Arch Biol Sci. 2018;70(3):449-458 https://doi.org/10.2298/ABS171209005Z

Grey relational analysis and fuzzy synthetic discrimination of antioxidant components in peach fruit

Binbin Zhang[1,2,3], Zhijun Shen[2,3], Ruijuan Ma[2,3], Juan Yan[2,3] and Mingliang Yu[1,2,3,*]

[1] *College of Landscape Architecture, Nanjing Forestry University*, Nanjing 210037, P.R. China

[2] *Institute of Pomology, Jiangsu Academy of Agricultural Sciences*, Nanjing 210014, P.R. China

[3] *Jiangsu Key Laboratory for Horticultural Crop Genetic Improvement*, Nanjing 210014, P.R. China

***Corresponding author**: mly1008@aliyun.com

Received: December 9, 2017; **Revised**: January 19, 2018; **Accepted**: January 30, 2018; **Published online**: February 9, 2018

Abstract: Free phenolic compounds and total phenolic content were quantified using four stages of four blood-flesh and four non-blood-flesh peach fruits. Data were used to assess the oxidation resistance using grey relational analysis and fuzzy synthetic discrimination methods. Data from equal-weight and weighted evaluations calculated using both grey relational analysis and fuzzy synthetic discrimination were very similar. The weighted relational grade and weighted evaluation value of the overall resistance to fruit oxidation were ordered according to the weight coefficient method, which demonstrated that there were discrepancies in the ranking of oxidation resistance of the tested varieties between early and late fruit developmental stages. During fruit development, the blood-flesh varieties showed a relatively high overall resistance to oxidation, with the highest observed in Beijingyixianhong. The results suggest that both grey relational analysis and fuzzy synthetic discrimination have high applicability in assessing the resistance to oxidation of peach varieties.

Key words: blood-flesh peach; resistance to oxidation; grey relational analysis; fuzzy synthetic discrimination; fruit ripening

INTRODUCTION

Public awareness of current improved concepts in nutrition is increasing and leading to an informed choice of healthier diets. Fruits and vegetables are attractive nutrient sources because of their rich content of phenolic compounds with antioxidant activity [1-5]. Phytochemicals such as flavonoids and other phenolics in fruits or vegetables may contribute to the prevention of some diseases, and those with antioxidant activity can reduce the incidence of oxidative damage caused by free radicals [6]. Tremendous efforts have been made in the application of phenols and other bioactive substances for the prevention of cancer, cardiovascular and other chronic diseases [7-10]. Fruit polyphenols include a wide range of compounds with antioxidant activity, such as hydroxycinnamates, flavan-3-ols, gallic acid derivatives, flavonols and anthocyanins [6]. In fruits, blueberries are widely recognized as having a high resistance to oxidation [11,12].

Research into the antioxidative activity of blood-fleshed fruit has increased in recent years. Hpvasantha et al. [13] reported that the antioxidant capacity varies between red-fleshed apples and other commercial cultivars. Vizzotto et al. [14] showed that the anthocyanin content, phenolic content and antioxidant activities in blood-flesh peaches were higher than in light-colored flesh varieties. In addition, a strong correlation was found between the total content of phenolic compounds and antioxidant activity in blood-flesh peaches [15]. Mature fruits were often used as materials for testing fruit oxidant resistance, however, only a few studies focused on fruit antioxidant activity changes during fruit growth and development. In addition, because various substrates, system compositions and analytical methods have been employed to evaluate the antioxidant capacities of fruits, it remains difficult to directly compare and interpret data from different studies [16].

Since its establishment, grey relational analysis [17] has been extensively employed in the field of agricultural research, including trait evaluation [18,19], and for identification of resistance to pathogens [20].

How to cite this article: Zhang B, Shen Z, Ma R, Yan J, Yu M. Grey relational analysis and fuzzy synthetic discrimination of antioxidant components in peach fruit. Arch Biol Sci. 2018;70(3):449-58.

It is closer to a scientific method to synthetically evaluate fruit characteristics using multiple quality indices of different varieties based on mathematical methods than to evaluate a single index. However, grey relational analysis has seldom been used to evaluate the overall oxidation resistance in fruits. In the present study, grey relational analysis and fuzzy synthetic discrimination were used to select peach varieties with high oxidation resistance by combining the indicators of individual phenolic content and the total content of phenols during fruit development in three types of peach with different flesh color. This approach provided a new avenue for the study of overall resistance of fruits to oxidation.

MATERIALS AND METHODS

Plant material

Experiments were performed at the National Fruit Germplasm Repository of Nanjing (32°2' N, 118°52' E, altitude 11 m) in 2016. The region has a subtropical monsoon climate characterized by an annual average temperature of 15.7°C (and an annual accumulated temperature around 4800°C), an annual precipitation of 1000-1100 mm, an average of 1900 h of sunlight per year, and an annual frost-free period of 220-240 days. Adult trees of four blood-flesh peach varieties (Heiyoutao, Tianjinshuimi, Yejihong and Beijingyixianhong) and four non-blood-flesh varieties (Baihuashuimi, Xiacui, Galaxy and Ruiguang 18), the rootstock of which were all wild peach, were used for the plant materials. The trees were in an open center with a 3.5 m×5 m planting space and were managed according to normal cultivation practices. The fruits were collected from each variety at four stages of development, designated as S1-S4, and the flesh types and sampling dates are shown in Supplementary Table S1. Ten fruits of each variety of comparable size, ripeness and no sign of insect or pathogen infection were randomly collected from the orchard between 7:00 and 8:00 am to maintain a lower respiratory intensity, and were cooled to 4°C in an ice box. For each developmental stage of each peach variety, 30 fruits were collected and used for all analyses with three replicates. From each peeled fruit, adaxial flesh on both sides of the suture was collected, minced, homogenized, frozen in liquid nitrogen and stored at -80°C until analysis.

Determination of the free phenol content

Extraction buffer (5 mL) containing 0.1% (v/v) H_3PO_4 (Sigma-Aldrich, St. Louis, USA) in methanol (Sigma-Aldrich, St. Louis, USA) (both chromatographic grade) was added to the ground pulp sample of 1.0 g. Samples were then subject to ultrasonic treatment (XO-5200DT, Atpio corporation, Nanjing, China) in the dark for 10 min before centrifugation at 13000x*g* for 5 min at 4°C (Centrifuge 5810 R, Eppendorf AG, Hamburg, Germany) and filtration of the supernatant. The content of individual phenolics (chlorogenic acid, neochlorogenic acid, catechin, epicatechin, ferulic acid, rutin, quercetin) in peach-flesh extracts was determined by chromatography using an Agilent 1100 HPLC system (Agilent Technology, USA) equipped with a VWD UV detector and an Agilent ZORBAX SB-C_{18} column (4.6 mm×250 mm, 5 μm) (Agilent Technology, USA). The detection wavelength was 280 nm and the injection volume was 5 μL. The sample contents of individual phenolic compounds were determined from the standard curves of each, and the total phenolic content was calculated as the sum of the individual phenols. The standard curves were all created from chromatographically pure chemicals purchased from Sigma-Aldrich Corporation (St. Louis, USA), which were dissolved in extraction buffer to concentrations of 1000, 500, 100, 50, 10, 5, 1, 0.5, 0.1, 0.05 and 0.01 mg/L and subjected to chromatography. Linear regression was carried out between the peak areas and the amount of each standard chemical to create the standard curves [21].

Data processing and analysis

Correlation analysis and determination of the weight coefficient

The correlation of eight individual indicators in all tested peach varieties was calculated using SPSS (version 20.0, Chicago, USA). The coefficient of variation (CV) for each indicator was determined. $CV = s / \bar{x}$, where s indicates the standard deviation and $\bar{x}$ the average. CV served as the weightings to obtain the weight coefficient w_j of each indicator, j, after normalization.

Grey relational analysis

The eight tested peach varieties were considered as one grey system and each variety as one factor in the system. To comparatively evaluate the antioxidant capacities of the peach varieties, the best values of individual indicators in S1 and S4 stages were combined to create an ideal, virtual variety [17], which was designated as X_0, and the individual indicators in the eight varieties constituted the comparison sequence X_i (i = 1, 2, … n, where n is the number of tested varieties). After the initialization of all the data, the correlation coefficient between the comparison sequence and reference sequence was obtained using equation (1) [17] and the equal-weight relational grade and weighted evaluation value were then calculated using equations (2) and (3), respectively.

$$\varepsilon_i(k)=\frac{\min_i \min_k |x_0(k)-x_i(k)|+\rho \max_i \max_k |x_0(k)-x_i(k)|}{|x_0(k)-x_i(k)|+\rho \max_i \max_k |x_0(k)-x_i(k)|} \quad (1)$$

$$r_i=\frac{1}{n}\sum_{k=1}^{n}\varepsilon_i(k) \quad (2)$$

$$r_i'=\sum_{k=i}^{n} w_j\varepsilon_i(k) \quad (3)$$

where n is the number of indicators, $\varepsilon_i(k)$ represents the correlation coefficient of X_i to X_0, and ρ is the resolution coefficient, generally between 0 and 1, but as is usual in analyses of agricultural systems [22], this was set to 0.5; $x_i(k)$ indicates the value of k indicators of the ith variety after data initialization, and $|x_0(k)-x_i(k)|$ represents the absolute difference between the k indicator of the ith variety and the reference indicator; r_i is the equal-weight relational grade, r_i' indicates the weighted relational grade and w_j represents the weight coefficients for each indicator.

Fuzzy synthetic discrimination

The membership grade of each indicator of the tested varieties was determined using equation (4) to obtain the fuzzy transition matrix [23]. In addition, the equal-weight comprehensive evaluation set (B) and the weighted comprehensive evaluation set (B') were calculated using equations (5) and (6), respectively,

$$r_{ij}=\frac{X_{ij}-\min(X_{ij})}{\max(X_{ij})-\min(X_{ij})} \quad (i=1,2,\ldots m; j=1,2,\ldots n) \quad (4)$$

$$B=\frac{1}{n}\sum_{i=1}^{n}R \quad R=(r_{ij}) \quad (5)$$

$$B'=\sum_{i=1}^{n}w_jR \quad R=(r_{ij}) \quad (6)$$

where n is the number of indicators, m indicates the number of tested varieties, X_{ij} represents the value of the jth indicator of the ith variety, and max (X_{ij}) and min (X_{ij}) are the maximal and minimal value of the jth indicator of the mth variety, respectively.

Spearman's rank correlation analysis

Spearman's rank correlation analysis was carried out between the equal-weight relational grade and weighted relational grade, and equal-weight comprehensive evaluation set (B) and the weighted comprehensive evaluation set (B') [24,25] using equation (7),

$$r_s=1-\frac{6\sum_{i=1}^{m}d_i^2}{m^3-m} \quad (7)$$

where d_i represents the ranking difference between the equal-weight relational grade and weighted relational grade, or between the equal-weight and weighted evaluation values, r_s indicates the spearman rank correlation coefficient and m is the number of tested varieties.

RESULTS

Changes in the content of phenolic compounds during fruit development in different peach varieties

Alterations in the content of individual phenols and total phenol during fruit development in the various peach varieties are shown in Fig. 1. In Heiyoutao, the content of chlorogenic acid, epicatechin, ferulic acid

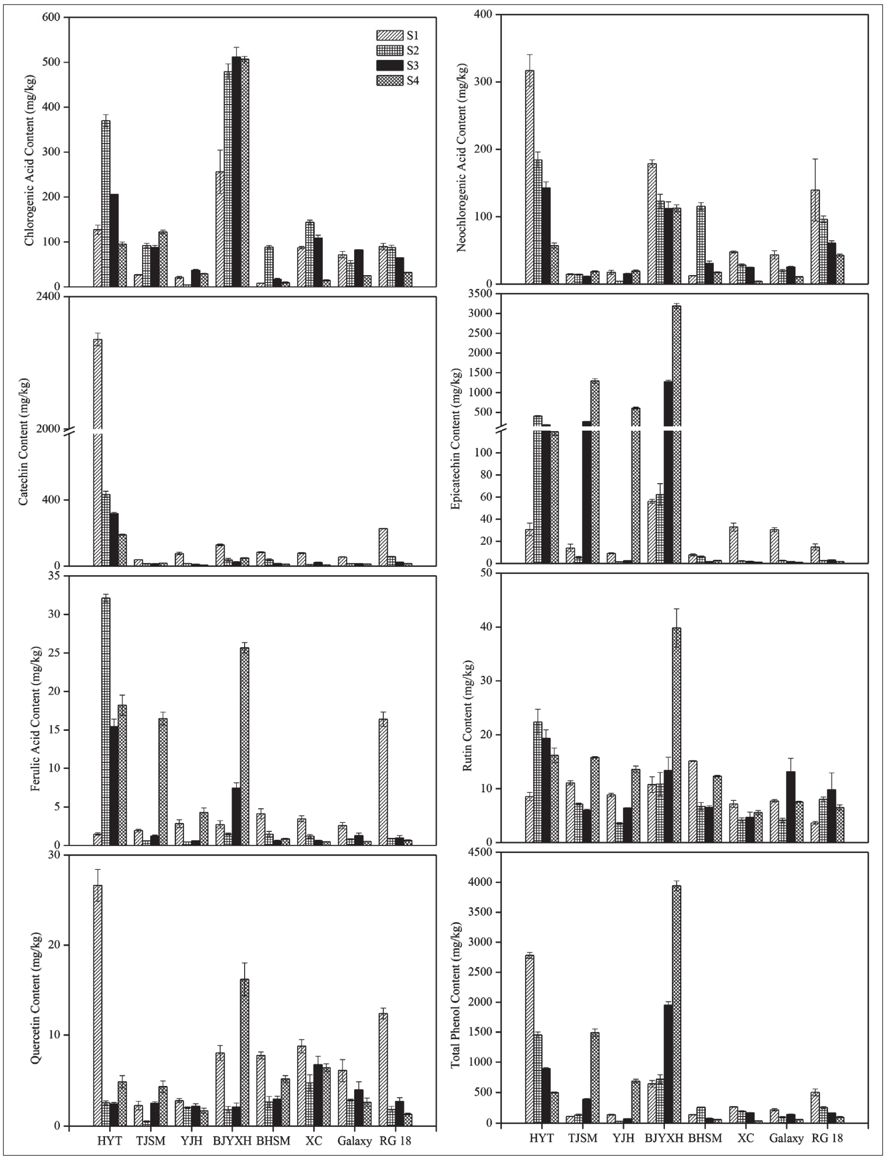

Fig. 1. Alterations in the content of individual and total phenolics during fruit development in different peach varieties.

and rutin was relatively low in S1 but increased in S2 and decreased in the later stages. Neochlorogenic acid, catechin, quercetin and total phenol showed different patterns, with the highest content in S1 and with the exception of quercetin, which decreased to the lowest values in S4.

In Tianjinshuimi, Yejihong and Beijingyixianhong, the chlorogenic acid content was relatively high in the later stage, and the highest content of epicatechin, ferulic acid, rutin and total phenols was observed in S4. The catechin content in S1 was higher than that in S4 in three varieties. The content of quercetin in Tianjinshuimi and Beijingyixianhong decreased and was followed by an increase to the highest level in S4, while in Yejihong, quercetin was high in S1 and lowest in S4. This indicated that there were capacity differences in the accumulating phenolics of blood-flesh peach varieties.

Neochlorogenic acid, chlorogenic acid, catechin, epicatechin, ferulic acid and the total phenolic content in non-blood-flesh peach varieties exhibited a general trend of reduction during fruit development.

The highest quercetin levels were found in S1 in all four varieties, followed by a significant reduction in S2. Differences among these four varieties, however, were observed during the mid-late stages, where Baihuashuimi quercetin levels were highest in S4, while the other three varieties demonstrated higher levels in S3. This indicated that most phenolics of non-blood-flesh peach varieties had the same tendency during the process of fruit development.

When comparing the eight different varieties, the phenolic indicators of Beijingyixianhong were all significantly higher than those of the other varieties, except for catechin at fruit maturity (S4), indicating its high resistance to oxidation. In addition, the catechin content in Heiyoutao was higher than in the other varieties. It can be judged that flesh color differences of the various peach varieties might be the main reason for the different contents of phenolic compounds (Fig. 2).

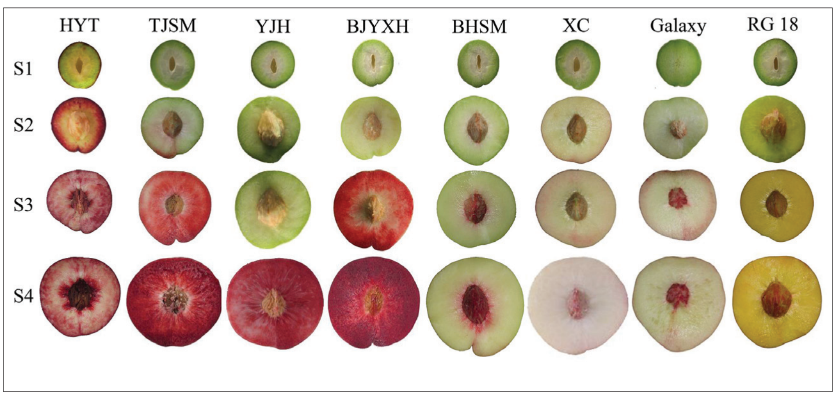

Fig. 2. Flesh appearance of different peach varieties during fruit development stages.

Correlation analysis of the contents of individual phenolic compounds with total phenols

Correlation analysis was performed based on the eight indicators in eight varieties (Table 1). The content of the seven individual indicators all showed a significantly positive correlation with the total phenol content, suggesting that the variation in total phenolic content in peach fruit is closely related to the accumulation of individual phenols.

Grey relational analysis

To evaluate the different peach varieties for phenolic content and potential resistance to oxidation, the best values of the individual indicators at S1 and S4 stages were determined and used as the reference variety, X_0, and a grey relational analysis to X_0 was performed for the eight tested varieties. The order of the resulting correlativity for each indicator and overall oxidation resistance in peach varieties (Tables 2 and 3) indicates that the relational grade of the 8 varieties to the reference variety varied. Similar differences in the oxidation resistance of peach varieties at S1 and S4 were observed regardless of whether equal-weight or weighted relational grades were applied. In S1, the top three varieties were Heiyoutao, Beijingyixianhong and Ruiguang 18, whereas Galaxy, Tianjinshuimi and Yejihong ranked bottom. In S4, the top four varieties were Beijingyixianhong,

Table 1. Correlation coefficients of individual phenolic compounds with total phenols in the tested varieties.

	Chlorogenic acid	Neochlorogenic acid	Catechin	Epicatechin	Ferulic acid	Rutin	Quercetin	Total phenol
Chlorogenic acid	1							
Neochlorogenic acid	0.532**	1						
Catechin	0.079	0.759**	1					
Epicatechin	0.631**	0.139	-0.060	1				
Ferulic acid	0.532**	0.376*	0.097	0.592**	1			
Rutin	0.604**	0.270	0.040	0.804**	0.747**	1		
Quercetin	0.159	0.617**	0.761**	0.270	0.198	0.230	1	
Total phenol	0.709**	0.625**	0.495**	0.821**	0.605**	0.735**	0.628**	1

**Significant at the P≤0.01 level. *Significant at the P≤0.05 level.

Table 2. The relational grade and its ranking for tested and reference varieties during the early stage (S1).

Indices	X_1 HYT	X_2 TJSM	X_3 YJH	X_4 BJYXH	X_5 BHSM	X_6 XC	X_7 Galaxy	X_8 RG 18	Weight value
Chlorogenic acid (k_1)	0.4943	0.3543	0.3489	1	0.3367	0.4273	0.4056	0.4308	0.1078
Neochlorogenic acid (k_2)	1	0.3400	0.3421	0.5297	0.3384	0.3664	0.3628	0.4678	0.1308
Catechin (k_3)	1	0.3333	0.3371	0.3424	0.3379	0.3373	0.3350	0.3530	0.2419
Epicatechin (k_4)	0.5203	0.3959	0.3699	1	0.3629	0.5424	0.5181	0.4002	0.0775
Ferulic acid (k_5)	0.3507	0.3578	0.3727	0.3709	0.3962	0.3838	0.3681	1	0.1282
Rutin (k_6)	0.5305	0.6468	0.5421	0.6298	1	0.4835	0.5011	0.3928	0.0427
Quercetin (k_7)	1	0.3492	0.3541	0.4124	0.4089	0.4225	0.3886	0.4786	0.0964
Total phenol (k_8)	1	0.3384	0.3409	0.3896	0.3410	0.3521	0.3477	0.3749	0.1747
Equal-weight relational grade	0.7370	0.3895	0.3760	0.5843	0.4402	0.4144	0.4034	0.4873	
No.	1	7	8	2	4	5	6	3	
Weighted relational grade	0.8050	0.3603	0.3572	0.5196	0.3829	0.3897	0.3792	0.4806	
No.	1	7	8	2	5	4	6	3	

Table 3. The relational grade and its ranking for tested and reference varieties during the late stage (S4).

Indices	X_1 HYT	X_2 TJSM	X_3 YJH	X_4 BJYXH	X_5 BHSM	X_6 XC	X_7 Galaxy	X_8 RG 18	Weight value
Chlorogenic acid (k_1)	0.3812	0.3973	0.3467	1	0.3376	0.3397	0.3447	0.3480	0.1555
Neochlorogenic acid (k_2)	0.5039	0.3749	0.3768	1	0.3719	0.3417	0.3564	0.4463	0.0976
Catechin (k_3)	1	0.3567	0.3423	0.4036	0.3485	0.3436	0.3500	0.3529	0.1526
Epicatechin (k_4)	0.3418	0.4568	0.3820	1	0.3334	0.3333	0.3333	0.3334	0.1669
Ferulic acid (k_5)	0.6326	0.5828	0.3750	1	0.3408	0.3376	0.3378	0.3391	0.1170
Rutin (k_6)	0.4572	0.4533	0.4314	1	0.4202	0.3675	0.3816	0.3741	0.0725
Quercetin (k_7)	0.4156	0.4044	0.3582	1	0.4223	0.4520	0.3731	0.3523	0.0868
Total phenol (k_8)	0.3641	0.4456	0.3770	1	0.3367	0.3356	0.3368	0.3391	0.1511
Equal-weight relational grade	0.5120	0.4340	0.3737	0.9255	0.3639	0.3564	0.3517	0.3606	
No.	2	3	4	1	5	7	8	6	
Weighted relational grade	0.5163	0.4325	0.3699	0.9090	0.3555	0.3503	0.3479	0.3558	
No.	2	3	4	1	6	7	8	5	

Heiyoutao, Tianjinshuimi and Yejihong, while Xiacui and Galaxy ranked the lowest. Differences between the equal-weight or weighted methods were only observed in mid-ranking varieties: the ranking of Baihuashuimi and Xiacui varieties in S1 and Baihuashuimi and Ruiguang 18 in S4 were interchangeable, depending on the method used.

The Spearman rank correlation coefficients, r_s, of S1 and S4, calculated by the equal-weight or weighted method were both 0.98, indicating agreement between the two methods and that such a ranking could characterize the order of overall resistance to oxidation in the eight peach varieties. These results demonstrated that the antioxidative capacities of the various peach varieties during early development were significantly different from that of mature fruits. In addition, blood-flesh peaches possessed a stronger resistance to fruit oxidation at maturity.

Fuzzy synthetic discrimination

The results of fuzzy synthetic discrimination for the overall resistance to oxidation of the peach varieties in S1 and S4 are shown in Tables 4 and 5. The rankings calculated from equal-weight and weighted methods of the peach varieties were identical. In S1, the antioxidative capacities of the peach varieties were ranked by fuzzy synthetic discrimination as Heiyoutao, Beijingyixianhong, Ruiguang 18, Xiacui, Galaxy, Baihuashuimi, Tianjinshuimi and Yejihong, while in S4 the order was

Table 4. Fuzzy synthetic discrimination of peach varieties during the early stage (S1).

Indices	X_1	X_2	X_3	X_4	X_5	X_6	X_7	X_8	Weight value
	HYT	TJSM	YJH	BJYXH	BHSM	XC	Galaxy	RG 18	
Chlorogenic acid (k_1)	0.4806	0.0750	0.0529	1	0	0.3198	0.2560	0.3293	0.1078
Neochlorogenic acid (k_2)	1	0.0075	0.0165	0.5459	0	0.1158	0.1018	0.4181	0.1308
Catechin (k_3)	1	0	0.0167	0.0398	0.0203	0.0178	0.0073	0.0836	0.2419
Epicatechin (k_4)	0.4747	0.1307	0.0295	1	0	0.5195	0.4702	0.1463	0.0775
Ferulic acid (k_5)	0	0.0308	0.0912	0.0838	0.1769	0.1327	0.0731	1	0.1282
Rutin (k_6)	0.4273	0.6466	0.4534	0.6197	1	0.3090	0.3560	0	0.0427
Quercetin (k_7)	1	0	0.0213	0.2357	0.2246	0.2668	0.1561	0.4156	0.0964
Total phenol (k_8)	1	0	0.0108	0.1985	0.0112	0.0585	0.0402	0.1469	0.1747
Equal-weight evaluation values	0.6728	0.1113	0.0865	0.4654	0.1791	0.2175	0.1826	0.3175	
No.	1	7	8	2	6	4	5	3	
Weighted evaluation values	0.7507	0.0508	0.0492	0.3609	0.0939	0.1603	0.1258	0.3157	
No.	1	7	8	2	6	4	5	3	

Table 5. Fuzzy synthetic discrimination of peach varieties during the late stage (S4).

Indices	X_1	X_2	X_3	X_4	X_5	X_6	X_7	X_8	Weight value
	HYT	TJSM	YJH	BJYXH	BHSM	XC	Galaxy	RG 18	
Chlorogenic acid (k_1)	0.1727	0.2271	0.0398	1	0	0.0098	0.0312	0.0454	0.1555
Neochlorogenic acid (k_2)	0.4890	0.1348	0.1414	1	0.1235	0	0.0627	0.3561	0.0976
Catechin (k_3)	1	0.0613	0	0.2310	0.0271	0.0055	0.0335	0.0455	0.1526
Epicatechin (k_4)	0.0371	0.4053	0.1909	1	0.0005	0.0001	0	0.0003	0.1669
Ferulic acid (k_5)	0.7040	0.6353	0.1506	1	0.0143	0	0.0012	0.0068	0.1170
Rutin (k_6)	0.3101	0.2990	0.2342	1	0.1980	0	0.0581	0.0277	0.0725
Quercetin (k_7)	0.2352	0.1989	0.0255	1	0.2560	0.3407	0.0860	0	0.0868
Total phenol (k_8)	0.1179	0.3716	0.1654	1	0.0051	0	0.0053	0.0155	0.1511
Equal-weight evaluation values	0.3832	0.2917	0.1185	0.9039	0.0781	0.0445	0.0347	0.0621	
No.	2	3	4	1	5	7	8	6	
Weighted evaluation values	0.3765	0.2949	0.1137	0.8826	0.0553	0.0319	0.0287	0.0539	
No.	2	3	4	1	5	7	8	6	

Beijingyixianhong, Heiyoutao, Tianjinshuimi, Yejihong, Baihuashuimi, Ruiguang 18, Xiacui and Galaxy.

It was shown that the rankings of the peach varieties obtained by equal-weight and weighted evaluation in fuzzy synthetic discrimination were consistent. Both rank correlation coefficients, r_s, of S1 and S4 were 1 according to the Spearman rank correlation analysis, indicating that this approach is useful for grading the antioxidative capacity of the eight peach varieties. In agreement with the rankings observed with grey relational analysis, Beijingyixianhong and Heiyoutao exhibited a relatively high resistance to oxidation at both early and late stages of development, and the resistance of both Tianjinshuimi and Yejihong was weak during S1 but higher in mature fruit (S4).

DISCUSSION

A relational grade is a measure of the relatedness between two systems or factors and describes the relative changes in the process of system development. Significant relational grades tend to occur when changes are consistent, whereas inconsistent changes promote insignificant grades. Relational grading also compensates for the shortcoming caused by the systematic analysis of mathematical statistics [17,26,27]. Based on this concept, the present study created the reference variety with the overall desired traits to perform a grey relational analysis of the antioxidant capacities of different peach varieties. Zadeh [23] proposed the concept of fuzzy sets and provided the definition of membership function, which served as a mathematical model to describe the intermediate transition of differences in fuzzy examples. In recent years, the membership function has been continuously improved and is widely used [28,29]. In the present study, we utilized fuzzy synthetic discrimination to evaluate oxidation resistance in peach varieties, which provides a new approach to the study of overall resistance to oxidation in peach fruit.

The application of grey relational analysis and fuzzy synthetic discrimination in the screening of crop germplasm has increased in recent years. Ma et al. [30] used 20 traits related to fruit quality of *Ziziphus jujube* Dongzao to comprehensively evaluate 20 germplasms, and 5 germplasms with a high overall quality were selected by combining grey relational analysis with weighted values for the creation of an ideal reference variety. Hou et al. [31] compared the advantages and disadvantages of the methods of fuzzy comprehensive evaluation, the analytic hierarchy process and grey correlation degree analysis in the evaluation of fruit quality. They identified the main factors affecting the comprehensive quality of fruit and showed that the comprehensive evaluation of fruit quality by data mining simplified the evaluation procedure and enabled the rapid determination of fruit quality. In the present study, the proportion of different indicators in the comprehensive evaluation of antioxidant capacity of peach fruit varied, so it was more logical and practical to evaluate the comprehensive trait from weighted values than with equal-weight values. The weight coefficients of the different indicators need to be determined when calculating the weighted relational grades and evaluation values. Determining the weight coefficient by a subjective weighting method is influenced by the knowledge structure and preferences of the evaluators, which is highly subjective. Therefore, in the present study, the coefficient of variation was used to determine the weight coefficient and thereby avoid subjective judgment of the results. The data obtained demonstrated that the weighted relational grades and weighted evaluation values of fruit traits in peach varieties at stage S4 were ranked as Beijingyixianhong, Heiyoutao, Tianjinshuimi and Yejihong, followed by white- or yellow-flesh-type varieties. This suggested that overall oxidation resistance of mature blood-flesh peaches was stronger than that of white- and yellow-colored flesh varieties, and that Beijingyixianhong exhibited the highest resistance to oxidation of the four blood-flesh peach varieties tested.

It has been demonstrated that the antioxidative capacity of fruit is closely related to its phenolic content [32-36]. In the present study, we have shown that the total phenolic content of Tianjinshuimi, Yejihong and Beijingyixianhong gradually increased with fruit development, revealing that their antioxidative capacity is greatly dependent on fruit maturation. This trend was opposite in Heiyoutao, Baihuashuimi, Xiacui, Galaxy and Ruiguang 18, suggesting that the main phenolic compounds were rapidly synthesized in the early stage of fruit development, but less so during later stages, or were degraded at a faster rate [37]. In addition, although the total phenolic content of Heiyoutao at S4 was lower than at other stages, its average level was significantly higher than that of white- and yellow-flesh varieties, pointing to its relatively high resistance to oxidation at fruit maturity and giving it a ranking in second place.

CONCLUSIONS

The selection of evaluation methods and evaluation indicators forms the basis for the evaluation of fruit characteristics by a scientific method. Indicators associated with the antioxidative capacity of peach fruit, namely individual phenolic compounds and total phenolic content, were selected in the current study. In addition, grey relational analysis and fuzzy synthetic discrimination were employed to evaluate and rank the oxidation resistance of eight peach varieties during early and later stages of fruit development. The results obtained using weighted relational grades and weighted evaluation values were consistent, indicating that the combination of grey relational analysis and fuzzy synthetic discrimination is highly applicable in the assessment of fruit quality, and can be widely used in the breeding of peach varieties possessing desirable traits.

Funding: This study was financially supported by the program of National Natural Science Foundation of China (No. 31471848) and Chinese Agricultural Research System (No. CARS-30).

Author contributions: Binbin Zhang and Mingliang Yu conceived and designed the study; Binbin Zhang performed the experiments; Juan Yan performed the data analysis; Binbin Zhang and Mingliang Yu wrote the paper; Zhijun Shen and Ruijuan Ma revised the paper. All authors read and approved the final manuscript.

Conflict of interest disclosure: The authors declare that there is no conflict of interest regarding the publication of this article.

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Supplementary Data

Supplementary Table S1. can be accessed via the following link: http://serbiosoc.org.rs/sup/sup2.pdf