	274–344	139–210
Green Bell pepper	463–490	389–422	207–290	109–183

This non-invasive, real-time gloss measurement in-situ using a luster sensor type CZ-H72 (Keyence, Osaka, Japan) enabled the best differentiation between fresh and stored fruit based on loss of produce gloss in accordance and increasing shrivel degree (Figure 2) as a suitable Freshness Index.

3.3. Sensory Assessment

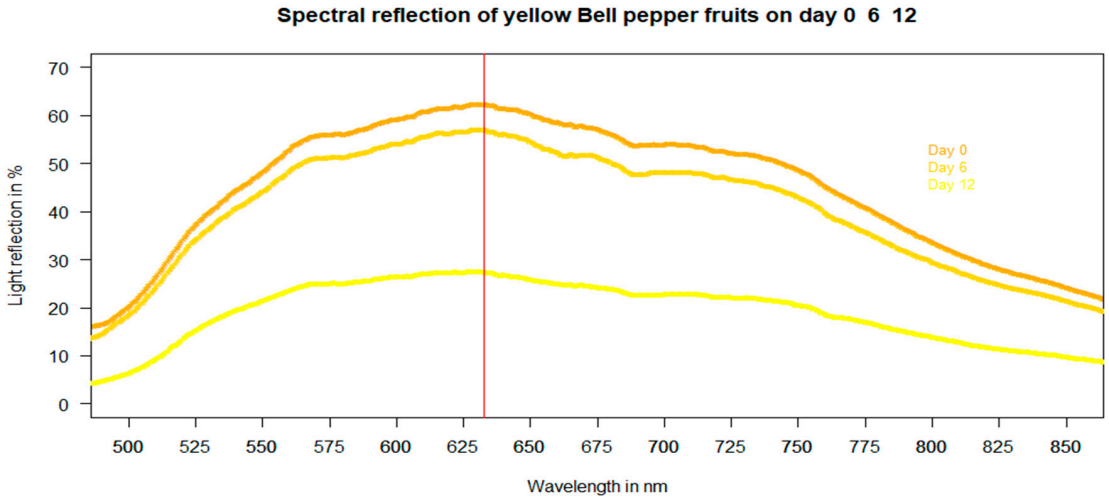
From dos 2 (Figure 2), Bell pepper fruit gradually lost taste (sweetness, juicyness, crispyness and crunchyness) as shown in Table 3; fruit from dos 3 were no longer suitable for fresh consumption.

Table 3. Physical and sensory properties for Bell pepper fruit ***irrespective*** of colour.

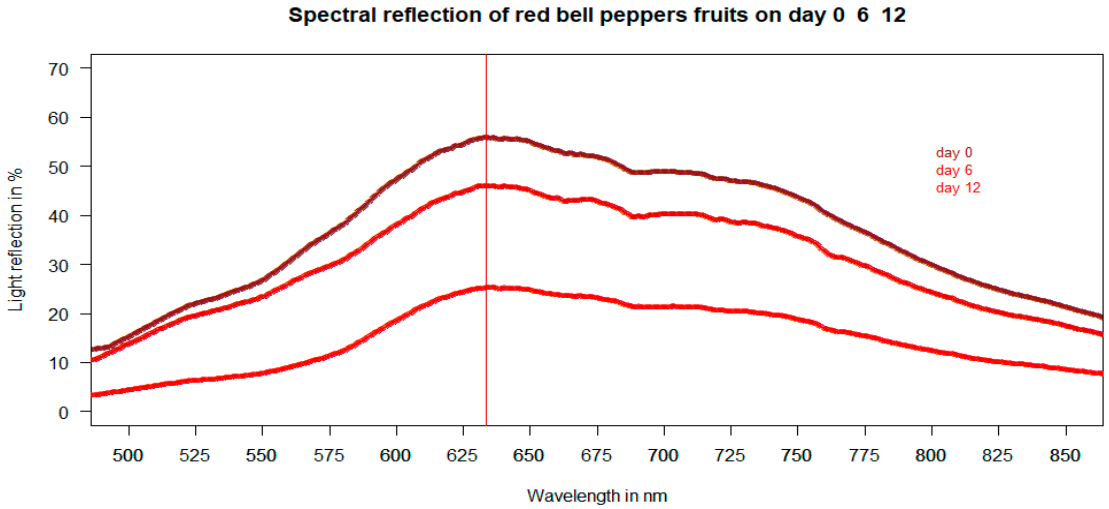
Parameter	Day 0 (Fresh)	Day 5 (dos 1)	Day 6–8(dos 2)	Day 9–10 (dos 3)	Day 12 (dos 4)
Fruit surface	smooth, glossy		Loss of gloss	Loss of gloss	Completely
Shrinkage	NO		Starts reversible	slight	shriveled
Resistance to indentation	high	large	moderate	NO	NO
Pulp	firm	firm	firm pulp	soft pulp	squashy

3.4. Spectral Light Reflectance—Development of a Second Freshness Index

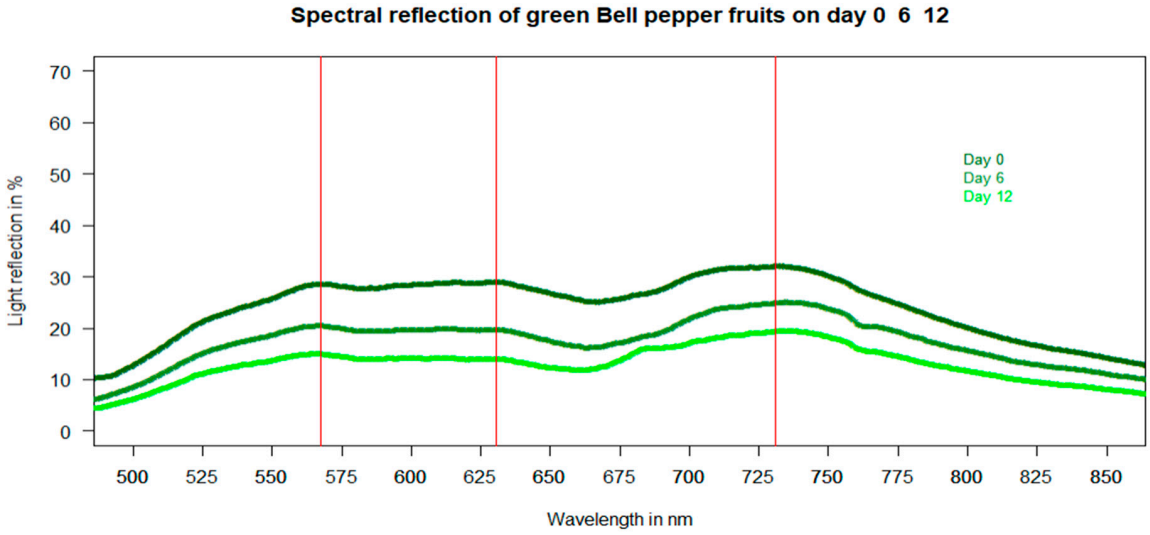
Light reflection was measured on the convex side of the fruit in situ, non-destructively and in real time with a portable unit. The magnitude of reflected light between 500 nm and 850 nm declined depending on the storage of Bell pepper fruits, but irrespective of fruit colour (Figure 5). Yellow bell pepper fruits showed the largest light reflection (Figure 4a), followed by red (Figure 5b), and then green fruit (Figure 5c). The spectra showed one uniform reflectance peak at the same wavelength of 630–632 nm, irrespective of fruit colour and freshness. However, the degree of light reflection declined with freshness in line with the glossiness values (Figure 3), irrespective of fruit colour.



(**a**)



(**b**)



(**c**)

Figure 5. Percentage spectral light reflection of (**a**) yellow, (**b**) red, and (**c**) green bell pepper fruits in three stages of freshness (shriveling and storage day 0 = fresh fruit, day 6 = shrivel level 2, day 12 = shrivel level 4) (barium sulfate = 100% light reflectance) (*n* = 20 fruit per colour, i.e., per curve; n = 60 overall—from Althaus and Blanke, 2020, with permission).

The second new Freshness index is suggested as the difference of the light reflectance between 630 nm and 500 nm using the following formula:

$$\text{Freshness index } [\%] = \text{Reflectance 630 nm} - \text{Reflectance 500 nm} \quad (1)$$

With fresh red pepper fruit, the difference in reflectance between 630 nm and 500 nm of 40.4% declined to 32.0% with 6-day old peppers (shriveling level—d.o.s. 2) (Figure 6) and finally to ca. 20.7% with 12-day old fruits (shriveling level -d.o.s. 4) (Table 4).

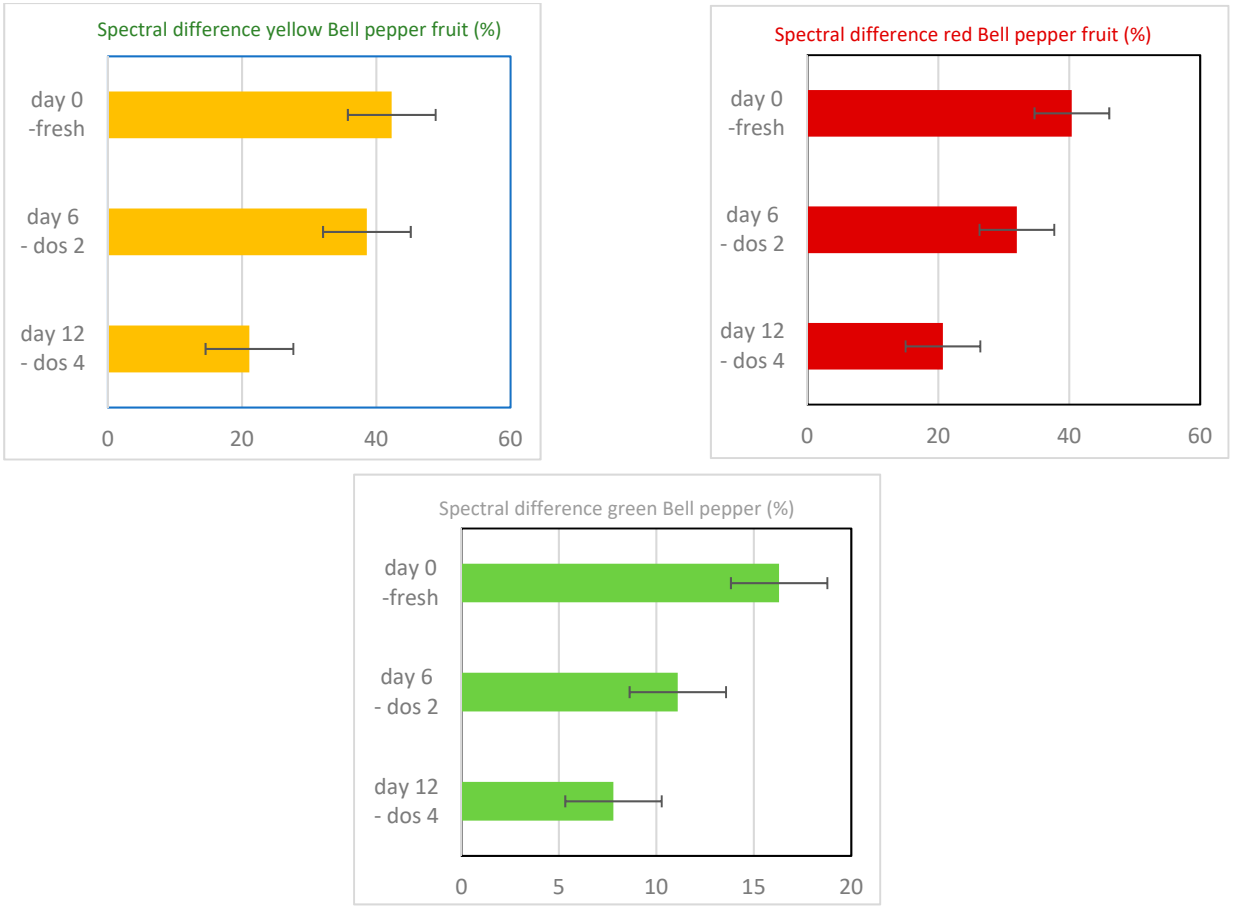


Figure 6. Second Freshness index for Bell pepper fruit classified by fruit colour, yellow (top-left), red (middle, right) and green (bottom), stored over 14 days (± SD)-scale varies.

Table 4. Freshness index based on the difference between light reflection at 630 nm and 500 nm.

Colour of Bell Pepper	Day 0 (Fresh)	Day 6 (d.o.s. 2)	Day 12 (d.o.s. 4)
Yellow Bell pepper	42.2%	38.6%	21.1%
Red Bell pepper	40.4%	32.0%	20.7%
Green Bell pepper	16.2%	11.1%	7.8%

3.5. Third Freshness Index

Freshness may be parametrized by the light reflectance peak at 630–633 nm and reflectance at 500 nm as (Formula (1)) expressed in Figure 5.

Overall, a third Freshness index could be suggested in combination with luster values larger than 480 a.u. (>460 with green pepper fruit) and >40% (>15 with green pepper fruit) as the difference of the light reflectance at 630 nm and at 500 nm.

4. Discussion

Produce quality includes "freshness". Freshness includes a glossy appearance with a range of fruits [4]. Gloss, in turn, provides the attractiveness of the fruit as perceived by the human eye. A precise determination of freshness is often requested in both retail the fresh fruit market [8,9]. The glossy appearance of fruit, e.g., pepper, aubergine and pomegranate fruit declines with age in line with fruit deterioration. With Bell pepper fruit, gloss deteriorates on shriveling (Figure 1), which started at 6.5% (green)—8.7% (yellow) weight loss in line with findings of 6% with Bell pepper fruit by Hiepler (2004) [10], who stored under a colder temperature (3.4 °C; 90% rh) in their experiments compared to our investigation (17 °C; 55% rh).

In Bell pepper, the chlorophyll content is also maintained during fruit maturation (Ziegler et al., 1983) [11] in contrast to dramatic chlorophyll degradation in many other fruits such as apple [3], cherry (Overbeck et al., 2017) [12] or banana (Ringer et al., 2021) [13]. This situation led to the exclusion of simple, solely colour measurements using a standard Minolta colour device or similar.

In Bell pepper fruit, the hollow volume is designated botanically as interlocular space by the German–Californian authors [6]. The hollow volume contained ca. 19.0% O_2 (Oomens et al., 1998) [14] confirming the original values of 19.2(±0.1)% O_2 and 1.8% CO_2 in MexiBell fruit at harvest in the pioneering work of Blanke and Holthe (1997) [6]. Whereas this beneficial CO_2 concentration resembles that seen in efficient long-term CA storage, but is hampered by the high oxygen concentration.

The pepper species belongs to the *Solanaceae* family, which includes tomato, pepper, and aubergine fruit. They are a dominant vitamin and mineral source in human nutrition worldwide and characterised by glossy fruit at maturity and absence from stomata from these three fruits (Blanke, 1986) [15], resulting in mostly cuticular transpiration and cuticular cracks as sources of water loss.

For the related aubergine (eggplant), a gloss index (GI) was developed by Mizrach et al. (2009) [16] for fresh apple, nectarine, plum, and tomato fruit, comparable to our approach with fresh and stored Bell pepper. Mizrach et al. (2009) [16], in a laboratory set-up in Michigan (USA), integrated the area underneath the gloss curves from 500 nm to 780 nm for both high gloss (probably waxed) US American Red Delicious and low gloss green-yellow Golden Delicious apples similar to our VIS light reflection spectra for Bell pepper fruit in Figure 4. Mizrach et al. (2009) [16] showed a similar light reflection peak at 630–640 nm using fresh Delicious apple fruit without storage or different degree of freshness and shrivel. The light reflectance of glossy fruit such as the waxed US American Red Delicious exceeded that of less glossy yellow-green Golden Delicious in line with our findings 10 years later with fresh and stored Bell pepper fruit, which lost glossiness over time taking Mizrach's original ideas at the time into another range of crops.

5. Conclusions

Overall, this study may be one of the first approaches to develop a Freshness index based on real-time, non-destructive in situ measurements. This novel opto-electronic approach uses surface features of certain fruits such as peel gloss, surface roughness, and shrivel. Bell pepper was used as the most difficult model fruit, as it comes in various colours and is cultivated on ca 2 mil ha. The results, including a Freshness index, may be transferable to other fruit with similar changes in the surface pattern on fruit maturation.

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

References

1. Kader, A.A.; Holcroft, D.M. Postharvest: An Introduction to the Physiology and Handling of Fruit, Vegetables and Ornamentals. *Horttech* **1999**, *9*, 299. [CrossRef]
2. Kays, S.J. Preharvest factors affecting appearance. *Postharvest Biol. Technol.* **1999**, *15*, 233–247. [CrossRef]
3. Salunkhe, D.K.; Desai, R.B. Pepper. In *Postharvest Biotechnology of Vegetables*; CRC: Boca Raton, FL, USA, 1984; Volume II, Chapter 5; pp. 49–58.
4. Althaus, B.; Blanke, M. Non-destructive, opto-electronic determination of the freshness and shrivel of Bell pepper fruits. *J. Imaging* **2020**, *6*, 112. [CrossRef] [PubMed]
5. Schüsseler, M.; Damerow, L.; Blanke, M.M. Does colouration affect non-invasive determination of russet on pome fruits? *Postharvest Biol. Technol.* **2019**, *152*, 54–59. [CrossRef]
6. Blanke, M.M.; Holthe, P.A. Bioenergetics, maintenance respiration and transpiration of pepper fruits. *J. Plant Physiol.* **1997**, *150*, 247–250. [CrossRef]
7. Blanke, M.; Lenz, F. Fruit photosynthesis. *Plant Cell Environ.* **1989**, *12*, 31–46. [CrossRef]
8. Czieczor, L.; Bentkamp, C.; Damerow, L.; Blanke, M.M. Non-invasive determination of the quality of pomegranate fruit. *Postharvest Biol. Technol.* **2018**, *136*, 74–79. [CrossRef]
9. Klemm, M.; Röttger, O.; Damerow, L.; Blanke, M.M. Non-Invasive Examination of Plant Surfaces by Opto-Electronic Means–Using Russet as a Prime Example. *Sensors* **2016**, *16*, 452. [CrossRef] [PubMed]
10. Hiepler, C. Capsaicinoide in Capsicum-Früchten Definierter Herkunft und Ihre Stabilität bei Verarbeitung und Lagerung. Ph.D. Thesis, Hrsg. v. Bergische Universität Wuppertal, Wuppertal, Germany, 2004. Available online: http://elpub.bib.uni-wuppertal.de/edocs/dokumente/fbc/chemie/diss2004/hiepler/dc0405.pdf (accessed on 25 September 2020).
11. Ziegler, H.; Schäfer, E.; Schneider, M.M. Some metabolic changes during chloroplast-chromoplast transition in *Capsicum annuum*. *Physiol. Veg.* **1983**, *21*, 485–494.
12. Overbeck, V.; Schmitz, M.; Blanke, M.M. Non-destructive sensor-based prediction of maturity and optimum harvest date in sweet cherry *(Prunus avium* L.). *Sensors* **2017**, *17*, 277. [CrossRef]
13. Ringer, T.; Damerow, L.; Blanke, M.M. Non-invasive determination of surface features of banana during ripening. *J. Food Sci. Technol.* **2018**, *55*, 4197–4203. [CrossRef]
14. Oomens, J.; Zuckermann, H.; Persijn, S.; Parker, D.H.; Harren, F.J.M. CO-laser-based photoacoustic trace gas detection: Applications in post-harvest physiology. *Appl. Phys.* **1998**, *67*, 459–466. [CrossRef]
15. Blanke, M.M. Comparative SEM study of the surface morphology of two Solanaceae fruits, tomato and aubergine. *Ejhs-Gartenbauwissenschaft.* **1986**, *51*, 225–230.
16. Mizrach, A.; Lu, R.; Rubino, M. Gloss Evaluation of Curved-surface Fruits and Vegetables. *Food Bioprocess Technol.* **2009**, *2*, 300–307. [CrossRef]