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Effect of Different Photo-sensitive Nets on the Colour of Apple Cv. Florina

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ABSTRACT

Background: Photo-selective shade netting technology is an emerging agro-technological concept, which aims at the improvement of crop quality by modification of spectral light and provides physical protection of the crop. The aim of this study was to investigate the influence of four protective nets with different colours on the colour of the apple fruits grown under the netting.

Methods: The colour of apple fruits, variety Florina, grown under different photo-selective nets: black, red, white and yellow was studied. The colour of the fruits studied was determined in terms of hue, saturation and brightness. The effect of white reflective ground cover on colour of the apples was also investigated. For this purpose, the reflective ground cover was applied for the duration of one month, during the fruit ripening period. To determine the colour and its descriptive values, spectrophotometric measurements were carried out with a CSS-D spectrophotometer, equipped with a CSS-45 sensor from Gigahertz-Optic. The spectrophotometric measurements show that the dominant colour of the apples was-yellow and the covering colour of the skin of the fruit falls in the orange section of the spectrum.

Result: As a summary of the obtained results, the most intense was the colour of apples, grown under a yellow net and the least intense was the apple colour when a white net and a reflective ground cover was used. It was found that, the colour of the apple skin, in terms of wavelength, significantly changes when a ground reflective cover was used. Noticeable differences in the intensity of the apple colour were found. The apple colour intensity was higher when only photo-selective nets were used. A deviation from this dependence was observed only for the black net. A correlation analysis was made between the spectral characteristics. The results show that there was strong, albeit negative, relationship between the half-width of the reflection peak and the rest of the spectral characteristics, the strongest being for the spectral colour of the apple fruit.

Key words: Apple colour, Apple orchard, Fruit colour, Photo-selective netting, Protective netting.

INTRODUCTION

Photo-selective shade netting technology is an emerging agro-technological concept, which aims at the improvement of crop quality by modification of spectral light. It also provides a physical protection of the crop. It was shown that light conditions, altered by photo-selective nets, can improve accumulation of phyto-chemicals and aroma compounds and ultimately, growth, yield and quality of selected vegetables such as tomatoes, sweet peppers, lettuce and aromatic herbs. It was shown that light quality, modified by photo-selective shade nets had a positive effect on the phyto-chemical content in fresh produce after postharvest storage (Sivakumar *et al.,* 2018).

The netting also has a microclimate impact, because it leads to reduction of incoming photosynthetic active radiation (PAR). Thus, the most important physiological processes, such as photosynthesis and carbon allocation, could be affected (Corelli-Grappadelli, 2003).

Photo-selective netting can be an effective tool to reduce the impact of global warming during vegetable production (Champaneri and Patel, 2022).

UV radiation is also altered under nets and affects the apple fruit quality, by stimulating the synthesis of anthocyanins, the pigment responsible for the red colour of the fruit (Solovchenko and Schmitz-Eiberger, 2003).

One of the primary benefits of protective netting is the reduction in solar radiation reaching the orchard environment underneath it. Protective netting has been reported to modify the orchard environment with respect to light intensity and canopy temperature, relative humidity and soil temperature (Kalcsits *et al.,* 2017).

The light environment of an apple orchard influences fruit quality, including fruit colour (Mupambi *et al.,* 2018). Food colour (along with appearance) plays an undeniably important role in the process of product quality and acceptability evaluation (Little, 1975). Fruit quality is of particular interest to the producers and different techniques has been applied to enhance the apple fruit quality (Sharma, 2014; Kumar, 2020).

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Early apple fruit development under photo-selective nets was recently investigated (Boini *et al.,* 2022).

The aim of this study was to investigate the influence of four protective nets with different colours on the colour of the apple fruits grown under the netting.

MATERIALS AND METHODS

The field experiment was carried out in an apple orchard variety Florina, located in Northern Bulgaria, during the year 2023. The planting density was 50 trees per decare. A sod-mulch system is applied to maintain the soil surface and trees were drip irrigated. All trees were grown under the same conditions. The colour of apple fruits, variety Florina, grown under different photo-selective nets, such as black, red, white and yellow was studied (Fig 1) at the Agricultural University of Plovdiv, Bulgaria. The colour of the fruits as determined in terms of hue, saturation and brightness. The effect of white reflective ground cover on colour of the apples was also investigated. For this purpose, the reflective ground cover was applied for the duration of one month, during the fruit ripening period.

To determine the colour and its descriptive values, spectrophotometric measurements were carried out with a CSS-D spectrophotometer, equipped with a CSS-45 sensor from Gigahertz-Optic. Fig 2 shows a diagram of the experimental set-up for determining the colour characteristics of apple fruits, variety Florina.

All measurements and calculations were made based on the spectral distribution of the light reflected from the surface of the apple fruits. The results are presented using CIE chromaticity diagrams.

RESULTS AND DISCUSSION

The spectrophotometric measurements showed that the dominant colour of the apples was yellow and the covering colour of the skin of the fruit falls in the orange section of the spectrum. Table 1 presents the colour coordinates of the measurements of the fruits grown under a different colour photo-selective net, in different coordinate systems.



Fig 1: The apple trees under nets.

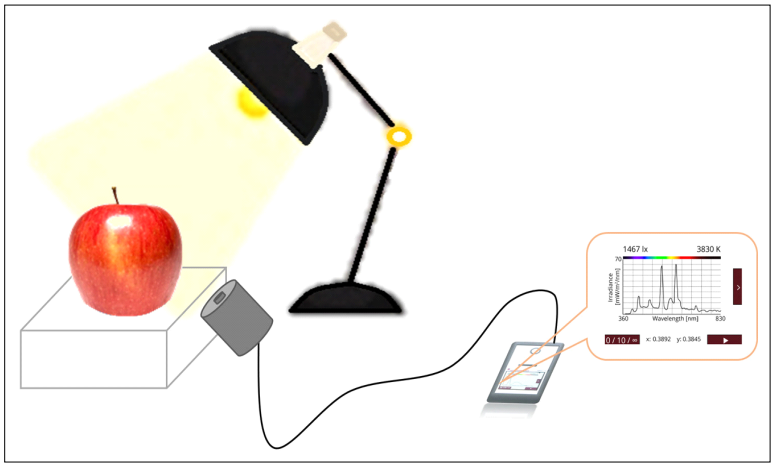

Fig 2: Schematic of an experimental setup for determining colour perception.

Table 1: Results of measurements of colour coordinates of apple fruits variety Florina, grown under different colour photo-selective nets.

	x	y	u′	v′	X	Y	Z
Black net	0.4212	0.37447	0.25332	0.50671	0.32444	0.28858	0.15773
Black net and cover	0.44154	0.37255	0.2681	0.50898	0.33821	0.28562	0.142757
Red net	0.44275	0.37867	0.26598	0.51182	0.3113	0.26613	0.12548
Red net and cover	0.46328	0.37612	0.28135	0.5139	0.27859	0.22611	0.096823
White net	0.43383	0.37528	0.26151	0.50899	0.35216	0.30465	0.15479
White net and cover	0.45401	0.38012	0.27296	0.51418	0.2868	0.24004	0.104684
Yellow net	0.45667	0.37886	0.27531	0.51401	0.34575	0.28736	0.126377
Yellow net and cover	0.45158	0.38023	0.271 25	0.51385	0.32718	0.27535	0.12156

Colour coordinates are represented by the 1931 CIE chromaticity diagram. (x, y), 1976 CIE uniform colour scale (u′, v′) and the values of the tristimulus colour matching functions XYZ (three-dimensional colour space). Fig 3 shows the exact locations of the measurements, relative to the distribution of the colour space (x, y).

The results showed that the apple skin colour and intensity change, are dependent on the colour of the photo-selective net used. The range of variation of the spectral colour by wavelengths, as well as its intensity, was determined. The results are presented graphically in Fig 4.

As a summary of the obtained results, the most intense was the colour of apples, grown under a yellow net and the least intense was the apple colour when a white net and a reflective ground cover was used.

Fig 4 shows that the colour of the apple skin varies in the range 606 nm - 620 nm and the intensity varies from 0.00396 to 0.00493 for fruits grown under black photo-selective net.

When a black net is used to cover the fruit trees, together with a reflective ground cover, the apple colour ranges from 615 nm to 625 nm and the intensity varies from 0.00371 to

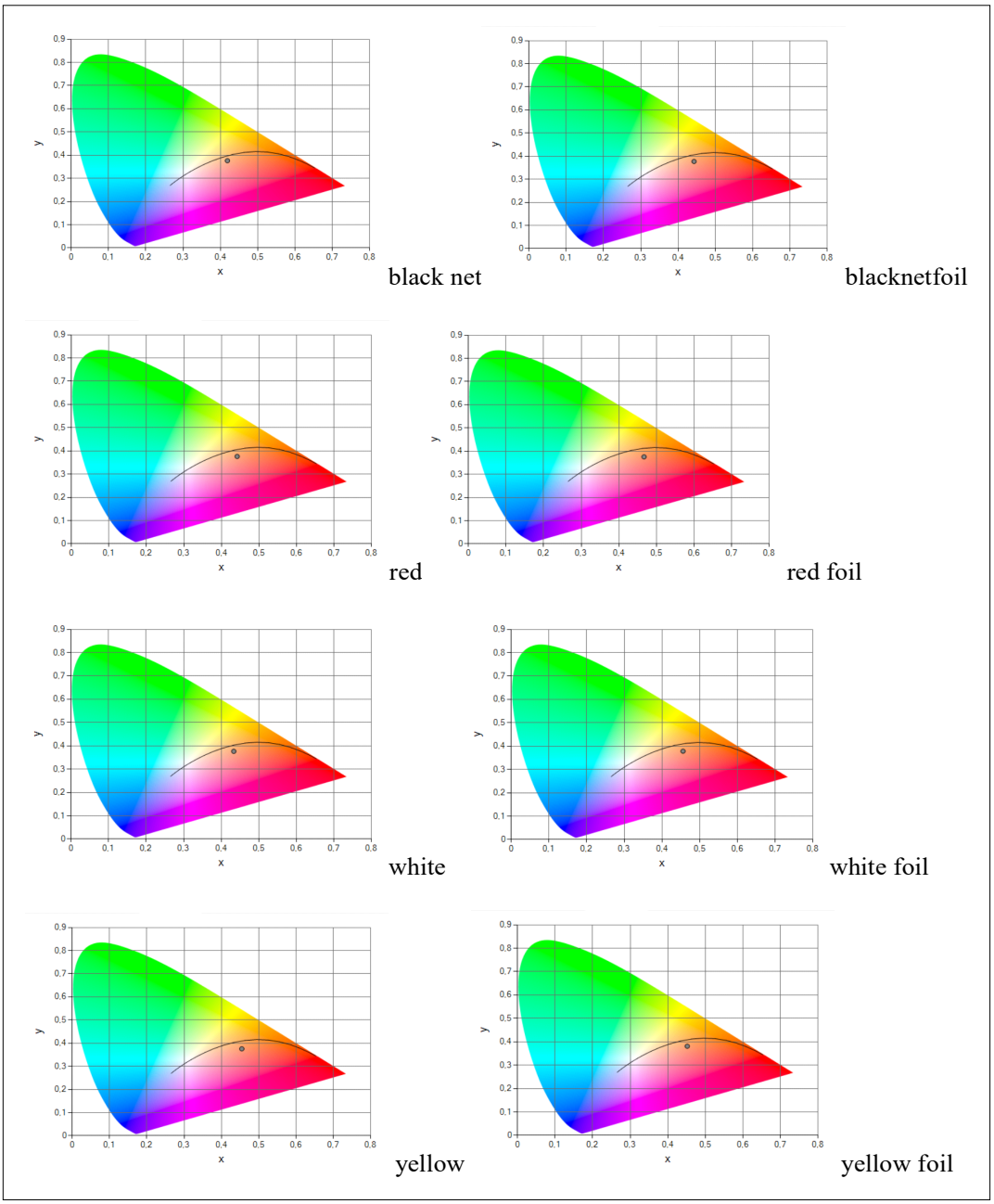

Fig 3: Colour diagrams of the studied apples, grown under different photo-selective nets, with and without the presence of a ground cover.

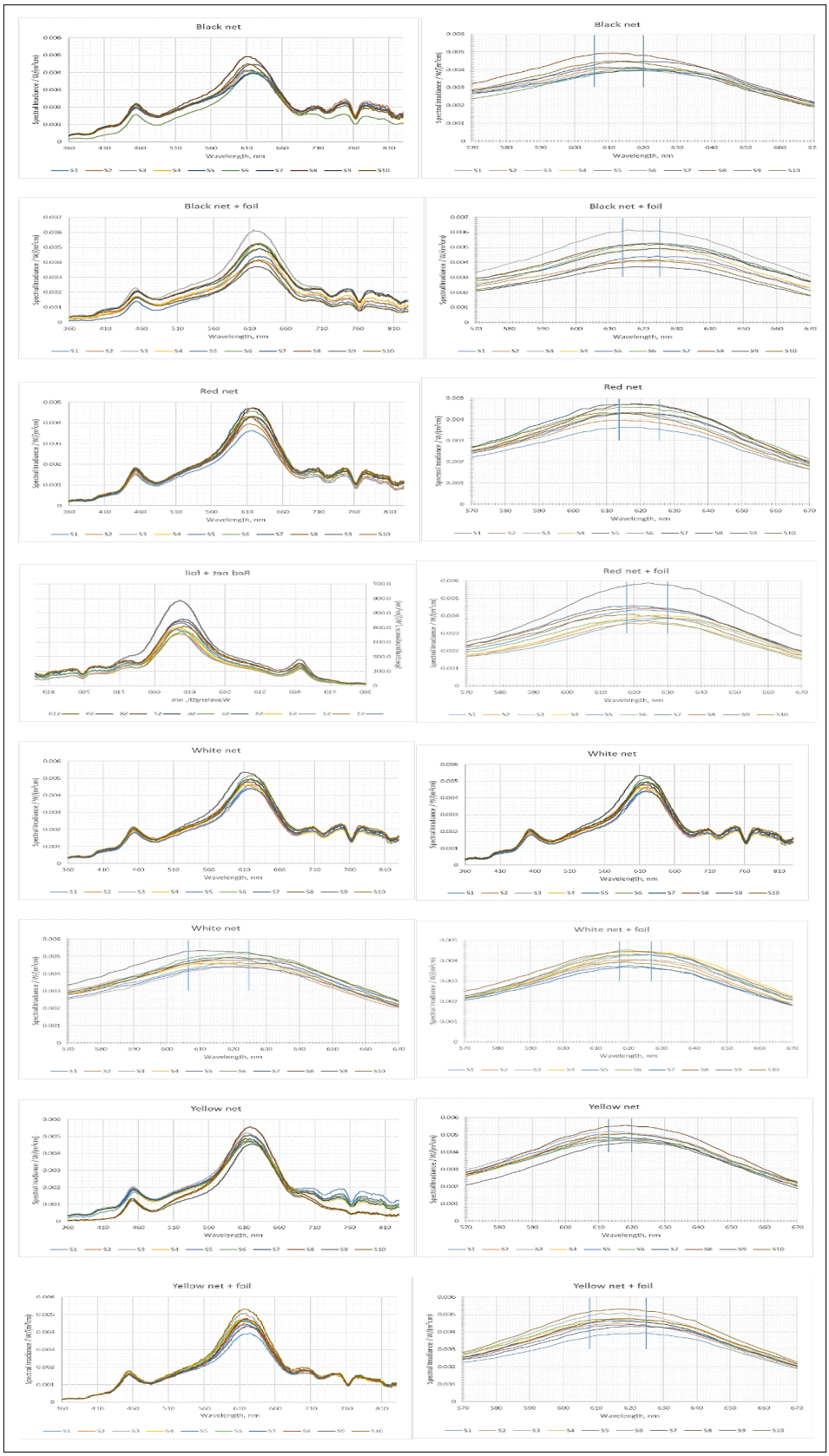

Fig 4: Spectral distribution of reflectance of apple fruits grown under different nets.

0.00616. It is shown that the average spectral colour shifts is 8 nano-meters, *i.e.* a change in the colour shade of the skin of the fruit.

When a red photo-selective net is used, the apple colour ranges from 613 nm to 624 nm and the intensity from 0.00362 to 0.00474. When red photo-selective net is used with a reflective ground cover, the colour ranges from 619 nm to 630 nm and the intensity varies from 0.00359 to 0.00587. In this case the average colour shift was 5 nanometres.

When a white photo-selective net is used, the colour ranges from 607 nm to 625 nm and the intensity from 0.00438 to 0.00534. When a white net is used with a reflective ground cover, the fruit colour ranges from 618 nm to 627 nm and the intensity varies from 0.00416 to 0.00454. The average offset that occurs between the two combinations is 4 nanometres.

When the apple trees are covered with a yellow photo-selective net, the colour of the fruits ranges from 613 nm to 620 nm and the intensity varies from 0.00457 to 0.00557. For a yellow net used in combination of a ground reflective cover, the colour ranges from 609 nm to 625 nm and the intensity varies from 0.00394 to 0.00531. The yellow net produces a relatively constant spectral colour of the skin of the fruit, even when combined with reflective ground cover.

It was found that the colour of apple skin, in terms of wavelength, significantly changes when a ground reflective cover was used. Noticeable differences in the intensity of the apple colour were found. The apple colour intensity is higher when only photo-selective nets were used. A deviation from this dependence was observed only for the black net (Fig 5).

The half-width of the maximum of the reflection spectrum from the surface of the apple fruits, as well as the purity of the measured colour compared to the pure spectral colours, were also determined. The data are presented in Table 2.

A correlation analysis was made between the spectral characteristics. The results are presented in Table 3.

The results show that that there was a strong, albeit negative, relationship between the half-width of the reflection peak and the rest of the spectral characteristics, the strongest being for the spectral colour of the apple fruit.

A correlation analysis of colour coordinates and spectral features against tristimulus matching functions

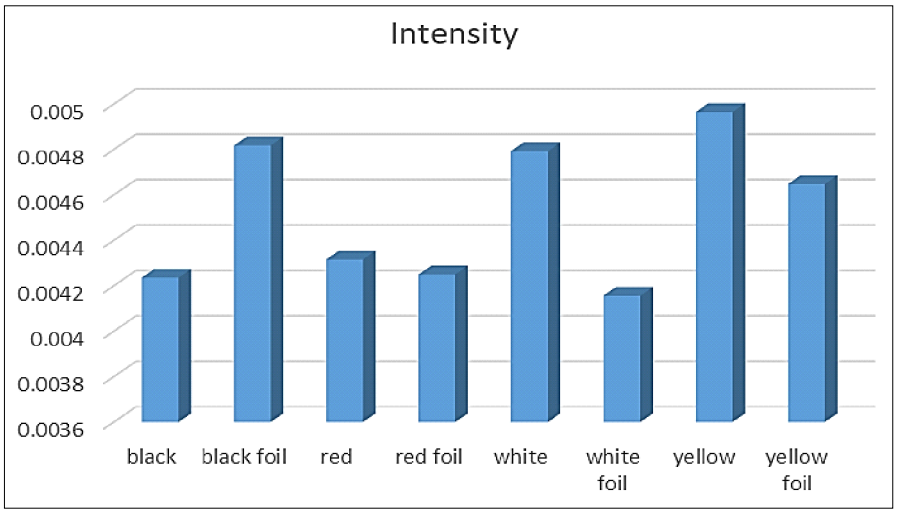

Fig 5: Diagram of averaged values of colour intensity for different variations of photo-selective nets.

Table 2: Characteristics of the spectral reflectance, averaged values.

	Dominant wave length/nm	Peak wave length/nm	FWHM /nm	Purity
Black	587.41	613.89	137.54	0.38784
Black foil	590.4	621.6	108.62	0.44303
Red	588.9	617.71	109.26	0.46507
Red foil	591.47	623.3	92.42	0.5191
White	588.84	617.87	118.96	0.4281
White foil	589.64	621.69	104.19	0.50326
Yellow	590.24	617.01	100.42	0.50749
Yellow foil	589.39	617.78	104.61	0.49636

Table 3: Correlation coefficients of spectral characteristics of apple fruits grown under different photo-selective networks.

	Dominant Wave length / nm	Peak Wave length / nm	Purity
FWHM/nm	-0.91019	-0.94529	-0.7444
Purity	0.77396	0.597896	-
Peak Wave length / nm	0.837032	-	-

Table 4: Correlation coefficients versus tristimulus functions for XYZ colour perception.

	Peak	Intensity	Purity	Dominant	FWHM	x	y	u′	v′
X	-0.5666	0.848581	-0.48046	-0.33769	0.403723	-0.47872	-0.2986	-0.47206	-0.46934
Y	-0.69117	0.690658	-0.66828	-0.54772	0.615578	-0.67804	-0.35726	-0.67667	-0.63505
Z	-0.68458	0.391459	-0.91416	-0.69479	0.846821	-0.90499	-0.59697	-0.88092	-0.89489

of perceived XYZ colours was also performed. The obtained results of this correlation analysis are presented in Table 4.

When examining the correlations between the spectrophotometer data and the tristimulus colour matching functions, a generally strong negative correlation of all metrics with the Z function was observed. This is due to the fact that the anthocyanins, accumulated in the skin of the apple fruits, strongly absorb light with wavelengths in the blue region. This leads to the lower values of the Z function.

CONCLUSION

As a summary of the obtained results, the most intense is the colour of apples, grown under a yellow net and the least intense was the apple colour when a white net and a reflective ground cover used. It was found that the colour of the apple skin, in terms of wavelength, significantly changes when a ground reflective cover was used. Noticeable differences in the intensity of the apple colour were found. The apple colour intensity is higher when only photo-selective nets were used. A deviation from this dependence was observed only for the black net.

There is a strong, albeit negative, relationship between the half-width of the reflection peak and the rest of the spectral characteristics, the strongest being for the spectral colour of the apple fruit. When examining the correlations between the spectrophotometer data and the tristimulus colour matching functions, a generally strong negative correlation of all metrics with the Z function was observed. This is due to the fact that the anthocyanins, accumulated in the skin of the apple fruits, strongly absorb light with wavelengths in the blue region. This leads to the lower values of the Z function.

As a summary of the obtained results, the most intense is the colour of apples, grown under a yellow net and the least intense is the apple colour, when a white net and a reflective ground cover is used.

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Conflict of interest

The authors declare that there are no conflicts of interest regarding the publication of this article. No funding or sponsorship influenced the design of the study, data collection, analysis, decision to publish, or preparation of the manuscript.

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