

35个荔枝品种抗氧化活性评价

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摘要:【目的】综合评价荔枝种质资源功能性品质并为抗氧化活性种质筛选提供理论依据。【方法】比较35个荔枝品种成熟果实果肉中多酚、黄酮、维生素C含量, 从铁离子还原能力(FRAP)、二苯代苦味酰基自由基(DPPH)清除能力、氧化自由基吸收能力(ORAC)三个方面分析各品种抗氧化能力差异, 并采用相关性分析、聚类分析对各品种的抗氧化能力进行相关性比较和分类。【结果】(1)不同荔枝品种间多酚、黄酮、维生素C含量存在显著差异($p < 0.01$), 其酚类物质主要以游离态形式存在, 游离酚、结合酚和总酚含量分别为64.92~173.64、2.01~23.45、69.74~186.22 mg·100 g⁻¹, 游离态酚含量占总酚含量的81.5%~97.76%;总黄酮含量介于73.44~331.52 mg·100 g⁻¹;维生素C含量介于6.00~56.33 mg·100 g⁻¹;不同荔枝品种间DPPH清除能力介于71.78%~99.61%, FRAP介于1.18~10.10 μmol·g⁻¹, ORAC介于0.97~39.72 μmol·g⁻¹。(2)荔枝果肉中游离多酚、总酚、总黄酮含量与FRAP、ORAC值均呈极显著正相关($p < 0.01$), 维生素C含量与FRAP呈显著正相关($p < 0.05$);依据相关系数大小排列:游离多酚>总酚>总黄酮>ORAC>FRAP>结合多酚>维生素C>DPPH清除能力;(3)聚类分析依据功能性物质含量及抗氧化活性高低将35个荔枝品种分为4大类。【结论】不同荔枝品种间抗氧化能力存在显著差异($p < 0.01$), 多酚、黄酮类物质是荔枝果肉发挥抗氧化作用的重要物质;‘妃子笑’‘绿纱’‘红绣球’‘井冈红糯’‘岭丰糯’‘金包银’‘状元红’是一类多酚、黄酮物质含量高, 抗氧化活性强的品种。

关键词:荔枝;品种;抗氧化活性;多酚;黄酮;维生素C;聚类分析

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Evaluation of antioxidant activity in pulp of 35 litchi varieties

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Abstract:【Objective】Litchi (*Litchi chinensis* Sonn.) has been cultivated in China for more than 2 300 years, and its cultivated area and yield have always ranked first in the world. After a long period of natural selection and artificial cultivation, a large number of ecotypes and local varieties of litchi have been reserved in China, with abundant germplasm resources. To explore and study phenolic substances and their antioxidant capacity in fruits and vegetables has become a common concern in food, medicine and other fields. Litchi has been regarded as a good nourishing produce since ancient times. Its pulp is rich in polyphenols, vitamin C and other functional nutrients, with high antioxidant capacity. At present, litchi is rich in polyphenols, vitamin C and other functional nutrients, but the research on its functional nutrition is mainly focused on the by-products such as pericarp and core, and the evaluation of nutritional function of fruits with different litchi varieties is less systematic at present. The main purpose of this study was to evaluate the functional quality of litchi germplasm resources and provide theoretical basis

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for the selection of antioxidant germplasm. **【Methods】** The contents of polyphenol, flavone and vitamin C in the pulp of 35 litchi varieties were compared, the differences in antioxidant capacity of each variety were analyzed from the following three aspects: Ferric Ion Reducing Antioxidant Power, DPPH Scavenging Activity and Oxygen Radical Absorbance Capacity, and the correlation analysis and cluster analysis were used to compare and classify the antioxidant capacity of each variety. **【Results】** (1) The contents of polyphenol, flavonoid and vitamin C were significantly different among different litchi varieties ($p < 0.01$). Free phenols mainly existed in free form, the contents of free phenols, binding phenols and total phenols were 64.92-173.64, 2.01-23.45 and 69.74-186.22 mg · 100 g⁻¹ with the coefficient of variation being 21.47%, 43.43% and 21.36%, respectively; and the content of free phenols was 81.5%-97.76% of total phenols. The total flavone content was 73.44-331.52 mg · 100 g⁻¹, with a coefficient of variation of 40.15%; vitamin C content was 6.00-56.33 mg · 100 g⁻¹ with a coefficient of variation of 38.39%; DPPH clearance capacity was 71.78%-99.61% with a coefficient of variation of 7.63%; FRAP was 1.18-10.10 μmol · g⁻¹ with a coefficient of variation of 45.29%; ORAC was 0.97-39.72 μmol · g⁻¹ with a coefficient of variation of 47.77%. (2) The correlation analysis showed that the contents of free polyphenol, total phenol and total flavone in pulp were very significantly positively correlated with FRAP and ORAC ($p < 0.01$), vitamin C content was positively correlated with FRAP ($p < 0.05$), but not with DPPH and ORAC ($p > 0.05$). The correlation coefficient showed: free polyphenols > total phenols > total flavonoids > ORAC > FRAP > binding polyphenols > vitamin C > DPPH clearance capacity. (3) According to the contents of functional substances and the level of antioxidant activity, 35 litchi varieties were divided into four categories by cluster analysis. The first category included seven varieties, i.e., 'Feizixiao' 'Lvsha' 'Hongxiuqiu' 'Jingganghongnuo' 'Lingfengnuo' 'Jinbaoyin' and 'Zhuangyuanhong', and the feature of this category was of the highest contents of total polyphenols, free polyphenols, total flavonoids and the highest level of antioxidant activity of FRAP and ORAC, but lower vitamin C content and DPPH scavenging ability. The second category included 15 varieties, such as 'Diwangnuo' 'Xiyuangularv' 'Huaizhi' 'Chouzhinuomici' 'Guiwei' 'Tianyan' 'Heizhenzhu' 'Shuijingqiu' 'Nuomici' 'Feicui' 'Miaozhongnuo' 'Caomeili' 'Xianpoguo' 'Xianjin-feng' and 'Jizuinuo', which was characterized by high contents of total polyphenols, free polyphenols, binding polyphenols, total flavonoids and strong level of DPPH scavenging ability and oxygen radical absorbance capacity, but low reduction ability of iron ions and the lowest content of vitamin C. The third category included six varieties, containing 'Yujinqiu' 'Baila' 'Yanzhihong' 'Xuehuaizi' 'Beiyuanlv' and 'Lingshanxiangli', which was characterized by the lower contents of total polyphenols, free polyphenols, binding polyphenols and lower level of Oxygen Radical Absorbance Capacity, and the lowest level of DPPH scavenging capacity and reduction ability of iron ions. The fourth category included seven varieties, such as 'Ziniangxi' 'Xiangmili' 'Sanyuehong' 'Baitangyin' 'Hexiachuan' 'Shuidong' and 'Heiye', which was characterized by the lowest content of total polyphenols, free polyphenols, combined polyphenols, total flavonoids and the lowest level of ORAC, but high level of FRAP and the highest level of DPPH scavenging capacity and vitamin C content. **【Conclusion】** There were significant differences in antioxidant capacity among different litchi varieties ($p < 0.01$). Polyphenols and flavonoids were important antioxidants in litchi pulp, while vitamin C was not closely related to the antioxidant capacity of litchi pulp. 'Feizixiao' 'Lvsha' 'Hongxiuqiu' 'JingganghongNuo' 'Lingfengnuo' 'Jinbaoyin' and 'Zhuangyuanhong' were the varieties with high contents of polyphenols and flavonoids as well as the strongest antioxidant activity, while 'Ziniangxi' 'Xiangmili' 'Sanyuehong' 'Bait-

‘angyin’ ‘Xiahechuan’ ‘Shuidong’ and ‘Heiye’ were the varieties with the lowest polyphenol and flavone contents as well as the lowest antioxidant capacity (ORAC). These studies can provide on only the basis for further study on the functional activity of litchi polyphenols, but also the direction for the application of functional components of different litchi varieties and the selection of new litchi varieties with high antioxidant activity.

Key words: Litchi; Varieties; Antioxidant activity; Polyphenols; Flavonoids; Vitamin C; Cluster analysis

荔枝(*Litchi chinensis* Sonn.)在中国已有2300多年的栽培历史^[1],“世界荔枝看中国”,到2018年我国荔枝栽培面积达到54.15万hm²,产量达287.88万t,一直以来栽培面积和产量均居世界首位^[2]。经过长期的自然选择和人工栽培,我国荔枝形成了大量的生态类型和地方品种,种质资源极为丰富。

大量研究结果表明,蔬菜、水果中富含的酚类物质、维生素C等物能够清除人体内过剩的自由基,防止DNA、蛋白质和脂质等大分子被破坏,还能预防癌症、糖尿病和心脑血管疾病的发生^[3],探寻和研究果蔬中酚类物质及其抗氧化能力已成为食品、医药等多个学科领域共同关注的课题。荔枝自古被认为是优良的滋补佳品,其果肉富含多酚类、维生素C等功能性营养化合物,具有较高的抗氧化能力^[4]。目前对荔枝功能性营养的研究也主要集中在果皮果核等副产物上^[5-8],而对果肉部分少有报道,供试的品种也仅限于少量有限的品种^[9],而对不同品种荔枝果实的营养功能性评价还较少开展系统的研究。

因此,笔者通过分析35个荔枝品种的果肉多酚、黄酮、维生素C含量及其果肉抗氧化活性,采用相关性分析、聚类分析来评价各品种的抗氧化能力,对荔枝果肉功能性品质进行综合评判,以期为荔枝原材料的选择和多酚的开发利用并筛选出抗氧化活性强的种质提供理论依据和方向。

1 材料和方法

1.1 材料与仪器

于2018年5—7月分别在广东、广西等省选取35个荔枝品种,作为试验材料,每个品种从3株不同树冠外围随机分别选取30个大小一致、成熟、无病虫害、无损伤的果实,及时运到实验室,液氮研磨后-80℃冷冻保存。其编号、名称、熟性及产地如表

1所示。

试剂:芦丁、没食子酸为色谱纯(HPLC≥98%)。氢氧化钠,草酸,2,6-二氯靛酚,抗坏血酸,浓盐酸、亚硝酸钠、硝酸铝、碳酸钠、甲醇、丙酮、乙酸乙酯、氯化铁、醋酸钠、冰醋酸、水合磷酸二氢钾、水合磷酸氢二钠、荧光素钠、福林酚试剂、DPPH、2,4,6-tripyridyl-8-trizine(TPTZ),6-羟基-2,5,7,8-四甲基色烷-2-羧酸(Trolox)、偶氮二异丁脒盐酸盐(AAPH)等试剂均为分析纯,购于精科生物技术有限公司。

仪器:搅拌榨汁机,Philips公司;Pocket PAL-1型数显手持便携式折光仪,日本ATAGO公司;XW-80A型旋涡混合器,上海精科实业有限公司;KQ-300VDE超声波清洗器,昆山舒美超声仪器有限公司;HH-4型数显恒温水浴锅,金坛市金祥龙电子有限公司;5702台式冷冻离心机,Burette III数字滴定器,德国Eppendorf公司;超纯水仪,美国Millipore公司;F-7000荧光分光光度计、U-2910紫外分光光度计,日本日立公司。

1.2 处理方法

1.2.1 游离酚提取物的制备 参考文献[10-12]的方法略加调整。精确称取荔枝果肉样品2g,加入80%(φ)预冷冻丙酮(4℃)水溶液30mL,用匀浆机匀浆3min,于超声清洗器中超声10min,离心(4℃、4000r·min⁻¹)10min,3次重复提取,合并提取液,45℃旋转蒸发除丙酮,用水转移定容至25mL,-20℃冰箱保存,待测游离酚含量、总黄酮含量、抗氧化活性。

1.2.2 结合酚提取物的制备 参考文献[10-12]的方法略加调整。向1.2.1中提取游离多酚后的果肉残渣中加入4mol·L⁻¹的NaOH溶液10mL,超声10min,加浓盐酸调pH至中性;加100mL乙酸乙酯摇匀萃取,4℃离心10min,萃取3次。合并萃取液,45℃旋转蒸发除乙酸乙酯,用水复溶,残余物定容至10mL.-20℃冰箱保存待测结合酚含量。

表1 35个荔枝品种来源
Table 1 Sample sources of 35 litchi varieties

编号 No.	品种名称 Varieties name	成熟期 Maturity	采收地点 Harvest site
1	香蜜荔 Xiangmili	早熟 Early-maturing	茂名电白 Dianbai, Maoming
2	三月红 Sanyuehong	早熟 Early-maturing	广州天河 Tianhe, Guangzhou
3	状元红 Zhuangyuanhong	早熟 Early-maturing	广州增城 Zengcheng, Guangzhou
4	白糖罂 Baitangying	早熟 Early-maturing	茂名电白 Dianbai, Maoming
5	妃子笑 Feizixiao	早熟 Early-maturing	茂名电白 Dianbai, Maoming
6	水东 Shuidong	早熟 Early-maturing	云南元江 Yuanjiang, Yunnan
7	御金球 Yujinqiu	中熟 Medium- maturing	珠海斗门 Doumen, Zhuhai
8	黑叶 Heiye	中熟 Medium- maturing	茂名高州 Gaozhou, Maoming
9	白蜡 Baila	中熟 Medium- maturing	茂名高州 Gaozhou, Maoming
10	桂味 Guiwei	中熟 Medium- maturing	广州天河 Tianhe, Guangzhou
11	绿纱 Lvsha	中熟 Medium- maturing	广州增城 Zengcheng, Guangzhou
12	水晶球 Shuijingqiu	中熟 Medium- maturing	广州增城 Zengcheng, Guangzhou
13	翡翠 Feicui	中熟 Medium- maturing	茂名电白 Dianbai, Maoming
14	草莓荔 Caomeili	中熟 Medium- maturing	惠州惠东 Huidong, Huizhou
15	鸡嘴荔 Jizuili	中熟 Medium- maturing	广西灵山 Lingshan, Guangxi
16	紫娘喜 Ziniangxi	晚熟 Late-maturing	珠海斗门 Doumen, Zhuhai
17	帝王糯 Diwangnuo	晚熟 Late-maturing	珠海斗门 Doumen, Zhuhai
18	西园挂绿 Xiyuanguolv	晚熟 Late-maturing	广州增城 Zengcheng, Guangzhou
19	怀枝 Huaizhi	晚熟 Late-maturing	广州从化 Conghua, Guangzhou
20	稠枝糯米糍 Chouzhinuomici	晚熟 Late-maturing	茂名信宜 Xinyi, Maoming
21	禾虾串 Hexiachuan	晚熟 Late-maturing	茂名电白 Dianbai, Maoming
22	甜岩 Tianyan	晚熟 Late-maturing	广州增城 Zengcheng, Guangzhou
23	黑珍珠 Heizhenzhu	晚熟 Late-maturing	广州增城 Zengcheng, Guangzhou
24	糯米糍 Nuomici	晚熟 Late-maturing	广州天河 Tianhe, Guangzhou
25	红绣球 Hongxiuqiu	晚熟 Late-maturing	广州天河 Tianhe, Guangzhou
26	井冈红糯 Jingganghongnuo	晚熟 Late-maturing	惠州惠东 Huidong, Huizhou
27	庙种糯 Miaozhongnuo	晚熟 Late-maturing	惠州惠东 Huidong, Huizhou
28	岭丰糯 Lingfengnuo	晚熟 Late-maturing	惠州惠东 Huidong, Huizhou
29	仙婆果 Xianpoguo	晚熟 Late-maturing	惠州惠东 Huidong, Huizhou
30	胭脂红 Yanzhihong	晚熟 Late-maturing	广州增城 Zengcheng, Guangzhou
31	雪怀子 Xuehuaizi	晚熟 Late-maturing	广州天河 Tianhe, Guangzhou
32	金包银 Jinbaoyin	晚熟 Late-maturing	广州增城 Zengcheng, Guangzhou
33	北园绿 Beiyuanlv	晚熟 Late-maturing	广州增城 Zengcheng, Guangzhou
34	仙进奉 Xianjinfeng	晚熟 Late-maturing	广州增城 Zengcheng, Guangzhou
35	灵山香荔 Lingshanxiangli	晚熟 Late-maturing	茂名化州 Huazhou, Maoming

1.3 测试指标

1.3.1 多酚含量 根据 Singleton 等^[12]的方法略加改动, 具体步骤: 准确移取 0.0、0.1、0.2、0.3、0.4、0.5、0.6 mL 没食子酸标准溶液于 10 mL 容量瓶中, 先加蒸馏水至 8 mL, 再加入 0.5 mL 福林酚试剂, 摆匀, 反应 8 min; 加入 20%(ρ)碳酸钠溶液 1.5 mL, 摆匀, 避光反应 60 min, 于 750 nm 处测定吸光度, 以多酚质量浓度为横坐标, 吸光度为纵坐标, 绘制标准曲线, 得回归方程 $y = 108.8x - 0.005$ ($R^2 = 0.997$)。准

确移取 0.5 mL 样品溶液, 按上述方法在 750 nm 处测量吸光度值, 计算各待测样品的游离酚和结合酚含量, 单位用 $\text{mg} \cdot 100 \text{ g}^{-1}$ 表示。总酚=游离酚+结合酚。

1.3.2 总黄酮含量 根据文献[13-14]的方法略加改动, 具体步骤: 准确移取 0.00、0.50、0.75、1.00、1.20、1.50、2.00 mL 芦丁标准溶液于 10 mL 容量瓶中。首先加 0.3 mL 的 5%(ρ)亚硝酸钠溶液, 摆匀, 反应 4 min; 再加入 0.3 mL 的 10%(ρ)硝酸铝溶液, 摆匀,

反应4 min;最后加入1 mol·L⁻¹氢氧化钠溶液4.0 mL,用50%(φ)甲醇稀释至刻度,摇匀,反应10 min。在波长510 nm下测量吸光度,以黄酮质量浓度为横坐标,吸光度为纵坐标,绘制标准曲线,得到回归方程 $y = 10.36x - 0.007$ ($R^2 = 0.998$)。准确移取1 mL的样品溶液,按上述方法在510 nm处测量吸光度值,计算总黄酮含量,单位用mg·100 g⁻¹表示。

1.3.3 维生素C含量采用2,6-二氯酚靛酚滴定法^[15]测定维生素C含量。

1.3.4 DPPH自由基清除能力参照Monica等^[16]的方法并略加改动。取2 mL样液(每mL 0.08 g荔枝果肉)置于10 mL离心管中,加入2 mL现配的0.1 mmol·L⁻¹的DPPH甲醇溶液,混合摇匀后,在室温下置于暗处静置30 min,于517 nm处测定吸光值。同时测定2.5 mL DPPH和1 mL去离子水混合后的吸光值Ao。DPPH自由基清除率的计算公式为:

$$\text{DPPH自由基清除率}(\%) = [1 - \frac{A_i - A_j}{A_o}] \times 100\%$$

式中:A_i为样液与DPPH甲醇溶液的吸光值;A_o为蒸馏水与DPPH甲醇溶液的吸光值;A_j为样液与甲醇溶液的吸光值。

1.3.5 FRAP抗氧化能力测定参考文献[17-18]的方法并略加调整。配制FRAP工作液:300 mmol·L⁻¹醋酸盐缓冲液,10 mmol·L⁻¹TPTZ,20 mmol·L⁻¹FeCl₃,体积比10:1:1,现用现配。取提取液,稀释2倍后,取100 μL,加入FRAP工作液3 mL,混匀反应20 min,于593 nm处读取吸光度。以Trolox为标准物质绘制标准曲线,得回归方程 $y = 0.040x - 0.007$ ($R^2 = 0.991$),FRAP单位为μmol·g⁻¹。

1.3.6 ORAC测定参考文献[19-20]的方法略加调整。分别精确移取20 μL的磷酸缓冲液(空白)、吸取

稀释10倍的样液100 μL及不同质量浓度Trolox标准液于96微孔板的相应孔中,准确移取69 nmol·L⁻¹的荧光素钠溶液1825 μL,充分混匀后在37 °C酶标仪中反应10 min,再加入510 mmol·L⁻¹的AAPH溶液200 μL,在激发波长493 nm,发射波长514 nm下立即读数,测定荧光强度,每min 1次,测定60 min,并绘制标准曲线,得相对荧光强度-时间曲线回归方程 $y = 1.863x + 1.363$, $R^2 = 0.993$,ORAC单位用μmol·g⁻¹表示。

1.4 数据处理

运用IBM SPSS Statistics 25对所有试验数据进行数理分析,差异显著性分析采用的邓肯氏新复极差法,相关性分析采用Pearson相关分析,聚类方法采用瓦尔德法;应用Excel 2016绘制图表。图表数据用平均值±标准误($n=3$)表示。

2 结果与分析

对于35个品种荔枝果实的总酚、游离多酚、结合多酚、游离酚/总酚、总黄酮、维生素C及三种抗氧化能力数据进行描述性统计及方差分析(表2)。其中结合多酚、总黄酮、总酚、游离多酚、维生素C、FRAP、ORAC的变异系数较大,这说明不同品种中上述变量化合物物质含量差异大,另一方面说明荔枝果实中所含酚类、黄酮类化合物的特异性和多样性。F值大小排序为总酚>游离多酚>总黄酮>DPPH>FRAP>ORAC>结合多酚>维生素C,F值越大说明变量处理之间差异越明显。各变量显著性数值介于0.000~0.003,显示出以上各变量存在显著性差异。

2.1 不同荔枝品种的游离酚、结合酚及总酚含量

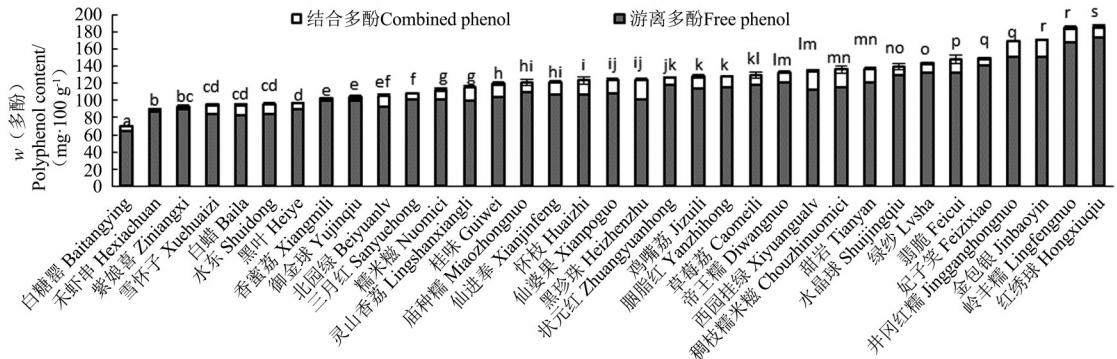
供试35个荔枝品种的游离酚含量、结合酚含

表2 数据描述性统计及方差分析
Table 2 Analysis of descriptive statistics and variance

参数 Parameter	w(游离多酚) Free polyphenols/ (mg·100 g ⁻¹)	w(结合多酚) Combined polyphenols/ (mg·100 g ⁻¹)	w(总酚) Total polyphenols/ (mg·100 g ⁻¹)	游离多酚/总酚 Ratio of free polyphenols to total polypheno/%	w(总黄酮) Total flavonoids/ (mg·100 g ⁻¹)	w(维生素C) Vitamin C content/ (mg·100 g ⁻¹)	DPPH/ % (μmol·g ⁻¹)	FRAP/ (μmol·g ⁻¹)	ORAC/ (μmol·g ⁻¹)
极差 Range	108.72	21.44	116.48	16.61	258.08	50.33	27.83	8.92	38.75
最小值 Min.	64.92	2.01	69.74	81.50	73.44	6.00	71.78	1.18	0.97
最大值 Max.	173.64	23.45	186.22	97.76	331.52	56.33	99.61	10.10	39.72
均值 Mean	112.16	12.46	124.62	90.13	155.21	32.97	92.77	4.33	16.10
标准差 Std	24.08	5.41	26.62	3.87	62.32	12.66	7.08	1.96	7.69
变异系数 CV/%	21.47	43.43	21.36	4.29	40.15	38.39	7.63	45.29	47.77
F值 F value	41.008	7.20	46.799	8.747	31.54	5.828	16.285	11.84	7.448
显著性 Saliency	0.000	0.001	0.000	0.000	0.000	0.003	0.000	0.000	0.001

量、总酚含量测定结果见图1。其中游离酚含量变幅为 $64.92\sim173.64 \text{ mg} \cdot 100 \text{ g}^{-1}$, 平均值为 $112.16 \text{ mg} \cdot 100 \text{ g}^{-1}$, 变异系数21.47%, 其中‘红绣球’含量最

高, ‘白糖罂’含量最低; 游离酚含量由高到低排名前10的依次是‘红绣球’‘岭丰糯’‘金包银’‘井冈红糯’‘妃子笑’‘翡翠’‘绿纱’‘水晶球’‘甜岩’‘帝王糯’。



不同小写字母代表各组间的差异显著($p < 0.05$)。总酚=游离多酚+结合多酚。下同。

Different small letters represent significant differences among groups ($p < 0.05$). Total phenol is the sum of free and combined polyphenols. The same below.

图1 35个荔枝品种游离酚、结合酚及总酚含量差异分析(平均±SD, n=3)

Fig. 1 Difference of contents of free, combined and total phenols in 35 litchi varieties (mean±SD, n=3)

结合酚含量变幅为 $2.01\sim23.45 \text{ mg} \cdot 100 \text{ g}^{-1}$, 平均值为 $12.46 \text{ mg} \cdot 100 \text{ g}^{-1}$, 变异系数为43.43%。其中‘黑珍珠’含量最高, ‘禾虾串’含量最低, 含量由高到低排名前10的依次是‘黑珍珠’‘西园挂绿’‘稠枝糯米糍’‘金包银’‘井冈红糯’‘岭丰糯’‘仙婆果’‘灵山香荔’‘怀枝’‘甜岩’。

总酚含量为游离酚含量与结合酚含量的总和, 变幅为 $69.74\sim186.22 \text{ mg} \cdot 100 \text{ g}^{-1}$, 平均值为 $124.62 \text{ mg} \cdot 100 \text{ g}^{-1}$, 变异系数为21.36%, 其中‘红绣球’总酚含量最高, ‘白糖罂’总酚含量最低。总酚含量由高到低排名前10的依次是‘红绣球’‘岭丰糯’‘金包银’‘井冈红糯’‘妃子笑’‘翡翠’‘绿纱’‘水晶球’

‘甜岩’‘稠枝糯米糍’。与游离酚的排序基本一致。游离酚/总酚变幅为81.5%~97.76%, 平均值为89.96%, 变异系数为4.38%, 这表明游离酚在总酚中占绝大多数。

2.2 荔枝总黄酮含量

供试35个荔枝品种的总黄酮含量测定结果见图2, 不同品种间总黄酮含量呈现出差异显著性($p < 0.01$), 其变幅为 $73.44\sim331.52 \text{ mg} \cdot 100 \text{ g}^{-1}$, 平均值为 $155.21 \text{ mg} \cdot 100 \text{ g}^{-1}$, 变异系数为40.15%, 其中‘岭丰糯’含量最高, ‘白糖罂’含量最低。总黄酮由高到低含量排名前10的依次是‘岭丰糯’‘红绣球’‘金包银’‘甜岩’‘绿纱’‘井冈红糯’‘水晶球’

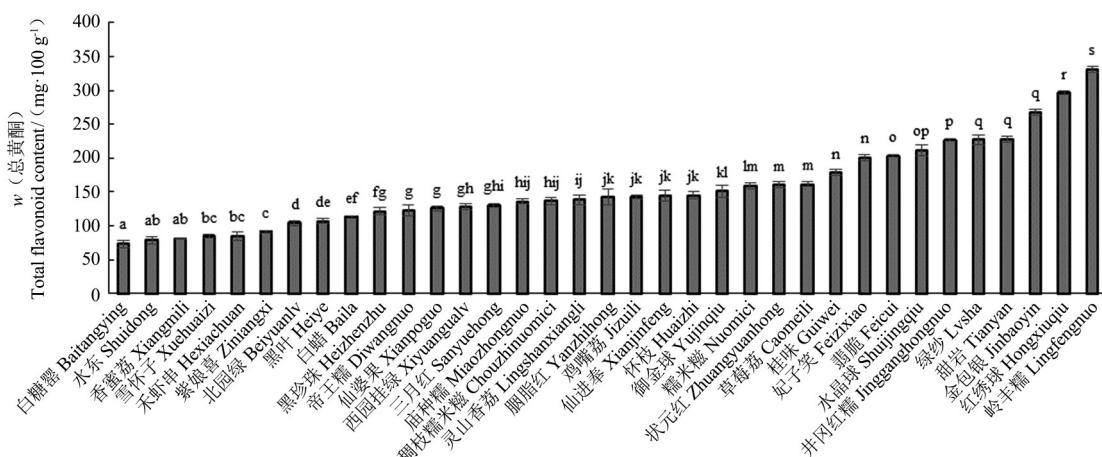


图2 35个荔枝品种总黄酮含量差异分析(平均±SD, n=3)

Fig. 2 Difference of total flavonoids content among 35 litchi varieties (average±SD, n=3)

‘翡翠’‘妃子笑’‘桂味’。

2.3 荔枝维生素C含量

供试 35 个荔枝品种的维生素 C 含量测定结果见图 3, 品种间维生素 C 含量呈现差异显著性($p < 0.01$), 变幅为 $6.00\text{--}56.33 \text{ mg} \cdot 100 \text{ g}^{-1}$, 平均值为

32.97 mg·100 g⁻¹, 变异系数为 38.39%, 其中‘红绣球’含量最高, ‘甜岩’含量最低。维生素 C 含量由高到低排名前 10 的依次是‘红绣球’‘井冈红糯’‘香蜜荔’‘妃子笑’‘水东’‘仙进奉’‘白糖罂’‘黑叶’‘禾虾串’‘水晶球’。

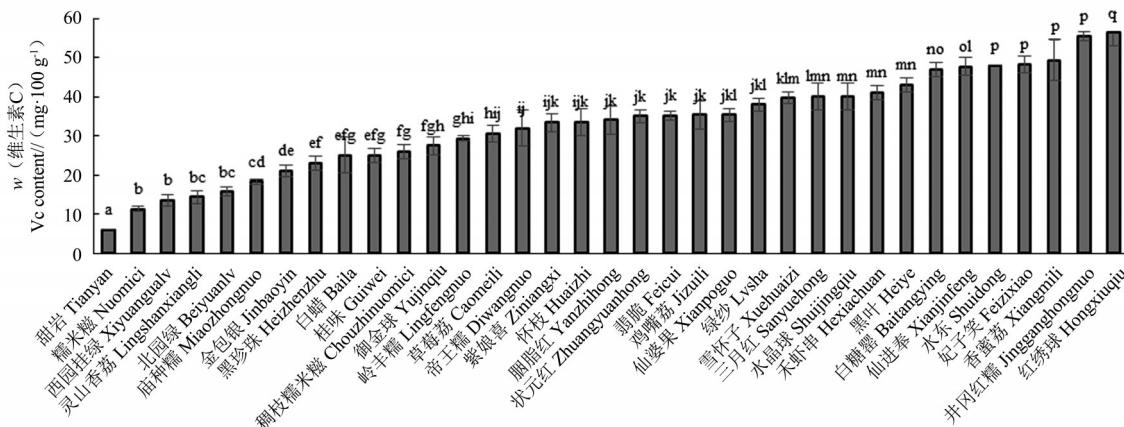


图3 35个荔枝品种维生素C含量差异分析(平均±SD, n=3)

Fig. 3 Difference of Vitamin C contents among 35 litchi varieties (average \pm SD, n=3)

2.4 荔枝抗氧化能力评价

2.4.1 DPPH 自由基清除能力评价 供试 35 个荔枝品种的 DPPH 自由基清除能力测定结果见图 4, 不同品种间清除率存在差异显著性($p < 0.01$), 变幅为 71.78%~99.61%, 平均值为 92.77%, 变异系数为 7.63%, 其中‘翡翠’DPPH 清除能力最高, ‘胭脂红’DPPH 清除能力最低。DPPH 清除能力由高到低排名前 10 的依次是‘翡翠’‘庙种糯’‘三月红’‘帝王糯’‘水东’‘妃子笑’‘金包银’‘禾虾串’‘井冈红糯’‘黑叶’。

2.4.2 FRAP 抗氧化能力评价 供试 35 个荔枝品种的 FRAP 抗氧化能力测定结果见图 5, 不同品种间存在差异显著性($p < 0.01$), 变幅为 1.18~10.10 $\mu\text{mol} \cdot \text{g}^{-1}$, 平均值为 4.33 $\mu\text{mol} \cdot \text{g}^{-1}$, 变异系数为

45.29%，其中‘妃子笑’FRAP 还原能力最高，‘白蜡’FRAP 还原能力最低。FRAP 抗氧化能力由高到低排名前 10 的依次是‘妃子笑’‘绿纱’‘状元红’‘红绣球’‘岭丰糯’‘三月红’‘黑叶’‘水东’‘金包银’‘井冈红糯’。

2.4.3 ORAC 评价 ORAC 法是目前国际上正在采用评价总抗氧化能力的最新方法, 现已经成为 FDA 评价食品抗氧化能力的重要标准^[21]。供试 35 个荔枝品种的 ORAC 测定结果见图 6, 不同品种间存在差异显著性($p < 0.01$), 变幅为 $0.97\sim39.72 \mu\text{mol}\cdot\text{g}^{-1}$, 平均值为 $16.10 \mu\text{mol}\cdot\text{g}^{-1}$, 变异系数为 47.77%, 其中‘红绣球’的 ORAC 最高, ‘庙种糯’的 ORAC 最低。ORAC 由高到低排名前 10 的依次是‘红绣球’、‘金包银’、‘妃子笑’、‘岭丰糯’、‘翡翠’、‘井冈红糯’。

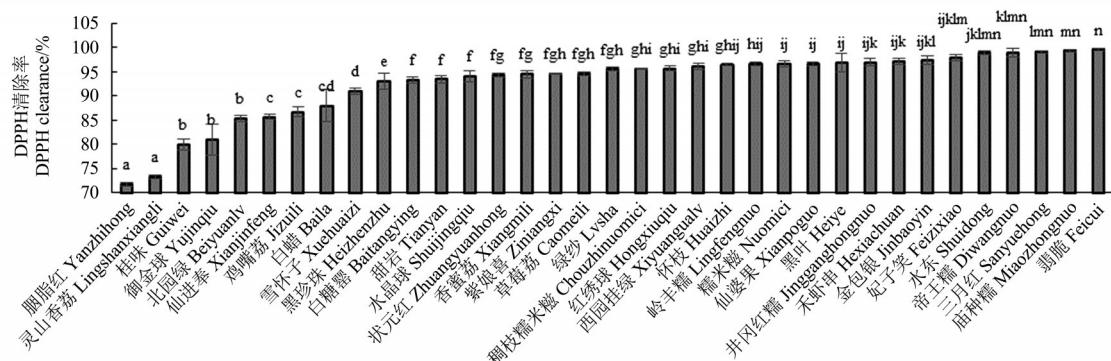


图4 35个荔枝品种DPPH清除能力的差异分析(平均±SD, n=3)

Fig. 4 Difference of DPPH clearance among 35 litchi varieties (mean \pm SD, n=3)

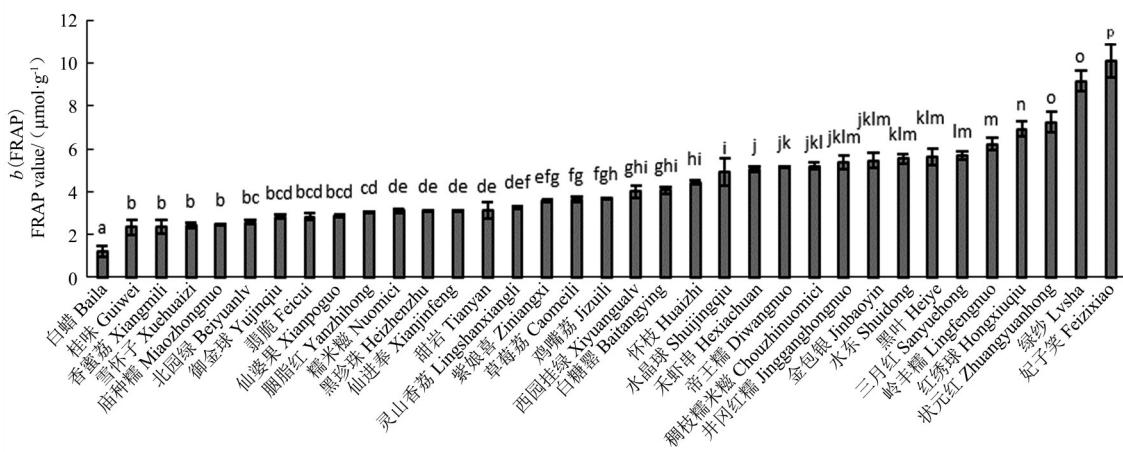


图5 35个荔枝品种FRAP抗氧化能力差异分析(平均±SD, n=3)

Fig. 5 Difference of FRAP antioxidant capacity among 35 litchi varieties (mean \pm SD, n=3)

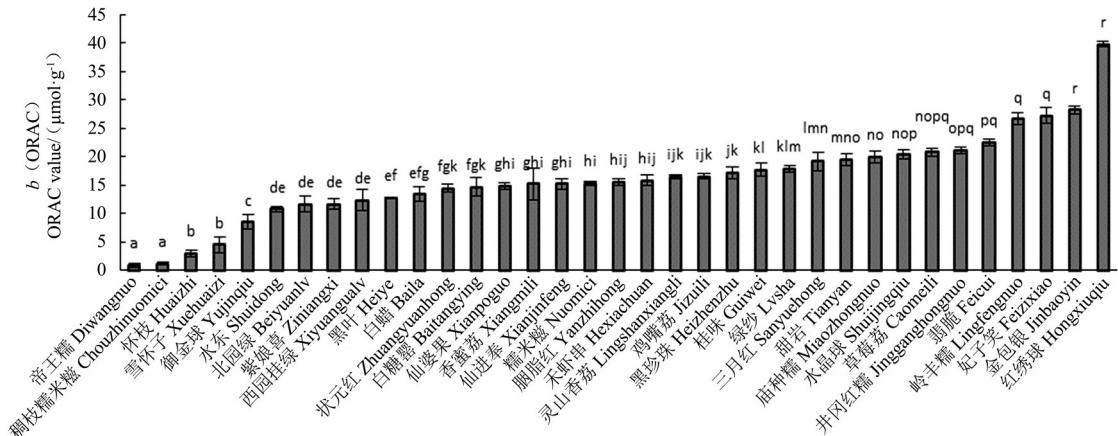


图6 35个荔枝品种ORAC氧自由基清除能力差异分析(平均±SD,n=3)

Fig. 6 Difference of ORAC among 35 litchi varieties (mean \pm SD, n=3)

‘草莓荔’‘水晶球’‘庙种糯’‘甜岩’。

2.5 荔枝总黄酮、总酚、维生素C与抗氧化活性的相关性分析

35个荔枝品种多酚、黄酮及维生素C含量与抗氧化能力的相关性分析结果见表3,结果显示,游离多酚含量与总酚、总黄酮含量均呈极显著正相关($p < 0.01$),与结合多酚呈显著正相关($p < 0.05$)、结合多酚含量与总黄酮、维生素C含量呈显著正相关($p < 0.05$)。总酚含量与游离多酚、总黄酮含量呈极显著正相关($p < 0.01$)。比较DPPH、FRAP与ORAC三种抗氧化活性,均呈正相关性,但不显著($p > 0.05$)。但ORAC、FRAP与游离多酚、总酚、总黄酮之间均存在极显著正相关性($p < 0.01$),与维生素C含量存在显著正相关性($p < 0.05$)。依据相关系数大小排列:游离多酚($r=1$)>总酚($r=0.982$)>总黄酮($r=0.921$)>ORAC($r=0.655$)>FRAP($r=0.517$)>结合多酚($r=0.383$)>

维生素 C ($r=0.118$) > DPPH ($r=0.088$)，多酚、黄酮类物质被认为与抗氧化能力相关，通常情况下，相关系数越大，相关性越强，该化合物对抗氧化能力贡献越大，由此可见荔枝果肉主要抗氧化活性成分是多酚与黄酮，维生素 C 与荔枝的抗氧化作用关系并不密切。三种抗氧化活性显示的评价性结果存在差异，可能是由于三种抗氧化活性是基于不同的评价体系，作用机制的复杂性及评价的侧重点不同^[22-23]。

2.6 荔枝抗氧化能力聚类分析

为了筛选出多酚、黄酮含量丰富,抗氧化活性高的荔枝品种,基于游离多酚、结合多酚、总酚、总黄酮、维生素 C 含量及 DPPH 清除能力、ORAC、FRAP 三种抗氧化能力,采用沃德联接法进行系统聚类,由图 7 可以看出,在欧式平方距离为 8 时,可以将 35 个荔枝品种(系)分为 4 个类群,见表 4,第 I 类包含 7 个品种,这一类品种多酚、黄酮含量最

表3 多酚、黄酮及维生素C含量与抗氧化能力的相关性分析

Table 3 Correlation analysis of polyphenols, flavonoids and vitamin C contents with antioxidant capacity

	游离多酚 Free polyphenols	结合多酚 Combined polyphenols	总酚 Total polyphenols	总黄酮 Total flavonoids	维生素C Vitamin C	DPPH	FRAP	ORAC
游离多酚	1	0.383*	0.982**	0.921**	0.118	0.088	0.517**	0.655**
Free polyphenols								
结合多酚		1	0.550**	0.362*	-0.375*	-0.115	-0.089	0.071
Combined polyphenols								
总酚			1	0.907**	0.031	0.057	0.449**	0.607**
Total polyphenols								
总黄酮				1	-0.016	0.027	0.441**	0.706**
Total flavonoids								
维生素C					1	0.256	0.423*	0.189
Vitamin C								
DPPH						1	0.297	0.024
FRAP							1	0.330
ORAC								1

注: **. 相关性在 0.01 水平上显著(单尾); *. 相关性在 0.05 水平上显著(单尾)。

Note: **. The correlation is significant at the level of 0.01 (single tail); *. The correlation is significant at the level of 0.05 (single tail).

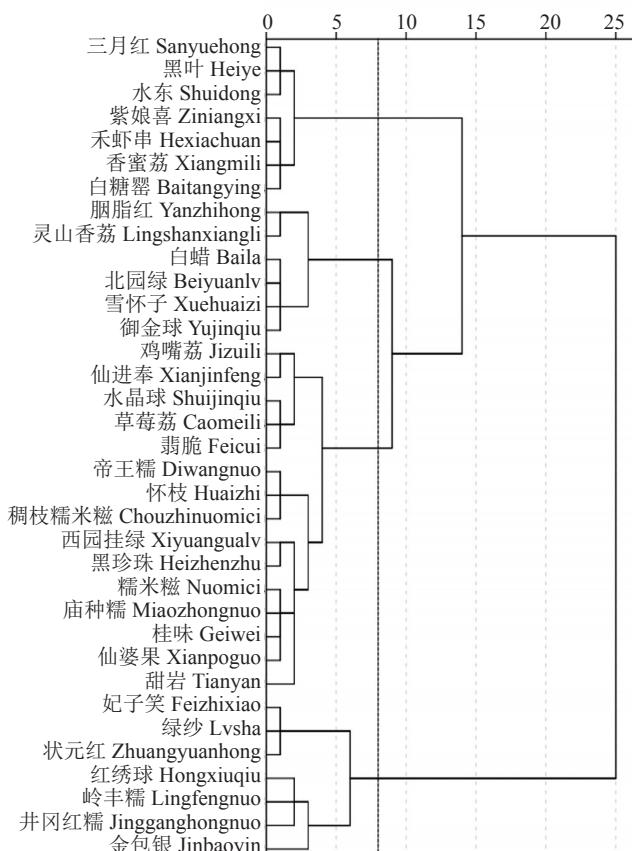


图7 不同品种荔枝基于多酚、黄酮、维生素C含量及抗氧化活性的聚类分析

Fig. 7 Cluster analysis charts of different litchi varieties based on the contents of polyphenols, flavonoids, vitamin C and their antioxidant activities

高, FRAP、ORAC 水平最强, 但维生素 C 含量较低、DPPH 清除能力水平较低; 第 II 类包含 15 个品种, 这一类品种数量占多数, 特点是多酚含量、黄酮含量较高, DPPH 清除能力、ORAC 水平较强, 但维生素 C 含量最低; 第 III 类包括 6 个品种, 特点是多酚、黄酮、维生素 C 含量较低, DPPH 清除能力、FRAP 水平最低。第 IV 类包含 7 个品种, 特点是多酚、黄酮含量最低, ORAC 水平最低, 但维生素 C 含量、DPPH 清除能力最高。

3 讨 论

果蔬多酚是水果和蔬菜植株体内来源于苯丙氨酸代谢途径和莽草酸途径的重要次生代谢物, 多酚类物质被称为“第七类营养素”^[24], 这类物质具有强抗氧化性, 抗肿瘤、抗突变、抑菌、防龋齿等多种功能, 是一种新型的天然生物活性物质^[25], 本研究结果表明, 荔枝品种间的总酚含量存在显著性差异, 这与 Li 等^[26]的研究结果一致, 总酚含量变幅范围介于 69.74~86.22 mg·100 g⁻¹, 变异系数达 21.36%, 同时发现荔枝中游离酚占总酚的百分比为 81.15%~97.76%, 平均 89.96%, 这表明荔枝多酚主要以游离形态存在, 这一结果与张东峰等^[27]、郑必胜等^[28]、Chu 等^[29]报道的柑橘、番石榴、蔬菜中游离酚占总酚含量的百分比占多数的结果相似。黄酮类物质因其供电子能力(还原力)和所生成的黄酮类自由基的稳

表4 35个荔枝品种抗氧化能力分类
Table 4 Classification of antioxidant capacity of 35 litchi varieties

类别 Category	品种 Varieties	特点 Features
第I类 Class I	妃子笑,绿纱,红绣球,井冈红糯,岭丰糯,金包银,状元红 Feizixiao, Lvsha, Hongxiuqiu, Jingganghongnuo, Lingfengnuo, Jinbaoyin, Zhuangyuanhong	总多酚、游离多酚、总黄酮、FRAP、ORAC 最高, 维生素 C、DPPH 清除能力较低 Highest content of total polyphenols, free polyphenols, total flavonoids and the highest level of antioxidant activity of FRAP and ORAC, but lower vitamin C content and DPPH scavenging ability
第II类 Class II	帝王糯,西园挂绿,怀枝,稠枝糯米糍,桂味,甜岩,黑珍珠,水晶球,糯米糍,翡翠,庙种糯,草莓荔,仙婆果,仙进奉,鸡嘴糯 Diwangnuo, Xiyuangualy, Huaizhi, Chouzhuinuomi-ci, Guiwei, Tianyan, Heizhenzhu, Shuijingqiu, Nuo-mici, Feicui, Miaozhongnuo, Caomeili, Xianpoguo, Xianjinfeng, Jizuinuo	总多酚、游离多酚、结合多酚、总黄酮、DPPH 清除能力、ORAC 较高, FRAP 较低、维生素 C 含量最低 High contents of total polyphenols, free polyphenols, combined polyphenols, total flavonoids and strong level of DPPH scavenging ability and ORAC, but low level level of FRAP and the lowest content of vitamin C
第III类 Class III	御金球,白蜡,胭脂红,雪怀子,北园绿,灵山香荔 Yujinqiu, Baila, Yanzhishong, Xuehuaizi, Beiyuanlv, Lingshanxiangli	总多酚、游离多酚、结合多酚、总黄酮、维生素 C、ORAC 较低, DPPH 清除能力、FRAP 最低 The lower contents of total polyphenols, free polyphenols, combined polyphenols, total flavonoids, vitamin C, lower level of ORAC, and the lowest level of DPPH scavenging capacity and FRAP
第IV类 Class IV	紫娘喜,香蜜荔,三月红,白糖罂,禾虾串,水东,黑叶 Ziniangxi, Xiangmili, Sanyuehong, Baitangying, He-xiachuan, Shuidong, Heiye	总多酚、游离多酚、结合多酚、总黄酮、ORAC 最低, FRAP 较高, 维生素 C、DPPH 清除能力最高 Lowest content of total polyphenols, free polyphenols, combined polyphenols, total flavonoids and the lowest level of ORAC, but high level of FRAP and the highest level of DPPH scavenging capacity and vitamin C content

定性,而成为有效的自由基清除剂,笔者发现荔枝果肉总黄酮含量介于 $73.44\sim331.52 \text{ mg} \cdot 100 \text{ g}^{-1}$, 变异系数为 40.15%。维生素 C 是生命活动不可缺少的一种小分子有机化合物,既参与体内氧化还原反应,又作为脯氨酸羟化酶的辅酶,参与胶原蛋白的合成,还与细胞间质的生成有关^[30],笔者发现荔枝果肉维生素 C 含量介于 $6.00\sim56.33 \text{ mg} \cdot 100 \text{ g}^{-1}$, 变异系数为 38.39%。

笔者采用了三种评价方法来测定不同荔枝品种的抗氧化能力,能较全面地反映荔枝的抗氧化功效,DPPH 清除能力介于 71.78%~99.61%, 变异系数为 7.63%; FRAP 铁离子的还原能力介于 $1.18\sim10.10 \mu\text{mol} \cdot \text{g}^{-1}$, 变异系数为 45.29%; ORAC 氧化自由基吸收能力介于 $0.97\sim39.72 \mu\text{mol} \cdot \text{g}^{-1}$, 变异系数为 47.77%。

相关性分析发现荔枝果肉中总多酚含量与 FRAP、ORAC 值呈极显著正相关($r=0.449, p < 0.01; r=0.607, p < 0.01$),同样地,总黄酮含量与 FRAP、ORAC 值分别呈极显著正相关($r=0.441, p < 0.01; r=0.706, p < 0.01$)这与 Oszmiański^[31]所得结果相一致,表明荔枝果肉中多酚及黄酮物质与抗氧化能力间的关系密切。但总酚、总黄酮与 DPPH 之间未呈现显著相关性($p > 0.05$);研究还

发现维生素 C 含量仅与 FRAP 显著相关($r=0.423, p < 0.05$),但与 DPPH、ORAC 仅呈正相关($p > 0.05$),说明多酚、黄酮是荔枝果肉抗氧化的重要物质,维生素 C 与荔枝果肉的抗氧化作用关系并不密切。

测试结果和聚类分析发现‘妃子笑’‘绿纱’‘红绣球’‘井冈红糯’‘岭丰糯’‘金包银’‘状元红’属于多酚黄酮物质含量高、抗氧化活性最强水平组,吴丹玲等^[9]在研究荔枝抗氧化性中也发现‘妃子笑’荔枝果肉中总多酚、总黄酮含量最高且 ORAC 值最高;几个早熟及中熟品种如‘香蜜荔’‘三月红’‘白糖罂’‘水东’‘黑叶’处于多酚、总黄酮含量最低但 ORAC 抗氧化活性最低水平,维生素 C、DPPH 清除能力最高组;大部分的晚熟品种如‘糯米糍’‘桂味’‘西园挂绿’‘仙进奉’‘怀枝’‘鸡嘴荔’‘翡翠’等主要集中在多酚、黄酮物质含量及抗氧化活性较高组,其中‘翡翠’是近年来发现及审定的一个新品种;而第 I 类中‘金包银’是商品性能优异的一个新品种,其抗氧化能力强,是一个值得挖掘的新品种。

4 结 论

综上所述,不同荔枝品种间游离态酚、结合态酚、总酚、总黄酮、维生素 C 含量和抗氧化能力存在

极显著差异($p < 0.01$)，酚类物质主要以游离态形式存在。荔枝果肉中总多酚含量、总黄酮含量与FRAP、ORAC值均呈极显著正相关($p < 0.01$)，维生素C含量虽与FRAP呈显著正相关($p < 0.05$)，但与DPPH、ORAC无显著相关性($p > 0.05$)；多酚、黄酮类物质是荔枝发挥抗氧化作用的重要物质，维生素C与荔枝的抗氧化作用关系并不密切；聚类分析结果表明‘妃子笑’‘绿纱’‘红绣球’‘井冈红糯’‘岭丰糯’‘金包银’‘状元红’是一类多酚、黄酮物质含量高，抗氧化活性最强的品种。上述研究为进一步研究荔枝多酚的功能活性提供研究基础，对不同荔枝品种多酚的应用及高抗氧化活性荔枝新品种的选育筛选提供了方向。

参考文献 References:

- [1] 广东省农业科学院果树研究所. 荔枝品种与栽培图说[M]. 广州:广东经济出版社,1997: 10.
Fruit Research Institute of Guangdong Academy of Agricultural Sciences. Lichee varieties and cultivation diagram [M]. Guangzhou: Guangdong Economic Press, 1997: 10.
- [2] 陈厚彬. 荔枝产业发展报告[J]. 现代农业装备, 2018(4): 22-24.
CHEN Houbin. Report of lichi industry development [J]. Modern Agricultural Equipment, 2018(4): 22-24.
- [3] QU H, MADL R L, TAKEMOTO D J, BAYBUTT R C, WANG W. Lignans are involved in the antitumor activity of wheat bran in colon cancer SW480 cells[J]. Nutrition, 2005, 135(3): 598-602.
- [4] LV Q, SI M M, YAN Y Y, LUO F L, HU G B, WU H S, SUN C D, LI X, CHEN K S. Effects of phenolic-rich litchi (*Litchi chinensis* Sonn.) pulp extracts on glucose consumption in human Hep G2 cells[J]. Journal of Functional Foods, 2014, 7(1): 621-629.
- [5] 颜仁梁,刘志刚. 荔枝核多酚类物质的分离与鉴定[J]. 中药材,2009,32(4):522-523.
YAN Renliang, LIU Zhigang. Separation and identification of polyphenols in litchi seed [J]. Chinese Herbal Medicine, 2009, 32(4): 522-523.
- [6] 杨子明,颜小捷,乔雪,陈月圆,刘金磊,李典鹏. 荔枝皮多酚体内抗氧化的作用研究[J]. 食品研究与开发, 2016, 37(10): 31-34.
YANG Ziming, YAN Xiaojie, QIAO Xue, CHEN Yueyuan, LIU Jinlei, LI dianpeng. Effects of *Litchi chinensis* pericarp polyphenols on the antioxidant capacity *in vivo*[J]. Food Research and Development, 2016, 37(10): 31-34.
- [7] 熊何健,郑建华,吴国宏,王美贵. 荔枝多酚的分离制备及清除DPPH活性[J]. 食品科学,2006,27(7):86-88.
XIONG Hejian, ZHENG Jianhua, WU Guohong, WANG Meigui. Preparation of lichee polyphenols and its DPPH radical scavenging activity [J]. Food Science, 2006, 27(7): 86-88.
- [8] 彭新生,周艳星,田圆,周艳芳,李宝红. 不同采收期荔枝叶中总黄酮含量的变化[J]. 广东医学院学报,2013,31(5):513-515.
PENG Xinsheng, ZHOU Yanxing, TIAN Yuan, ZHOU Yanfang, LI Baohong. Total flavone content of litchi leaves at different harvest times [J]. Journal of Guangdong Medical College, 2013, 31(5): 513-515.
- [9] 吴丹玲. 三种热带水果的抗氧化及抗增殖活性研究[D]. 广州: 华南理工大学,2011.
WU Danling. Antioxidant and antiproliferative activities of three tropical fruits [D]. Guangzhou: South China University of Technology, 2011.
- [10] KELLY W, WU X Z, LIU R H. Antioxidant activity of apple peels[J]. Food Science and Technology, 2003, 51(3): 609-614.
- [11] 万红霞,李艳,刘冬. 龙眼果肉多酚提取条件的优化[J]. 湖北农业科学,2011(17): 3602-3604.
WAN Hongxia, LI Yan, LIU Dong. Optimization of extraction conditions of polyphenols from longan flesh [J]. Hubei Agricultural Science, 2011(17): 3602-3604.
- [12] SINGLETON V L, ORTHOFER R, LAMUELA-RAVENTÓS MUELA-RAVENTOS R M. Analysis of total phenols and other oxidation substrates and antioxidants by means of Folin-Ciocalteu reagent[J]. Methods Enzymology, 1999, 299: 152-178.
- [13] 钟秋平,林美芳. 黄皮果中总黄酮含量的测定及其黄酮[J]. 食品科学,2007,28(8):411-413.
ZHONG Qiuping, LIN Meifang. Determination of contents of flavones and identification of flavones species in *Fructus clausenae Lanii*. [J]. Food Science, 2007, 28(8): 411-413.
- [14] 柴建新,万茵,付桂明,谢明勇,陈建芳. 杜仲叶总黄酮含量测定方法优化[J]. 中国食品学报,2013,13(4):226-230.
CHAI Jianxin, WAN Yin, FU Guiming, XIE Mingyong, CHEN Jianfang. Optimization of determination method of total flavonoids in *Eucommia ulmoides* Oliv. leaves [J]. Chinese Journal of Food Science, 2013, 13(4): 226-230.
- [15] 中华人民共和国国家卫生和计划生育委员会. 食品中抗坏血酸的测定:GB/T 5009.86—2016[S]. 北京:中国标准出版社, 2017.
National Health and Family Planning Commission of the People's Republic of China. Determination of ascorbic acid in food: GB/T 5009.86—2016[S]. Beijing: China Standards Press, 2017.
- [16] MONICA L, ROBERTO G, FABIANO T, JEAN-DANIEL C, MAURIZIO R, MARCO A. Study of the DPPH scavenging activity: Development of a free software for the correct interpretation of data[J]. Food Chemistry, 2009, 114: 889-897.
- [17] 陈玉霞,刘建华,林峰,杜向党. DPPH 和 FRAP 法测定 41 种中草药抗氧化活性[J]. 实验室研究与探索, 2011, 30(6):11-14.
CHEN Yuxia, LIU Jianhua, LIN Feng, DU Xiangdang. Determination of antioxidative activity of 41 kinds of Chinese herbal

- medicines by using DPPH and FRAP methods [J]. Laboratory Research and Exploration, 2011, 30(6): 11-14.
- [18] BENZIE I F , STRAIN J J. The Ferric Reducing Ability of Plasma (FRAP) as a measure of “Antioxidant Power”: The FRAP assay[J]. Analytical Biochemistry, 1996, 239: 70-76.
- [19] LIN L Z, ZHAO H F, DONG Y, YANG B, ZHAO M M. Macroporous resin purification behavior of phenolics and rosmarinic acid from *Rabdosia serra* (Maxim.) HARA leaf[J]. Food Chemistry, 2012, 130(2): 417-424.
- [20] WOLFE K L, KANG X M, HE X. Cellular antioxidant activity of common fruits [J]. Journal of Agricultural and Food Chemistry, 2008, 56(18): 8418-8426.
- [21] 续洁琨,姚新生,栗原博.抗氧化能力指数(ORAC)测定原理及应用[J].中国药理学通报,2006,22(8): 1015-1021。
XU Jiekun, YAO Xinsheng, LI Yuanbo. Oxygen radical absorbance capacity assay and its application [J]. Chinese Pharmacological Bulletin, 2006, 22 (8): 1015-1021.
- [22] 许红星,曹晖,刘方方.两种方法评价常见水果的抗氧化活性[J].扬州大学烹饪学报,2012(4): 38-42.
XU Hongxing, CAO Hui, LIU Fangfang. Two method evaluating the antioxidant activities of some common fruits [J]. Cuisine Journal of Yangzhou University, 2012(4): 38-42.
- [23] SUN T, HO C T. Antioxidant activities of buckwheat extracts[J]. Food Chemistry, 2005, 90: 743-749.
- [24] 凌关庭.有“第七类营养素”之称的多酚类物质[J].中国食品添加剂,2000(1): 28-37.
LING Guanting. Polyphenols are called as “the seventh nutrient” [J]. Chinese Food Additives, 2000 (1): 28-37.
- [25] 刘贤青,涂虹,王守创,张红艳,罗杰,徐娟.不同类型柑橘果实汁胞中类黄酮的液相色谱质谱联用分析[J].植物生理学报,2016,52(5): 762-770.
LIU Xianqing, TU Hong, WANG Shouchuang, ZHANG Hongyan, LUO Juan, XU Juan. Flavonoid composition of Citrus juice sacs determined by high- performance liquid chromatography coupled with tandem electrospray ionization mass spectrometry [J]. Plant Physiology Journal, 2016, 52(5): 762-770.
- [26] LI W, LIANG H, ZHANG M W, ZHANG R F, DENG Y Y, WEI Z C, ZHANG Y, TANG X J. Phenolic profiles and antioxidant activity of litchi (*Litchi chinensis* Sonn.) fruit pericarp from different commercially available cultivars[J]. Molecules, 2012, 12: 14954-14967.
- [27] 张东峰,陈家豪,郭静,陈海槟,李平凡.7种柑橘多酚、黄酮含量及其抗氧化活性比较研究[J].食品研究与开发,2019,40 (6):69-74.
ZHANG Dongfeng, CHEN Jiahao, GUO Jing, CHEN Haibin, LI Pingfan. Comparative Study on the polyphenol, flavonoid and antioxidant activity of seven varieties of citrus[J]. Food Research and Development, 2019, 40(6): 69-74.
- [28] 郑必胜,曹双,钟伟.不同品种番石榴的酚类物质及抗氧化活性[J].食品科技,2014,39(12):225-230.
ZHENG Bisheng, CAO Shuang, ZHONG Wei. Analysis of phenolic compounds and antioxidation in different cultivar guavas [J]. Food Science and Technology, 2014, 39(12): 225-230.
- [29] CHU Y F, SUN J, WU X Z, LIU R H. Antioxidant and antiproliferative activities of common vegetables[J]. Agriculture and Food Chemistry, 2002, 50: 6910-6916.
- [30] 苏淑贞,缪应庭,高玉红,芮莉莉.66种植物维生素C含量的分析[J].河北农业大学学报,1996,19(3): 67-71.
SU Shuzhen, MIAO Yingting, GAO Yuhong, RUI Lili. A study on vitamin C content in 66 kinds of plants [J]. Journal of Hebei Agricultural University, 1996, 19(3): 67-71.
- [31] OSZMIAŃSKI J, KOLNIAK-OSTEK J, LACHOWICZ S, GOREZELANY J, MATIOK N. Phytochemical compounds and antioxidant activity in different cultivars of cranberry (*Vaccinium macrocarpon* L.) [J]. Journal of Food Science, 2017, 82(11): 2569-2575.