

河北省野生红树莓果实品质差异分析及评价

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摘要:【目的】探究野生红树莓(*Rubus idaeus* L.)的果实品质差异,为红树莓高效栽培和品种选育提供理论依据。【方法】以河北省冀东区(秦皇岛市)、冀北区(承德市)、冀西北区(张家口市)以及冀西太行山区(保定市)4个野生红树莓种质资源主要分布区域的13个县域野生红树莓为研究对象,通过对果实外在表型性状和内在营养成分等指标的测定,对比分析不同区域野生红树莓的果实特性差异,运用相关性分析、主成分分析和聚类分析法,对野生红树莓的果实品质进行综合评价。【结果】冀北区野生红树莓的果实大小显著大于冀东区、冀西太行山区和冀西北区,纵径与横径分别在9.64~14.41 mm、9.48~16.30 mm之间,且该区的单果质量和单株产量更高,最高单株产量为306.70 g,各区域果形无显著差异;冀西太行山区的红树莓可溶性蛋白含量(w,后同)高于其他地区,在1.78~1.84 mg·g⁻¹之间;冀西北区的红树莓具有较高的维生素C含量(22.83~29.79 mg·100 g⁻¹)和较高的氨基酸含量(12.47~12.96 mg·g⁻¹);冀东区的红树莓花青素含量较为突出,在587.82~599.19 mg·kg⁻¹之间;经主成分分析,将18个指标经简化为4个相对独立的综合指标,累积方差贡献率为88.530%,综合得分排名前三位的地区为宽城、兴隆和围场;通过聚类分析,将13个样地的野生红树莓果实分为3类。【结论】结合河北省分区综合评价果实品质,得出冀北区的野生红树莓产量大、风味佳,适合鲜食生产,而冀西北区、冀西太行山区和冀东区的野生红树莓果实有机物含量突出,适合不同需求的加工生产。

关键词:野生红树莓;果实品质;主成分分析;聚类分析;评价

中图分类号:S663.2

文献标志码:A

文章编号:1009-9980(2024)04-0712-13

Analysis and evaluation of difference in fruit quality of wild red raspberries in Hebei province

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Abstract: 【Objective】 The study investigated the differences in the fruit quality of wild red raspberries (*Rubus idaeus* L.) in order to provide reference for efficient cultivation and variety breeding of red raspberry. 【Methods】 Wild red raspberries in Hebei Province was used as the research object, and a comparative analysis of the differences in the fruit characteristics of wild red raspberries from different regions was performed involving the determinations of external phenotypic traits, internal nutrient composition and other indexes of the fruit, and correlation analysis, principal component analysis and cluster analysis were applied to comprehensively evaluate the fruit quality of wild red raspberries. 【Results】 Longitudinal and transverse diameters of the fruits in each area ranged from 9.64 to 14.41 mm and 9.48 to 16.30 mm, respectively, with the largest fruit size occurring in Xinglong and the smallest in Changli and Fuping. Comprehensive comparisons revealed that the fruit size of wild red raspberries in northern Hebei was significantly greater than that in eastern Hebei, the West Hebei Taihang Mountains and northwestern Hebei, with longitudinal and transverse diameters ranging from 11.68 to 16.30 mm. There was no significant difference in fruit shape among areas. There were obvious regional differences in fruit yield, and single fruit weight and yield per plant in each area ranged from 0.34 to 2.03 g and 23.89 to

收稿日期:2023-12-22 接受日期:2024-02-16

基金项目:河北省重点研发计划(20326338D)

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306.70 g, respectively, with those in Xinglong area being significantly higher than those of the other areas, and Changli and Fuping being the lowest. A comprehensive comparison found that the single fruit weight and yield per plant in Northern Hebei were significantly higher than those of the other regions. In fruit nutrient composition, the soluble protein and amino acid contents in wild red raspberry fruits in each area were between 1.10 to 1.97 mg · g⁻¹ and 9.84 to 12.96 mg · g⁻¹, respectively, and the soluble protein content of Funing red raspberry and the amino acid content of Chicheng red raspberry were significantly higher than those in the other areas. The vitamin C and anthocyanin contents varied greatly among areas, ranging from 8.40 to 29.79 mg · 100 g⁻¹ and 203.02 to 599.19 mg · kg⁻¹, respectively, with vitamin C content of red raspberries in Chicheng, and flavonoid content in Kuancheng area being significantly higher than those in the other areas. There was no regional distribution pattern of flavonoids and total phenols in wild red raspberry fruits, which ranged from 2.32 to 6.69 mg · g⁻¹ and 1.91 to 4.24 mg · g⁻¹, respectively, and the total phenol content of red raspberries in Luanping, and the anthocyanins content of red raspberries in Funing and Changli were significantly higher than those in the other areas. Comprehensive comparisons revealed that the soluble protein content of red raspberries from West Hebei Taihang Mountains was higher than that of other regions, ranging from 1.78 to 1.84 mg · g⁻¹; the red raspberries from Northwestern Hebei had a high vitamin C content of 22.83 to 29.79 mg · 100 g⁻¹ and a high amino acid content of 12.47 to 12.96 mg · g⁻¹. The anthocyanin content of red raspberries from Eastern Hebei was relatively high, ranging from 587.82 to 599.19 mg · kg⁻¹. Soluble sugar and titratable acid contents differed significantly, ranging from 51.24 to 84.69 mg · g⁻¹ and 45.53 to 75.27 mg · g⁻¹, respectively; the soluble sugar content of red raspberries in Kuancheng, and the titratable acid of red raspberries in Funing and Yixian were significantly higher than those in the other areas. The acid-sugar ratio ranged from 0.72 to 1.48, with the highest in Xinglong and the lowest in Changli. The soluble solid content and solid-acid ratios ranged from 9.53% to 14.77% and 1.45 to 2.67, respectively, and the two indexes in Xiahuyuan were significantly higher than those in the other areas. Comprehensive comparison revealed that Kuancheng, Xinglong and Weichang in the northwestern Hebei and northern Hebei regions had a higher soluble sugar content, solid-acid ratio and sugar-acid ratio, together with a lower amount of titratable acid, resulting in a sweeter fruit flavor and a richer texture; however, Changli and Funing in East Hebei and Yixian, Lai and Fuping in the West Hebei Taihang Mountains had a lower soluble sugar content and greater amount of titratable acid, which resulted in a more acidic fruit flavor. Correlation analysis of 18 indicators, including fruit traits, yield, nutrient composition and flavor, revealed a total of 19 pairs of correlated indicators. Accordingly, through principal component analysis, the 18 indicators were simplified into 4 relatively independent composite indicators, with a cumulative variance contribution rate of 88.530%, and the top three areas in terms of fruit quality composite score were Kuancheng, Xinglong and Weichang. A cluster analysis revealed that wild red raspberries in northern Hebei Province had outstanding fruit quality compared with those in the other regions; the wild red raspberries in the 13 sampling sites were divided into three categories: the first category included Weichang and Longhua, and the second Funing, Yixian, Laishui, Chicheng, Xiahuyuan, Fuping, and Changli.; and the third Luanping, Chengde, Kan Cheng and Xinglong. **【Conclusion】** A comprehensive evaluation of fruit quality revealed that the wild red raspberries in northern Hebei Province have large yields and good flavors and are suitable for table fruit production, whereas those in northwestern Hebei Province, the West Hebei Taihang Mountains and eastern Hebei Province, which have outstanding fruit organic content, are suitable for the production of wild red raspberries for processing and other purposes.

Key words: Wild red raspberry; Fruit quality; Principal component analysis; Cluster analysis; Evaluation

红树莓(*Rubus idaeus* L.)为蔷薇科(Rosaceae)悬钩子属(*Rubus* L.)多年生落叶果树,为小浆果灌木。果实颜色鲜艳,味道酸甜,营养价值高,富含人体所需的多种营养元素^[1-3],被称为“天然绿色食品”、“维生素宝库”,具有食品、医药等多领域的开发潜力和利用价值^[4-6]。

我国有200多个红树莓品种^[7],野生种质资源非常丰富,但多处于未经深度研究与开发利用的状态^[8]。虽然国内市场上红树莓品种繁多但产地各异,而不同产地的红树莓品质存在较大差距。目前国内对于红树莓的果实品质相关研究也多集中于相同产地间^[9-10],李鹏举^[11]对绥化地区引种的26个树莓品种果实品质经综合分析后发现,北京32和红玉的平均单果质量最大,澳洲红维生素C含量、欧洲红花青素含量较高。陈天乐^[12]对北京基地栽植的24个树莓品种果实的感官品质、营养成分、香气成分等相关指标进行调查和测定,结果表明,R24和R33的综合性状较好,果实大小、营养成分含量突出,为育种亲本选择提供了依据。有研究对东北地区24个红树莓品种的综合品质进行评价,利用主成分分析法筛选出8个重要的加工属性指标,并初步筛选出糖酸比适宜、适合鲜食或直接加工成果汁或其他产品的品种^[13]。目前对于不同产地间红树莓营养品质的差异却鲜见报道。野生红树莓具有很高价值,尤其我国本土野生红树莓,不仅在糖分含量、口感气味及抵御病虫害方面有着优异表现,还具有可溶性固形物含量较高、丰产性和抗逆性较强等突出特点^[14]。近年来红树莓的综合利用逐渐成为研究热点,国内分布的野生红树莓也因具有较强的抗性且营养成分突出^[15],受到了更多研究者的关注。

河北省山区的红树莓资源丰富,挖掘出适应河北省的野生红树莓资源,对种质资源高效利用、功能食品开发和乡村振兴等具有重要意义。因此笔者依托河北省丰富的红树莓野生资源,进行果实特性的调查和测定,比较省内不同区域野生红树莓的果实品质差异,对果实品质进行综合评价,对合理开发利用红树莓野生资源、推进不同用途红树莓良种选择和定向育种具有重要作用。

1 材料和方法

1.1 研究区概况

河北省野生红树莓多沿燕山及太行山山区分

布,燕山和太行山都处于暖温带大陆性季风气候区。燕山、太行山年均温6~10℃,年降水量534~700 mm。河北省不同地区都具有较多的野生红树莓资源,依照河北省野生红树莓种质资源分布状况^[16],将调查地主要划分为4大区域,分别是冀东区(秦皇岛市)、冀北区(承德市)、冀西北区(张家口市)以及冀西太行山区(保定市),共包含13个样地。采集区具体信息如表1所示。

1.2 试验材料

于2020—2021年每年6—8月,在河北省4个分区共13个分布区域中,分别随机选取3~6株生长健壮、长势一致、具有代表性的野生红树莓植株,选取成熟度一致、果实面完全均匀着色、无病虫害的果实进行采集,各样地随机取样100个果实,设3次重复,分装后放入车载冰箱-16℃保存。

1.3 测定指标与方法

1.3.1 外部形态指标测定 在采集地现场进行外部形态指标测定,主要包括:(1)果实大小及果形:随机选取大小均匀的果实10颗,用数显游标卡尺测量果实横径、果实纵径,重复测定3次,精确到0.01 mm,计算果形指数(纵径/横径);(2)果实产量:随机选取新鲜采摘的不带花托的果实10个,置于电子天平上称取质量,重复测定3次,精确到0.01 g,计算平均去托单果质量。观测记录各植株的果实数量取均值,根据单果质量估算野生红树莓的单株产量。

1.3.2 内在营养成分测定 除可溶性固形物含量用仪器即时测定外,其他营养成分均是对前期采集并用车载冰箱保存带回的红树莓果实,进行-20℃低温冷冻,试验时进行破碎处理后测定。主要包括:(1)可溶性糖含量测定:蒽酮比色法^[17];(2)可滴定酸含量测定:氢氧化钠滴定法^[18];(3)可溶性固形物含量测定:手持折光仪测量,精确到0.01%,重复测定3~5次取平均值^[19];(4)可溶性蛋白含量测定:考马斯亮蓝染色法^[20];(5)维生素C含量测定:2,6-二氯酚酚滴定法^[21];(6)氨基酸含量测定:茚三酮显色法^[22];(7)黄酮含量测定:氯化铝显色法^[23];(8)总酚含量测定:福林酚试剂比色法^[24];(9)花青素含量测定:pH示差法^[25]。

1.4 数据处理

使用Excel进行统计分析,使用SPSS Statistics 24软件对不同区域野生红树莓的果实品质指标进行差异显著性分析、相关性分析、主成分分析及聚类分析。

表1 河北省野生红树莓分布区域样地地理位置

Table 1 Geographical location of sample plots of wild red raspberry distribution area in Hebei province

区域 Region	样地 Sample area	纬度 Latitude/°N	经度 Longitude/°E	海拔 Altitude/m
冀西北区 Northwest Hebei	张家口市下花园鸡鸣乡芦苇沟村 Luweigou village, Jiming town, Xiahuayuan district, Zhangjiakou city	40°30' 25.82"	115°24' 04.84"	1217
冀西北区 Northwest Hebei	张家口市赤城大海陀自然保护区 Dahaituo Nature Reserve, Chicheng county, Zhangjiakou city	40°36' 23.20"	115°44' 17.11"	1259
冀北区 Northern Hebei	承德市宽城县汤道河镇季杖子村 Jizhangzi village, Tangdaohe town, Kuancheng county, Chengde city	40°32' 29.00"	118°55' 03.00"	586
冀北区 Northern Hebei	承德市承德县六沟镇化营村 Huaying village, Liugou town, Chengde county, Chengde city	41°20' 46.00"	118°19' 04.00"	605
冀北区 Northern Hebei	承德市兴隆县兴隆镇王平石村 Wangpingshi village, Xinglong town, Xinglong county, Chengde city	40°21' 07.00"	117°34' 14.00"	678
冀北区 Northern Hebei	承德市滦平县金沟屯镇大杨树沟村 Dayangshugou village, Jingoutun town, Luanping county, Chengde city	41°01' 23.41"	117°12' 55.32"	941
冀北区 Northern Hebei	承德市隆化县茅荆坝乡千松甸村 Qiansongdian village, Maojingba town, Longhua county, Chengde city	41°31' 46.00"	118°17' 40.00"	1349
冀北区 Northern Hebei	承德市围场县马鞍山乡嵩松沟村 Songsongou village, Ma'anshan town, Weichang county, Chengde city	41°55' 23.00"	116°50' 18.00"	1642
冀东区 Eastem Hebei	秦皇岛市昌黎县两山乡长峪山村 Changyushan village, Liangshan town, Changli county, Qinhuangdao city	39°46' 54.00"	119°09' 55.00"	116
冀东区 Eastem Hebei	秦皇岛市抚宁县新寨镇小河峪村 Xiaoheyu village, Xinzhai town, Funing county, Qinhuangdao city	40°01' 41.00"	119°22' 30.00"	218
冀西太行山区 West Hebei Taihang Mountains	保定市易县千佛山森林公园 Qianfoshan Forest Park, Yi county, Baoding city	39°29' 34.00"	115°24' 28.00"	250
冀西太行山区 West Hebei Taihang Mountains	保定市涞水赵各庄镇平峪村 Pingyu village, Zhaogezhuang town, Laishui county, Baoding city	39°39' 32.00"	115°19' 13.00"	357
冀西太行山区 West Hebei Taihang Mountains	保定市阜平县龙泉关镇骆驼湾村 Luotuowan village, Longquanguan town, Fuping county, Baoding city	38°52' 46.00"	113°49' 30.00"	1767

2 结果与分析

2.1 野生红树莓果实特性

2.1.1 野生红树莓果实主要经济性状差异 13个样地的野生红树莓果实如图1所示。由表2可知,各地区野生红树莓果实的纵径与横径分别在9.64~14.41 mm、9.48~16.30 mm之间。其中兴隆、围场和隆化的红树莓果个显著大于其他地区,以兴隆地区的果个最大;宽城、承德县、滦平次之;而昌黎和阜平的果个最小,两地间果个差异不显著。综合对比发现,冀北区红树莓的果个显著大于其他地区,果形方面地区间差异不显著,除下花园、宽城、兴隆、承德县为圆形果外,其他地区均为圆锥形果。

野生红树莓果实产量有着明显区域性差异,各地区野生红树莓果实的单果质量及单株产量分别在0.34~2.03 g、23.89~306.70 g之间,其中兴隆地区果实的单果质量及单株产量显著高于其他地区;宽城

的单果质量及宽城、承德县和滦平的单株产量都次之;而昌黎和阜平果实的单果质量及单株产量最低,两地间差异不显著。综合比较发现,冀北区的单果质量及单株产量显著高于其他地区,其余各地均存在一定差异。

2.1.2 野生红树莓果实营养成分差异 由表3可知,各地区野生红树莓果实的可溶性蛋白与氨基酸含量(w ,后同)分别在1.10~1.97 mg·g⁻¹、9.84~12.96 mg·g⁻¹之间,抚宁红树莓的可溶性蛋白含量、赤城红树莓的氨基酸含量显著高于其他地区;各地区野生红树莓果实的维生素C与花青素含量有较大差异,分别在8.40~29.79 mg·100 g⁻¹、203.02~599.19 mg·kg⁻¹之间,赤城红树莓的维生素C含量、抚宁和昌黎红树莓的花青素含量显著高于其他地区;各地区野生红树莓果实中黄酮与总酚含量无区域性分布规律,分别在2.32~6.69 mg·g⁻¹、1.91~4.24 mg·g⁻¹之间,宽城地区红树莓的黄酮含量、滦平地区红树莓的总酚含量显著



A. 下花园;B. 赤城;C. 宽城;D. 承德县;E. 兴隆;F. 滦平;G. 隆化;H. 围场;I. 昌黎;J. 抚宁;K. 易县;L. 涑水;M. 阜平。

A. Xiahuayuan; B. Chicheng; C. Kuancheng; D. Chengde county; E. Xinglong; F. Luanping; G. Longhua; H. Weichang; I. Changli; J. Funing; K. Yi county; L. Laishui; M. Fuping.

图 1 13 个样地野生红树莓果实

Fig. 1 Fruits of wild red raspberries from 13 sample areas

高于其他地区。综合比较发现,冀西北区野生红树莓具有较高的维生素C和氨基酸含量;冀北区各样地营养成分存在个体差异;冀西太行山区和冀东区野生红树莓大多营养成分无显著差异,且相较其他地区具有较高的可溶性蛋白和花青素含量。

2.1.3 野生红树莓果实风味差异 果实内部可溶性糖和有机酸的含量,是影响水果风味最直观的因素。由表4可知,各地区野生红树莓的可溶性糖与可滴定酸含量存在显著差异,分别在 $51.24\sim 84.69\text{ mg}\cdot\text{g}^{-1}$ 、 $45.53\sim 75.27\text{ mg}\cdot\text{g}^{-1}$ 之间,宽城红树莓的可溶性糖含量、抚宁和易县红树莓的可滴定酸含量显著高于其他地区;各地区野生红树莓的糖酸比在 $0.72\sim 1.48$ 之间,兴隆的红树莓糖酸比最高,而昌黎最低;各地区野生红树莓的可溶性固形物含量与固酸比分别在 $9.53\%\sim 14.77\%$ 、 $1.45\sim 2.67$ 之间,下花园红树莓的2个指标均高于其他地区。

综合比较发现,冀西北区和冀北区的宽城、兴隆和围场有着较高的可溶性糖含量、固酸比和糖酸比,以及较低的可滴定酸含量,因此果实口味更甜、口感

更加丰富;而冀东区的昌黎和抚宁、冀西太行山区的易县、涑水和阜平果实中可溶性糖含量较低,可滴定酸含量较高,果实口味偏酸。

2.2 野生红树莓果实品质综合评价

2.2.1 果实品质性状相关性分析 对野生红树莓果实性状、产量、营养成分及其风味共18项指标进行相关性分析,由图2可知,共有19对指标相关性达到显著水平($p<0.05$),28对指标相关性达到极显著水平($p<0.01$)。在3个果形指标中,果实的横径与纵径呈极显著正相关,而与纵横比呈显著负相关;在4个果实产量指标中,单果质量和最大单果质量都与果实纵径和横径呈极显著正相关,而单株产量也与果实纵径、横径、单果质量和单株果数呈极显著正相关,说明果个和果数都显著影响野生红树莓的产量;在6个果实营养成分指标中,黄酮含量与可溶性蛋白含量呈极显著正相关,而与氨基酸含量呈极显著负相关,与维生素C含量呈显著负相关。花青素含量与多种果形以及果实产量指标呈显著、极显著负相关,即果个越大、单株产量越多的野生红树莓果实

表2 各区域野生红树莓的果实性状比较
Table 2 Comparison of fruit characters of wild red raspberries in each region

区域 Region	县域 County	纵径 Longitudinal diameter/mm	横径 Transverse diameter/mm	纵横比 Ratio of longitudinal diameter to transverse	果形 Fruit shape	单果质量 Single fruit mass/g	最大单 果质量 Maximum fruit mass/g	单株果数 Number of fruits per plant	单株产量 Yield per plant/g
冀西北区 Northwest Hebei	下花园 Xiahuayuan	11.52±0.33 c	12.94±0.34 d	0.89	圆形 Circular	0.74±0.01 d	1.41	97±2.03 d	71.21±1.49 d
冀西北区 Northwest Hebei	赤城 Chicheng	11.97±0.33 bc	12.36±0.30 de	0.97	圆锥形 Conicalness	0.79±0.02 cd	1.19	87±2.73 e	68.18±2.15 d
冀北区 Northern Hebei	宽城 Kuancheng	12.73±0.20 b	15.11±0.25 b	0.84	圆形 Circular	1.05±0.04 b	1.38	151±1.76 c	254.91±3.65 b
冀北区 Northern Hebei	承德县 Chengde county	11.68±0.34 c	14.16±0.26 bc	0.82	圆形 Circular	0.86±0.03 c	1.32	226±3.21 a	224.36±2.78 b
冀北区 Northern Hebei	兴隆 Xinglong	14.41±0.31 a	16.30±0.33 a	0.89	圆形 Circular	2.03±0.04 a	2.68	168±2.31 b	306.70±3.57 a
冀北区 Northern Hebei	滦平 Luanping	11.74±0.27 c	14.40±0.26 bc	0.82	圆锥形 Conicalness	0.85±0.03 c	1.36	242±3.46 a	248.96±3.26 b
冀北区 Northern Hebei	隆化 Longhua	13.82±0.24 a	14.02±0.19 c	0.99	圆锥形 Conicalness	0.83±0.02 c	1.36	164±2.64 b	138.62±2.14 c
冀北区 Northern Hebei	围场 Weichang	14.11±0.33 a	14.14±0.32 c	1.00	圆锥形 Conicalness	0.84±0.02 c	1.42	172±2.46 b	144.48±2.45 c
冀东区 Eastern Hebei	昌黎 Changli	9.64±0.18 d	9.78±0.12 g	0.96	圆锥形 Conicalness	0.34±0.01 e	0.48	68±2.31 f	23.89±0.49 e
冀东区 Eastern Hebei	抚宁 Funing	11.19±0.34 c	11.99±0.17 e	0.93	圆锥形 Conicalness	0.82±0.02 cd	1.12	83±2.91 e	137.20±1.89 c
冀西太行山区 West Hebei Taihang Mountains	易县 Yi county	10.42±0.24 cd	10.86±0.32 f	0.96	圆锥形 Conicalness	0.75±0.01 d	1.08	80±2.74 e	124.12±2.26 c
冀西太行山区 West Hebei Taihang Mountains	涿水 Laishui	10.36±0.32 cd	10.54±0.18 f	0.98	圆锥形 Conicalness	0.72±0.02 d	1.06	80±2.41 e	76.36±2.46 d
冀西太行山区 West Hebei Taihang Mountains	阜平 Fuping	9.98±0.27 d	9.48±0.26 g	1.05	圆锥形 Conicalness	0.46±0.03 e	0.68	72±1.78 f	36.21±0.83 e

注:同列不同小写字母表示差异显著($p<0.05$)。下同。

Note: Different small letters in the same column indicate significant difference at $p<0.05$. The same below.

含有的花青素含量越少;在5个果实风味指标中,固酸比与可溶性固形物含量呈显著正相关,与可滴定酸含量呈极显著负相关。而糖酸比不仅与可溶性糖含量和固酸比呈极显著正相关,与可滴定酸含量呈极显著负相关,还与果形指标纵径、横径呈极显著正相关,与果实产量指标中的单果质量和最大单果质量呈显著正相关,这说明影响果实风味的糖酸比和固酸比有协同一致的作用,且果形及单果质量越大的果实,其糖酸比越高,风味越好。

2.2.2 果实品质性状主成分分析 对各地区野生红树莓有关果实品质的18项指标进行主成分分析,共提取出特征值 >1 的4个主成分。由表5可知,4个

主成分方差贡献率由大到小依次为42.009%、26.101%、14.090%、6.330%,累积方差贡献率为88.530%,基本代表了果实指标中的18个性状,可作为评价指标。为了更好地解释成分,对其旋转后系数更接近1,使各成分贡献率在累积贡献率不变的情况下重新分配。

通过最大方差法旋转后的矩阵表6可知,第1主成分综合了最大单果质量、纵径、单果质量、横径、糖酸比、可滴定酸含量、花青素含量、单株产量和固酸比的信息,PC1较大时,果实的果个、单株产量较大,且可滴定酸含量、花青素含量、糖酸比和固酸比较高;第2主成分综合了纵横比、总酚含量和单株果数

表 3 各区域野生红树莓果实的营养成分

Table 3 Nutritional composition of wild red raspberry fruits in each region

区域 Region	县域 County	w(可溶性蛋白) Soluble protein content/ (mg·g ⁻¹)	w(氨基酸) Amino acids content/ (mg·g ⁻¹)	w(维生素C) Vitamin C content/ (mg·100 g ⁻¹)	w(黄酮) Flavonoids content/ (mg·g ⁻¹)	w(总酚) Total phenols content/ (mg·g ⁻¹)	w(花青素) Anthocyanins content (mg·kg ⁻¹)
冀西北区 Northwest Hebei	下花园 Xiahuayuan	1.10±0.01 g	12.47±0.05 b	22.83±0.30 b	2.33±0.02 e	1.91±0.05 e	388.98±4.04 c
冀西北区 Northwest Hebei	赤城 Chicheng	1.19±0.02 f	12.96±0.02 a	29.79±0.32 a	2.32±0.02 e	2.78±0.03 d	513.51±5.43 b
冀北区 Northern Hebei	宽城 Kuancheng	1.81±0.02 b	11.14±0.02 c	8.40±0.03 d	6.69±0.13 a	3.74±0.04 b	378.78±2.26 c
冀北区 Northern Hebei	承德县 Chengde county	1.48±0.02 d	12.38±0.03 b	8.54±0.03 d	3.82±0.02 d	3.82±0.04 b	376.36±2.07 c
冀北区 Northern Hebei	兴隆 Xinglong	1.50±0.02 d	10.07±0.03 d	12.53±0.10 c	5.34±0.14 c	2.69±0.05 d	203.02±3.61 e
冀北区 Northern Hebei	滦平 Luanping	1.37±0.02 e	12.46±0.03 b	8.69±0.14 d	3.72±0.04 d	4.24±0.02 a	269.62±4.29 d
冀北区 Northern Hebei	隆化 Longhua	1.62±0.01 c	11.16±0.03 c	12.66±0.02 c	5.39±0.08 c	2.64±0.04 d	386.74±3.73 c
冀北区 Northern Hebei	围场 Weichang	1.57±0.01 c	11.08±0.03 c	12.73±0.14 c	5.24±0.12 c	2.76±0.04 d	394.80±3.24 c
冀东区 Eastem Hebei	昌黎 Changli	1.48±0.02 d	9.92±0.03 d	8.54±0.08 d	3.89±0.06 d	2.73±0.03 d	587.82±5.64 a
冀东区 Eastem Hebei	抚宁 Funing	1.97±0.04 a	10.05±0.01 d	12.24±0.09 c	5.75±0.08 b	3.61±0.01 c	599.19±4.81 a
冀西太行山区 West Hebei Taihang Mountains	易县 Yi county	1.84±0.03 b	10.08±0.02 d	12.08±0.12 c	5.16±0.10 c	3.32±0.03 c	508.54±2.67 b
冀西太行山区 West Hebei Taihang Mountains	涞水 Laishui	1.78±0.02 b	9.84±0.02 d	11.82±0.28 c	5.64±0.12 b	2.84±0.03 d	496.65±3.21 b
冀西太行山区 West Hebei Taihang Mountains	阜平 Fuping	1.81±0.02 b	11.16±0.02 c	11.96±0.16 c	5.20±0.12 c	3.46±0.04 c	502.63±2.87 b

的信息,PC2较大时,果实的纵横比、单株果数较大,且总酚含量较高;第3主成分综合了黄酮、可溶性蛋白、氨基酸和维生素C含量的信息,PC3较大时,果实中这4个成分的含量较高;第4主成分综合了可溶性糖和可溶性固形物含量的信息,PC4较大时,果实中这2个成分的含量较高。

各地区的野生红树莓主成分得分及果实品质排名如表7所示,兴隆、围场和隆化地区,滦平、承德县和宽城地区,宽城、抚宁和阜平地区,宽城、下花园和隆化地区分别在第1至第4主成分的得分较高,果实品质较好;果实品质最终综合评价得分(*F*)排名前三位的分别是宽城、兴隆和围场。比较发现冀北区的野生红树莓相较其他区域有着突出的果实品质。

2.2.3 聚类分析 依据野生红树莓果实品质的18项指标对13个样地中分布的野生红树莓进行聚类分析。由图3可知,在欧式距离为7的情况下,可将

各样地的野生红树莓分为3类:第一类包括围场和隆化,此类野生红树莓果实品质相较其他地区,果个、糖酸比和固酸比相对较高,可用于营养成分含量均衡、果实风味相对较好的红树莓资源的筛选。第二类包括抚宁、易县、涞水、赤城、下花园、阜平和昌黎,此类野生红树莓果个、单果质量、单株果数以及单株产量较小,但部分营养元素含量较为突出,并且可以分为抚宁、易县和其他5个地区2个亚类,前者野生红树莓可溶性蛋白、花青素、可滴定酸含量较为突出,后者氨基酸、维生素C、可溶性固形物含量和固酸比较为突出,因此第二类可用于上述7个成分指标含量较高的红树莓资源筛选。第三类包括滦平、承德、宽城和兴隆,此类的野生红树莓果个、单果质量、单株果数以及单株产量都较为突出,且同样可分为滦平、承德县和宽城、兴隆2个亚类,前者的总酚含量较为突出,后者的黄酮、可溶性糖含量和糖酸

表4 各区域野生红树莓的风味特征

Table 4 Flavor characteristics of wild red raspberry fruit in each region

区域 Regional	县域 County	w(可溶性糖) Soluble sugar content/ (mg·g ⁻¹)	w(可滴定酸) Titratable acid content/(mg·g ⁻¹)	w(可溶性固形物) Soluble solids content/%	糖酸比 Sugar-acid ratio	固酸比 Solids-acid ratio
冀西北区 Northwest Hebei	下花园 Xiahuayuan	75.35±0.29 b	55.33±0.02 d	14.77±0.20 a	1.36	2.67
冀西北区 Northwest Hebei	赤城 Chicheng	69.10±0.13 c	53.83±0.03 e	11.23±0.15 b	1.28	2.09
冀北区 Northern Hebei	宽城 Kuancheng	84.69±0.23 a	62.30±0.03 c	11.07±0.12 bc	1.36	1.78
冀北区 Northern Hebei	承德县 Chengde county	66.47±0.18 d	72.17±0.02 b	10.54±0.03 c	0.92	1.45
冀北区 Northern Hebei	兴隆 Xinglong	67.30±0.26 d	45.53±0.02 g	9.53±0.09 d	1.48	2.09
冀北区 Northern Hebei	滦平 Luanping	66.98±0.14 d	71.30±0.03 b	10.57±0.29 c	0.94	1.48
冀北区 Northern Hebei	隆化 Longhua	69.45±0.34 c	52.86±0.02 e	11.02±0.01 bc	1.31	2.08
冀北区 Northern Hebei	围场 Weichang	69.54±0.21 c	50.70±0.03 f	10.97±0.03 bc	1.37	2.16
冀东区 Eastem Hebei	昌黎 Changli	51.24±0.16 f	71.23±0.02 b	10.42±0.18 c	0.72	1.46
冀东区 Eastem Hebei	抚宁 Funing	59.07±0.37 e	75.27±0.02 a	11.50±0.29 b	0.78	1.53
冀西太行山区 West Hebei Taihang Mountains	易县 Yi county	60.23±0.28 e	74.64±0.02 a	11.42±0.18 b	0.81	1.53
冀西太行山区 West Hebei Taihang Mountains	涿水 Laishui	62.54±0.18 e	72.46±0.02 b	11.18±0.22 b	0.86	1.54
冀西太行山区 West Hebei Taihang Mountains	阜平 Fuping	65.84±0.12 d	64.26±0.02 c	10.36±0.24 c	1.02	1.61

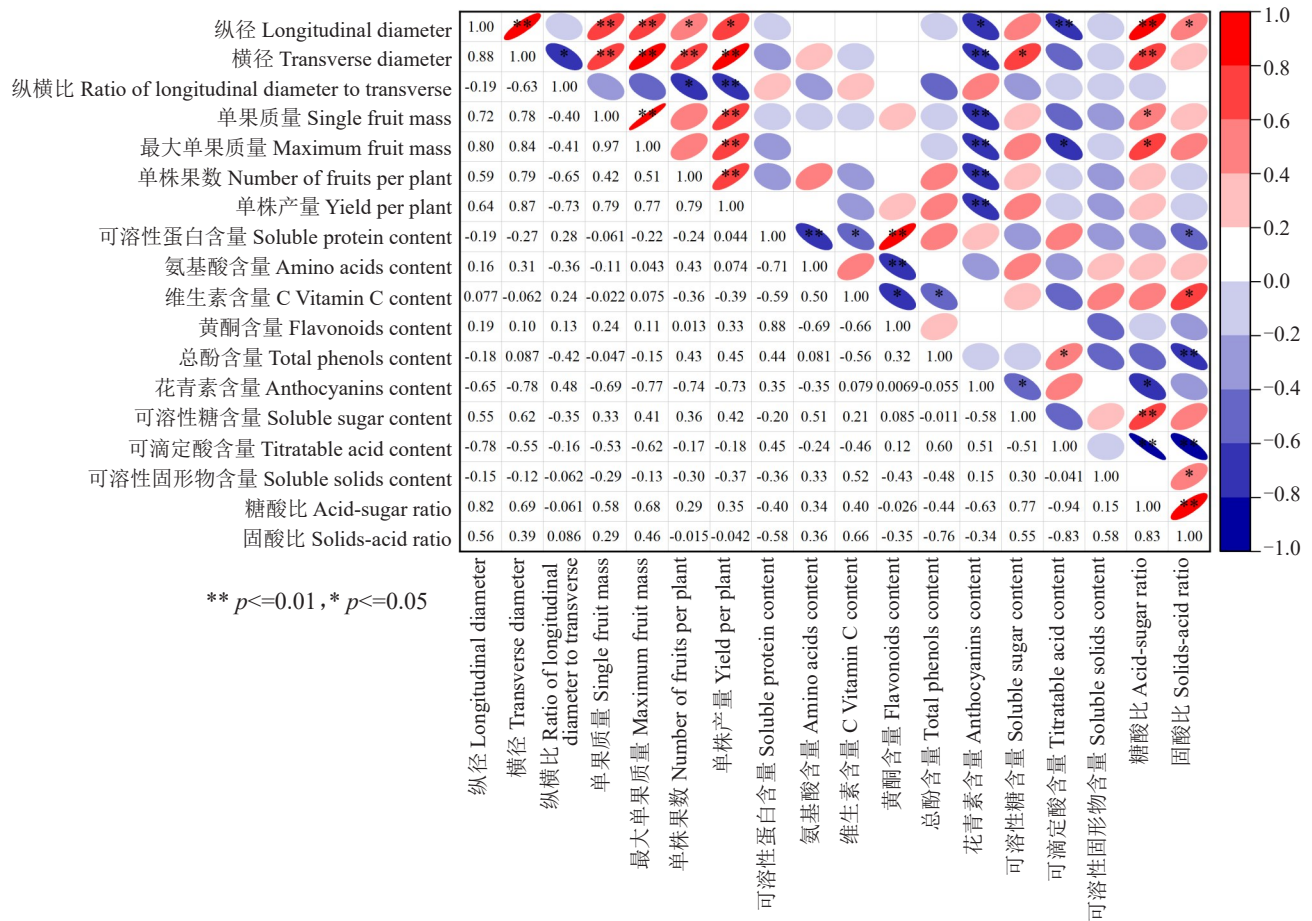


图2 野生红树莓果实品质性状相关性分析

Fig. 2 Correlation analysis of fruit quality traits of wild red raspberry

表5 野生红树莓果实品质的主成分特征值及方差贡献率

Table 5 Principal component eigenvalues and variance contribution of fruit quality of wild red raspberries from different areas

主成分 Principal component	提取载荷平方和 Extraction sum of squared loads			旋转载荷平方和 Rotation sum of squared loads		
	特征值 Eigen value	贡献率 Contribution rate/%	累积贡献率 Accumulated contribution rate/%	特征值 Eigen value	贡献率 Contribution rate/%	累积贡献率 Accumulated contribution rate/%
1	7.562	42.009	42.009	6.648	36.933	36.933
2	4.698	26.101	68.110	3.634	20.188	57.121
3	2.536	14.090	82.200	3.522	19.569	76.690
4	1.139	6.330	88.530	2.131	11.839	88.530

表6 野生红树莓果实品质的主成分因子旋转载荷矩阵

Table 6 Rotated loading matrix of principal component factors for fruit quality of wild red raspberry

指标 Index	主成分 1 PC1	主成分 2 PC2	主成分 3 PC3	主成分 4 PC4
最大单果质量 Maximum fruit mass	0.942	0.117	-0.041	-0.040
纵径 Longitudinal diameter	0.914	0.035	0.034	0.190
单果质量 Single fruit mass	0.904	0.123	0.108	-0.151
横径 Transverse diameter	0.851	0.437	-0.060	0.195
糖酸比 Sugar-acid ratio	0.806	-0.201	-0.162	0.493
可滴定酸含量 Titratable acid content	-0.794	0.415	0.240	-0.248
花青素含量 Anthocyanins content	-0.768	-0.404	0.154	-0.112
单株产量 Yield per plant	0.698	0.662	0.202	-0.046
固酸比 Solids-acid ratio	0.532	-0.467	-0.430	0.530
纵横比 Ratio of longitudinal diameter to transverse diameter	-0.245	-0.816	0.205	-0.086
总酚含量 Total phenols content	-0.238	0.814	0.350	-0.126
单株果数 Number of fruits per plant	0.521	0.752	-0.113	-0.011
黄酮含量 Flavonoids content	0.163	0.037	0.983	0.017
可溶性蛋白含量 Soluble protein content	-0.234	-0.002	0.944	-0.080
氨基酸含量 Amino acids content	0.045	0.371	-0.734	0.441
维生素C含量 Vitamin C content	0.065	-0.492	-0.662	0.307
可溶性糖含量 Soluble sugar content	0.465	0.224	-0.015	0.823
可溶性固形物含量 Soluble solids content	-0.233	-0.234	-0.400	0.660

表7 野生红树莓主成分得分及排名

Table 7 Principal component score and ranking of wild red raspberries from different regions

区域 Region	县域 County	F1	F2	F3	F4	F	排序 Ranking
冀北区 Northern Hebei	宽城 Kuancheng	0.394	1.030	1.453	1.858	0.969	1
冀北区 Northern Hebei	兴隆 Xinglong	2.613	-0.360	0.179	-1.417	0.858	2
冀北区 Northern Hebei	围场 Weichang	0.829	-0.625	0.305	0.402	0.324	3
冀北区 Northern Hebei	隆化 Longhua	0.702	-0.571	0.370	0.432	0.302	4
冀北区 Northern Hebei	滦平 Luanping	-0.062	2.150	-0.798	-0.443	0.229	5
冀北区 Northern Hebei	承德县 Chengde county	-0.163	1.826	-0.621	-0.437	0.153	6
冀东区 Eastem Hebei	抚宁 Funing	-0.754	-0.057	1.016	-0.193	-0.129	7
冀西太行山区 West Hebei Taihang Mountains	易县 Yi county	-0.721	-0.165	0.586	-0.407	-0.263	8
冀西太行山区 West Hebei Taihang Mountains	滦水 Laishui	-0.615	-0.562	0.715	-0.336	-0.271	9
冀西北区 Northwest Hebei	下花园 Xiahuayuan	-0.049	-0.700	-1.741	1.746	-0.331	10
冀西太行山区 West Hebei Taihang Mountains	阜平 Fuping	-0.938	-0.579	0.636	0.195	-0.357	11
冀西北区 Northwest Hebei	赤城 Chicheng	-0.030	-0.739	-1.784	0.142	-0.556	12
冀东区 Eastem Hebei	昌黎 Changli	-1.207	-0.646	-0.317	-1.543	-0.927	13

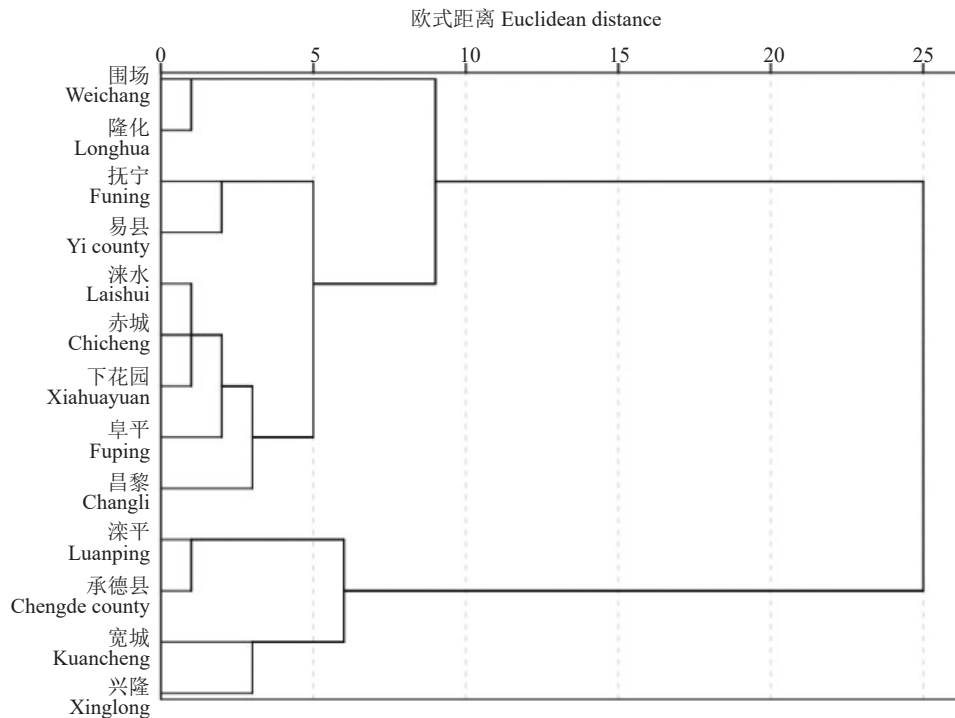


图3 各样地野生红树莓果实品质聚类分析

Fig. 3 Cluster analysis of fruit quality of wild red raspberry in various areas

比较为突出,因此第三类可用于果个、产量较大且上述4个成分指标含量较高的红树莓资源筛选。综合比较发现,冀北区的野生红树莓产量大、风味佳,适合鲜食生产,而其他3个区域的野生红树莓,果实有机物含量突出,适合加工生产。

3 讨论

3.1 野生红树莓的果实特性

野生红树莓果实的外部性状及产量通常受生长环境条件、基因等多个因素的影响^[26-27],存在区域性差异。本研究结果表明,冀北区的红树莓果个显著大于其他区域,且该区单果质量更大,单株产量更高,这可能是由于该区所处地理位置及其气候、土壤等环境因素利于果实生长或受优良种质因素影响。其中兴隆地区的红树莓果个和单株产量显著高于其他地区,其单果质量(2.03 g)显著高于宋建新等^[28]测定的Sunrise(1.62 g)、周双等^[9]测定的DNS9(1.82 g)及陈乐天^[12]测定的R22(1.606 5 g)、R10(1.857 g),有引种用于栽培生产的优势。

果实的维生素C、总酚和花青素等都是天然的抗氧化活性剂^[29],可帮助人体增强免疫力,促进新陈代谢。根据研究结果可知,河北省不同区域的野生红树莓果实的营养品质存在显著差异。综合比较发

现,冀西北区的野生红树莓具有较高的维生素C和氨基酸含量,其维生素C含量(22.83~29.79 mg·100 g⁻¹)与张家口地区海尔特兹红树莓测定结果相近^[30],但显著高于沈阳农业大学树莓种植基地采收的15个树莓品种(6.86~10.60 mg·100 g⁻¹)^[28],是其中维生素C含量最高品种Cuthbert的2~3倍;冀西太行山区和冀东区野生红树莓分别具有较高的可溶性蛋白和花青素含量,其中冀东区花青素含量(587.82~599.19 mg·kg⁻¹)是北京基地栽植的R4、R6、R7红树莓品种的2~3倍^[12],且各区域野生红树莓总酚含量(1.91~4.24 mg·g⁻¹)显著高于北京基地栽植的14个树莓品种(0.566~1.882 mg·g⁻¹)^[12],因此冀西北区、冀东区及冀西太行山区的红树莓果实富含天然抗氧化成分,具有较强的抗氧化活性,在延长食品加工保鲜期的同时,改善了口感,提高了营养价值^[31]。分析冀西北区维生素C含量较高的原因,可能是该区生长地光照充足,促进了植株的光合作用及生长发育。而冀东区花青素含量较高,则可能是由于该地区适宜的土壤条件和充足的降水促进了花青素积累,黄洁帆等^[32]在研究中发现,该地区野生红树莓的适生土壤均为酸性土,加之雨水条件充足,有助于提高植物对铝、镁等合成花青素等关键矿质元素的吸收能力,Pott等^[33]在黑加仑果实品质的研究中也证明了

降雨对果实中花青素的含量有积极影响。

综合比较各区域的果实风味发现,冀西北区和冀北部分地区的红树莓果实具有较高的糖分、糖酸比、固酸比及可溶性固形物含量,尤其冀西北区果实风味显著突出,原因可能是该区气候较为干旱,且山区地形起伏较大,导致昼夜温差变大,从而在一定程度上促进了果实中有机物的积累。王程宽等^[34]对柑橘品质的研究同样表明,昼夜温差显著影响果实风味,较大的昼夜温差有助于果实糖分累积。

3.2 野生红树莓的果实品质综合评价

使用科学合理的评估方法挑选出品质优良的种质,对育种工作至关重要^[35]。目前相关性分析、主成分分析及聚类分析被广泛应用在有关果实品质的数据分析和综合评价中^[36-37]。笔者通过对各样地中有关野生红树莓果实性状、产量、营养成分及其风味共18项指标进行相关性分析,发现19对指标相关性达到显著水平,28对指标相关性达到极显著水平,表明各项指标间既相互独立,又有一定关联性,相互影响。进而运用主成分分析,从18个果实品质指标中提取出4个主成分,包含所有品质指标88.530%的信息,可作为指标综合评价各样地的红树莓果实品质,并依据各指标得分综合评价不同样地的红树莓果实品质。

通过聚类分析,将13个样地的野生红树莓果实分为3类,在野生红树莓资源的开发利用中,果形大、产量且营养成分含量高的野生红树莓具有较高的价值,在优异种质选育中可以作为特异种质培养。

4 结 论

不同区域的野生红树莓果实特性及果实营养成分存在差异,冀北区的野生红树莓果个和产量显著大于其他区域;冀西北区的野生红树莓具有较高的维生素C和氨基酸含量;冀西太行山区和冀东区野生红树莓具有较高的可溶性蛋白和花青素含量;而冀北区各样地红树莓营养成分存在个体差异。经主成分分析和聚类分析后,果实品质综合得分排名前三位的地区为宽城、兴隆和围场,结合河北省分区得出,冀北区的野生红树莓产量大、风味佳,有发展为鲜食生产的潜质,而冀西北区、冀西太行山区和冀东区的野生红树莓,果实有机物含量突出,适合不同需求的加工生产。

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