

鲁丽苹果在不同产地果实风味及品质差异分析

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摘要:【目的】风味是苹果的重要品质因子, 明确不同产地鲁丽苹果果实风味品质指标的差异, 探究环境因子对苹果果实风味的影响, 对筛选适生区、改善果实风味具有重要意义。【方法】选取山东、河北、辽宁、新疆、陕西、山西、安徽等7个苹果主产省份17个县(市、区)鲁丽苹果果实为研究对象, 对其单果质量、硬度, 以及可溶性固形物、可溶性糖、可滴定酸含量等常规品质指标, 以及糖酸组分含量、香气成分进行检测, 分析不同产地鲁丽苹果果实风味品质差异。【结果】不同产地果实平均单果质量为196.71 g, 果实的果形指数差异不大, 在0.83~0.99之间, 变异系数仅为4.53%, 阿克苏、广饶和平度果实硬度相对较高, 在10.00 kg·cm²以上; 新疆阿克苏鲁丽苹果的可溶性固形物、可溶性糖和可滴定酸含量均为最大值。果实中糖组分中以果糖含量最高, 其含量(w)范围为30.94~55.08 mg·g⁻¹, 葡萄糖和蔗糖含量略低于果糖; 果实中的有机酸以苹果酸为主; 检测出香气成分65种, 其中酯类31种, 醇类22种, 醛类6种, 萜烯类2种, 其他类4种。【结论】不同的产地对鲁丽果实品质指标影响较大, 烟台蓬莱地区具有最大果实单果质量, 阿克苏具有高糖高酸的特点, 果实香气类型可划分为“果香型”。

关键词:鲁丽苹果; 不同地区; 风味品质; 香气

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Analysis of fruit flavor and quality variation of Luli apple from different regions

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Abstract: 【Objective】Apple planting area is widely distributed in China, involving 25 provinces. Affected by soil characteristics, altitude and climate, fruit quality indexes such as weight, color and sugars and acids differ in different growing areas, which lead to the flavor differences between producing areas. Fruit flavor is the internal quality of fruit, which is related to taste sense and olfactory sense. Taste perception is based on sweet and sour tastes, while olfactory sense is the smell of a mix of large number of volatile aromatic substances in the fruit. There have been few reports on the performance of new varieties in different producing areas, and there is a lack of objective and scientific evaluation system of fruit flavor. In this study, sugars, acids and aroma components of Luli apple fruit from 17 regions were determined, and the difference in fruit quality of the new variety in different regions was clarified. The study provides technical support for the promotion and application of the new variety. 【Methods】Fruit samples were collected from 12 regions in Shandong province and 5 in other provinces. During the ripening period of Luli apples in each region, 50 apple fruit were randomly selected from representative orchards. The quality indexes, such as single fruit weight, shape index, soluble solid content, titratable acid content, soluble sugar content, and sugar to acid ratio, were determined. High performance liquid

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chromatography (HPLC) was used to determine sugars and acids, and the aroma components of fruit were determined by headspace solid phase extraction (HS-SPME) and gas chromatography-mass spectrometry (GC-MS). The data were statistically analyzed with SPSS.19.0, and Origin 2018 was used for heat map. **【Results】** The average single fruit weight in each region was 196.71 g. The fruit shape index in different regions had little difference, ranging from 0.83 to 0.99. The variation coefficient of fruit shape index was only 4.53%. Fruit hardness of fruit from Aksu, Guangrao and Pingdu was higher than $10.00 \text{ kg} \cdot \text{cm}^{-2}$. Aksu had the highest value in soluble solids, soluble sugars and titratable acids. The contents of soluble solids and soluble sugars in fruit from Taian and Yanggu were low, but titratable acid content was high. Sugar to acid ratio was the highest in fruit from Mengyin (67.46) and the lowest in those from Tai'an (12.61). Among the sugar components in fruit, fructose was the highest, and its content ranged from 30.94 to 55.08 $\text{mg} \cdot \text{g}^{-1}$. Glucose content was the second highest, with an average of 18.05 $\text{mg} \cdot \text{g}^{-1}$. Sucrose content in fruit varied greatly and was highest in Mengyin (22.84 $\text{mg} \cdot \text{g}^{-1}$), which was 6.78 times that of the fruit from Tai'an, which was the lowest. The content of sorbitol in fruit in all regions was low, and the average content was 4.64 $\text{mg} \cdot \text{g}^{-1}$. Malic acid was the main organic acid in apple fruit, and its content was the highest among organic acids, with an average value of 2547.81 $\mu\text{g} \cdot \text{g}^{-1}$, followed by tartaric acid content, ranging from 321.58 to 564.11 $\text{mg} \cdot \text{g}^{-1}$. Fruit from Aksu and Guangrao had a higher tartaric acid content than the other areas. The average contents of oxalic acid, citric acid and succinic acid were 138.01 $\mu\text{g} \cdot \text{g}^{-1}$, 107.09 $\mu\text{g} \cdot \text{g}^{-1}$ and 85.57 $\mu\text{g} \cdot \text{g}^{-1}$, respectively. A total of 65 aroma components were detected from fruit samples from the 17 regions, including 31 esters, 22 alcohols, 6 aldehydes, 2 terpenes and 4 other aroma components. Fruit from Tai'an had the most abundant aroma components, with 41 aroma components detected, followed by Guangrao with 38 components. Fruit from Jieshou was least in aroma abundance with only 17 detected. There were 13 common aroma components in Luli fruit from the 17 regions. The main aroma components in samples from Jieshou and Yanggu were aldehydes and alcohols, accounting for 48.49% and 37.01% of the total aroma components, respectively. Esters were the main volatile substances in Luli fruit from the other 15 regions, accounting for more than 48% of the total aroma. The typical correlation analysis of fruit aroma components and sugar and acid contents showed that glucose, citric acid, succinic acid and sucrose were closely related to the aroma, while fructose and malic acid had limited effects on the aroma. **【Conclusion】** The fruit appearance quality, sugar, acid, aroma and other flavor quality indexes of Luli apple from different regions were compared and analyzed. The single fruit weight was the largest in fruit from Penglai. The hardness and soluble solids content of Luli apple were higher than those of mid-early maturing apples in the Chinese national standard 《Fresh apple》. Fructose was higher in fruit from Huangsanjiao, Wanrong, and Guangrao. Fruit from Aksu, Pingdu and Huangsanjiao contained higher malic acid. Luli apple was rich in aroma substances, with a total of 65 species were detected. This paper preliminarily reported the quality performance of Luli apple in different regions of our country, which has certain reference significance for determining suitable areas for production of Luli apple in our country.

Key words: Luli apple; Different regions; Flavor quality; Aroma

我国苹果栽培面积、总产量、人均占有量与出口量均居世界第一,是世界上最大的苹果生产和消费国^[1]。苹果种植区域在我国广泛分布,涉及25个省份,除黄土高原、环渤海、黄河故道和西南冷凉高地产区等四大主产区外,在部分省份如内蒙古、黑龙

江、新疆等地还有特色的生产区分布^[2]。因受土壤特性、海拔和气候环境的影响,不同种植地区果实质量、着色、糖酸含量等品质指标存在差异,从而导致产地之间的风味差异^[3]。风味是苹果的重要品质因子^[4],不仅决定了其食用性,而且使其具有了区别于其他水

果的风味特点^[5]。目前研究认为果实风味是果实的内在品质,由味感和嗅感构成^[6]。味感以甜味、酸味为评价指标,并依此将苹果分为甜、酸甜、酸甜适度、甜酸和酸5类^[7];嗅感是由嗅觉感知到的果实中大量混合挥发性芳香物质,包括酯、醇、醛、酮等香气成分^[8]。随着我国自育苹果品种日益丰富和多样化,新品种在不同地域环境下果实风味品质差异的相关研究受到越来越多的关注^[9],对影响果实品质的环境因子的研究,可以筛选适生区,生产具有独特风味的果品^[10]。产地环境的不同可以通过果实糖、酸、香气等不同的风味指标表现出来^[11]。温度决定果树生长和品质的形成,苹果生长旺季时18~24℃可以促进同化作用,提高果实糖分积累量^[12];果树的生长状况与其所处的光环境密切相关,光强较弱的条件下,果实中糖的积累量明显减少,黄酮的积累量也随之降低^[13-14],红光和蓝光的光谱分别能促进可溶性糖的积累和叶绿素的合成^[15-16]。目前关于苹果风味的研究

大多集中在不同品种的比较方面^[17-18],对于不同产地果实风味差异的研究较少,尤其是新品种在不同产区的表现情况鲜有报道。笔者在本研究中以采自17个地区鲁丽苹果为试验材料,对果实糖、酸组分及香气物质进行测定,通过比对分析,明确在不同地区果实品质差异,为进一步推广和应用提供技术支持。

1 材料和方法

1.1 材料

果实样品分别采自山东、辽宁、新疆、山西、安徽及河北的17个县(市、区)(表1)。各产地通过淀粉-碘染色法确定果实成熟后,选择果树树龄相当、栽培管理和树势基本一致的果园进行采果。随机选取5株健壮、无病虫害的果树,在树冠外围、离地1.5 m以上的位置选择无机械损伤、无病虫害的成熟果实。每个果园采果实50个,带回实验室4℃低温保存备用。

表1 样品采集地及采样时间

Table 1 Sample collection site and sampling time

编号 Number	产地 Origin	采样时间 Picking date	编号 Number	产地 Origin	采样时间 Picking date
1	辽宁省台安县 Tai'an County, Liaoning Province	2022-08-20	10	山东省平度市 Pingdu City, Shandong Province	2022-08-08
2	山东省高密市 Gaomi City, Shandong Province	2022-08-04	11	山东省坊子区 Fangzi District, Shandong Province	2022-08-03
3	新疆维吾尔自治区阿克苏市 Aksu City, Xinjiang	2022-08-10	12	山东省即墨区 Jimo District, Shandong Province	2022-08-06
4	山东省蓬莱区 Penglai District, Shandong Province	2022-08-10	13	山西省万荣县 Wanrong County, Shanxi Province	2022-08-02
5	山东省山亭区 Shanting City, Shandong Province	2022-08-05	14	山东省黄三角(黄河三角洲农业高新技术产业示范区) Huangsanjiao, Shandong Province	2022-08-02
6	山东省广饶市 Guangrao City, Shandong Province	2022-08-07	15	安徽省界首市 Jieshou City, Anhui Province	2022-07-23
7	山东省蒙阴县 Mengyin County, Shandong Province	2022-08-08	16	河北省固安县 Gu'an County, Hebei Province	2022-08-12
8	山东省乐陵市 Laoling City, Shandong Province	2022-08-03	17	山东省阳谷县 Yanggu County, Shandong Province	2022-07-25
9	山东省茌平区 Chiping District, Shandong Province	2022-07-28			

1.2 测定方法

1.2.1 品质指标测定 平均单果质量:随机选取30个苹果进行称量,计算平均值;果形指数:使用游标卡尺测量果实纵径和横径,计算纵横径比值;硬度:在果实赤道处阴阳两面去皮后,用GY-1型硬度计测定果实硬度;可溶性固形物含量:用PAL-1型数字糖度计进行测定;采用蒽酮比色法测定可溶性糖含量;

可滴定酸:采用GMK-855F便携式酸度计测定可滴定酸含量;糖酸比:可溶性糖与可滴定酸的比值。

1.2.2 糖酸组分测定 将苹果切碎后,称取10 g样本,加入40 mL水研磨捣碎成浆,超声浸提60 min,8000 g离心10 min,取出上清液。上清液定容至40 mL。取适量上清液用针头式过滤器过滤后,用水稀释5倍后上机检测。使用Waters 1525高效液相色谱仪和

RIGOL L3000 高效液相色谱仪进行测定。糖组分检测条件:使用 Multospher Sugar 色谱柱(250 mm×4.6 mm, 5 μm),柱温 40 °C,流动相:乙腈、水体积比 70:30,流速为 1.0 mL·min⁻¹,进样体积为 10 μL。酸组分检测条件:色谱柱使用 Kromasil C₁₈反相色谱柱(250 mm×4.6 mm, 5 μm),柱温 30 °C,流动相:0.1 mol·L⁻¹的磷酸二氢钠溶液(pH=2.5)、甲醇体积比 95:5,流速为 1.0 min,检测时长 20 min,进样体积 10 μL,检测波长 214 nm。

1.2.3 挥发性物质测定 采用顶空固相萃取(HS-SPME)和气相色谱-质谱联用(GC-MS)检测果实香气成分。首先进行萃取头的老化,选用的是 PDMS/DVB 黑色萃取头,厚度为 65 μm。老化温度为 250 °C,时间为 0.5 h。将苹果解冻后迅速切成 0.2 cm×0.2 cm×0.2 cm 的碎块并混匀准确称取 5 g 样品放入 50 mL 的锥形瓶中,并加入 3 μL 内标物 2-辛醇(0.016 44 g·L⁻¹),用锡箔纸进行密封。将准备好的样品瓶放置在磁力搅拌器上,设定温度为 40 °C,同时将老化好的萃取头插入到样品瓶中进行固相顶空萃取 30 min,吸附成分后立即注射至 GC 进样口进行解析。解析时间为 5 min。色谱条件:选用 Restek Rtx-5MS;进样口温度 230 °C;柱温 40 °C 保持 3 min,以 6 °C·min⁻¹升至 120 °C,以 10 °C·min⁻¹升至 180 °C;最后以 15 °C·min⁻¹升温至 230 °C并保持 7 min。质谱条件:载气 He 气,柱流量 1.0 mL·min⁻¹,电离方式 EI,电子能量 70 eV,离子源温度 200 °C,扫描质量范围 45~450 amu。

挥发性成分的定性方法:未知化合物经计算机检索,同时与质谱库 NIST17-1、NIST17-2、NIST17-S 相匹配,确认各种挥发性成分。定量方法:根据公式计算出各组分的含量(w):

各组分含量($\mu\text{g}\cdot\text{g}^{-1}$)=各组分峰面积/(内标峰面积× m)× $C_{\text{内标}}\times V_{\text{内标}}\times 1000$; m :样品质量(g); $C_{\text{内标}}$:内标质量浓度($\text{g}\cdot\text{L}^{-1}$); $V_{\text{内标}}$:内标体积(μL)。

1.3 数据处理与分析

采用 Excel 2017 软件进行数据统计和分析,采用 SPSS 19.0 软件进行差异显著性分析,使用 Origin 2018 作热图。

2 结果与分析

2.1 不同产地鲁丽果实主要品质比较

17个产地鲁丽果实品质指标的测定结果如表 2

所示,由表 2 可知,除果形指数外,其他几项指标变异系数均在 10%以上,可见不同产地间果实品质差异较大。烟台蓬莱产地果实单果质量最大,为 260.87 g,显著高于其他产地,最小的为山亭,为 148.81 g;不同产地果实的果形指数差异不大,在 0.83~0.99 之间,变异系数仅为 4.53%,离散程度较小;阿克苏、广饶和平度产地果实硬度相对较高,在 10.00 kg·cm⁻²以上,蒙阴、茌平、即墨和阳谷产地果实硬度较低,低于 8.0 kg·cm⁻²;阿克苏产地果实可溶性固形物、可溶性糖和可滴定酸含量均有最大值,3 种品质指标含量分别为最低产地的 1.67 倍、1.64 倍和 2.27 倍,果实高糖高酸的特点可能与当地高日照时数和昼夜温差有关^[9];糖和酸的比例很大程度上影响果实的甜酸口味,糖酸比以山亭产地的最高,为 81.64,台安最低,为 30.93,且 7 项果实品质指标中,糖酸比变异系数最高,说明地域因素对鲁丽苹果甜酸风味影响较大。

2.2 不同产地鲁丽果实糖酸组分差异分析

从表 3 可以看出,17个产地鲁丽苹果果实中 4 种糖组分存在显著差异。果实糖组分中以果糖含量最高,其含量范围为 30.94~55.08 mg·g⁻¹,其中黄三角、万荣、广饶等地果糖含量较高,在 50.00 mg·g⁻¹以上,茌平含量最低,为 30.94 mg·g⁻¹;葡萄糖含量仅次于果糖,平均含量为 18.05 mg·g⁻¹,除蒙阴、平度产地外,其余产地葡萄糖含量均高于蔗糖含量;果实中蔗糖含量差异较大,含量最高的蒙阴产地为 22.84 mg·g⁻¹,是含量最低的台安的 6.78 倍;各产地果实中山梨醇含量较低,平均含量为 4.64 mg·g⁻¹,仅阿克苏山梨醇含量高于 10 mg·g⁻¹,其他产地含量在 0.51~8.33 mg·g⁻¹之间。

从表 3 可以看出,不同产地鲁丽果实中,有机酸均以苹果酸含量最高,平均含量为 2547.81 μg·g⁻¹,是苹果中最主要的有机酸;酒石酸含量次于苹果酸,含量范围为 321.58~564.11 μg·g⁻¹,阿克苏和广饶产地的酒石酸含量较高,在 550 μg·g⁻¹以上,低于 400 μg·g⁻¹的产地为台安和茌平;各产地果实中草酸、柠檬酸、琥珀酸含量较低,平均含量分别为 138.01、107.09 和 85.57 μg·g⁻¹。同一产地不同酸组分含量有较大差异,阿克苏产地果实苹果酸和酒石酸含量较高,而琥珀酸含量较低;山亭产地果实 5 种酸组分含量均处于较低水平;阳谷产地果实酒石酸、柠檬酸、琥珀酸含量较高,苹果酸和草酸含量为中等水平。

表 2 17 个地区鲁丽果实品质差异

Table 2 Quality comparison of Luli apple fruits from 17 regions in China

产地 Origin	单果质量 Single fruit mass/g	果形指数 Fruit shape index	硬度 Fruit firmness/ (kg·cm ⁻²)	w(可溶性固形物) Soluble solids content/%	w(可溶性糖) Soluble sugar/%	w(可滴定酸) Titratable acid content/%	糖酸比 RST
台安 Tai'an	177.14±28.65 ef	0.97±0.05 ab	8.12±0.88 de	12.11±0.67 k	10.48±0.47 fg	0.34±0.04 ab	30.93±4.39 f
高密 Gaomi	164.88±11.17 fg	0.89±0.04 cd	8.06±0.87 de	13.87±1.10 hi	11.80±1.09 defg	0.18±0.05 ef	69.03±19.43 abc
阿克苏 Aksu	178.21±27.75 ef	0.86±0.04 e	10.03±0.94 ab	20.24±0.91 a	16.74±1.09 a	0.39±0.08 a	44.50±9.21 cdef
蓬莱 Penglai	260.87±18.56 a	0.89±0.05 cd	8.48±0.70 d	14.60±1.19 gh	11.61±0.57 efg	0.29±0.03 abcd	39.72±3.06 def
山亭 Shanting	148.81±15.39 g	0.96±0.05 ab	8.74±0.89 cd	15.11±0.85 fg	13.52±0.63 bcdef	0.17±0.03 f	81.64±17.22 a
广饶 Guangrao	193.49±23.20 cde	0.96±0.05 ab	10.39±0.77 a	16.23±0.90 de	13.68±0.87 bcde	0.28±0.04 abcde	49.15±9.52 bcdef
蒙阴 Mengyin	228.66±29.44 b	0.93±0.05 abc	7.71±0.73 ef	13.56±0.52 ij	11.24±0.82 efg	0.17±0.04 ef	66.77±10.36 abcd
乐陵 Laoling	230.77±19.49 b	0.92±0.05 bc	9.65±0.92 ab	15.62±0.72 ef	12.42±2.25 bcdefg	0.34±0.05 ab	36.70±3.95 ef
茌平 Chiping	177.29±16.58 ef	0.83±0.05 de	7.01±0.69 f	12.44±0.67 k	10.94±2.46 efg	0.17±0.06 f	68.54±20.05 abc
平度 Pingdu	162.69±18.47 fg	0.91±0.07 bc	10.42±0.65 a	15.66±0.42 ef	14.87±2.61 acdb	0.26±0.06 bcdef	60.21±25.65 abcde
坊子 Fangzi	185.57±17.29 de	0.91±0.07 bc	8.09±0.76 de	14.89±1.08 fg	13.68±0.39 bcde	0.25±0.08 bcdef	58.37±20.98 abcde
即墨 Jimo	198.25±15.49 cd	0.95±0.05 abc	7.61±0.70 ef	15.04±0.96 fg	13.43±0.90 bcdef	0.18±0.01 ef	75.55±1.72 ab
万荣 Wanrong	178.15±16.05 ef	0.93±0.05 abc	9.88±0.99 ab	17.70±0.81 b	15.32±3.24 ab	0.22±0.02 cdef	72.10±19.36 abc
黄三角 Huangsanjiao	236.91±22.90 b	0.94±0.07 abc	9.35±0.49 bc	17.34±1.78 bc	15.41±1.26 ab	0.21±0.04 def	76.23±13.39 ab
界首 Jieshou	226.20±25.88 b	0.99±0.05 a	8.80±0.47 cd	15.18±0.74 fg	12.08±2.25 cdefg	0.24±0.10 bcdef	55.54±19.60 abcde
固安 Gu'an	209.85±13.89 c	0.95±0.07 abc	9.54±0.86 b	16.62±0.88 cd	14.99±1.47 abc	0.20±0.06 def	79.33±15.06 a
阳谷 Yanggu	187.14±19.38 de	0.88±0.06 cd	7.43±0.60 ef	12.76±0.83 jk	10.22±1.09 g	0.32±0.09 abc	33.62±8.38 ef
平均值 Average	196.71	0.92	8.77	15.23	13.19	0.25	58.70
标准偏差 Standard deviation	36.06	0.04	1.29	2.00	2.43	0.08	20.54
变异系数 CV/%	18.33	4.53	14.71	13.11	18.40	33.52	34.99

注: 不同小写字母表示差异达显著水平($p<0.05$)。下同。

Note: Different small letters indicate significant difference ($p<0.05$). The same below.

2.3 不同产地鲁丽果实香气分析

17个产地鲁丽苹果主要挥发性物质种类如图1所示,主要有酯类、醇类、醛类组成,还有萜烯类及其他香气成分,挥发性物质含量和种类差异构成了苹果香味的特异性。界首、阳谷地区果实主要的香气种类分别是醛类和醇类,占其香气成分总含量的48.49%和37.01%;其余15个产地鲁丽果实挥发性物质均以酯类为主,占总香气的48%以上。酯类成分含量在高密表现最高,为711.49 $\mu\text{g}\cdot\text{kg}^{-1}$,乐陵次之,其成分含量为676.26 $\mu\text{g}\cdot\text{kg}^{-1}$,界首酯类含量最低,仅占其香气成分总含量的36.87%。果实香气中醇类物质含量在85.69~348.35 $\mu\text{g}\cdot\text{kg}^{-1}$,阳谷的醇类物质含量最高,是含量最低的界首的4.07倍。17个地区果实香气中醛类物质平均含量为220.55 $\mu\text{g}\cdot\text{kg}^{-1}$,醛类含量大于250 $\mu\text{g}\cdot\text{kg}^{-1}$ 的地区有7个,其中阿克苏最高,为301.91 $\mu\text{g}\cdot\text{kg}^{-1}$ 。果实中萜烯类香气成分含量较低,最高的为阳谷,含量为75.76 $\mu\text{g}\cdot\text{kg}^{-1}$,茌平和界首未检测出萜烯类物质。

由图2可知,17个产地鲁丽果实共检测出香气成分65种,其中酯类31种,醇类22种,醛类6种,萜烯类2种,其他类4种。在各产地中,台安香气成分最丰富,共检测出41种香气成分,其次是广饶,检测出38种成分,界首香气成分最少,仅检测出17种。17个地区鲁丽果实共有香气成分13种,分别为:乙酸丁酯、2-甲基丁基乙酸酯、乙酸己酯、2-甲基丁酸丁酯、丙酸己酯、2-甲基丁酸己酯、3-甲基-1-丁醇、2-甲基-1-丁醇、己醇、2-乙基己醇、正己醛、2-己烯醛和草蒿脑;独有的香气成分有17种,包括9种酯类,6种醇类,1种醛类和1种酮类。

在果实香气成分含量方面,各产地果实香气成分含量差异较大,以高密香气总含量最高为1 241.09 $\mu\text{g}\cdot\text{kg}^{-1}$,黄三角香气含量次之为1 071.17 $\mu\text{g}\cdot\text{kg}^{-1}$,界首香气成分总含量最低,仅为585.25 $\mu\text{g}\cdot\text{kg}^{-1}$ 。酯类物质中2-甲基丁基乙酸酯和乙酸乙酯含量最高,二者平均占其所含酯类成分含量的64.31%,乙酸乙酯是苹果中常见的香气成分,在高密含量最高,在蓬莱表现最

表 3 17 个地区鲁丽果实糖酸组分差异

Table 3 Variation of sugar and acid components in Luli apple fruits from 17 regions

产地 Origin	果糖 Fructose/ (mg·g ⁻¹)	葡萄糖 Glucose/ (mg·g ⁻¹)	蔗糖 Sucrose/ (mg·g ⁻¹)	山梨醇 Sorbitol/ (mg·g ⁻¹)	苹果酸 Malic acid/ (μg·g ⁻¹)	草酸 Oxalic acid/ (μg·g ⁻¹)	酒石酸 Tartaric acid/ (μg·g ⁻¹)	柠檬酸 Citric acid/ (μg·g ⁻¹)	琥珀酸 Succinic acid/ (μg·g ⁻¹)
台安 Tai'an	37.61± 3.21 g	12.68± 1.16 f	3.37± 0.26 g	0.51± 0.05 i	1 922.41± 145.23 fgh	108.28± 7.62 gh	325.07± 17.64 e	81.37± 3.92 ef	73.95± 2.53 cdef
高密 Gaomi	45.17± 3.50 cde	23.66± 2.45 b	8.61± 0.26 ef	4.54± 0.87 de	1 835.24± 110.51 gh	119.89± 12.61 fg	538.91± 18.51 b	127.04± 11.10 cd	89.12± 5.36 c
阿克苏 Aksu	52.05± 1.54 ab	27.23± 3.11 a	3.74± 0.22 g	16.53± 1.04 a	3 626.60± 211.56 a	149.19± 22.23 cde	564.11± 30.84 a	139.66± 7.16 bc	69.19± 6.20 ef
蓬莱 Penglai	38.82± 1.70 fg	16.61± 1.25 de	8.72± 0.46 ef	1.82± 0.54 hi	2 512.48± 137.00 bc	120.41± 7.89 fg	402.29± 15.66 d	129.55± 28.65 cd	63.88± 4.10 f
山亭 Shanting	45.46± 2.63 cde	17.87± 0.93 d	13.58± 0.47 cd	3.28± 0.43 efgh	1 728.55± 121.84 h	83.95± 3.16 i	451.20± 32.13 c	71.49± 15.93 fg	72.30± 1.78 cdef
广饶 Guangrao	53.84± 1.04 ab	18.22± 1.38 d	8.78± 0.88 ef	4.09± 0.65 defg	2 222.37± 101.68 de	166.50± 10.67 bc	562.03± 21.89 a	58.54± 3.91 g	122.38± 10.06 b
蒙阴 mengyin	42.61± 1.01 efg	13.96± 0.76 f	22.84± 1.83 a	1.65± 0.55 hi	2 795.74± 80.94 b	181.17± 11.74 ab	429.32± 12.44 cd	131.97± 11.07 cd	83.50± 7.55 cde
乐陵 Laoling	43.46± 1.72 def	16.79± 0.73 de	9.23± 0.80 ef	7.25± 0.77 b	2 727.82± 257.53 b	126.31± 8.20 efg	466.40± 10.28 c	80.64± 6.43 ef	32.66± 2.72 g
茌平 Chiping	30.94± 3.57 h	8.15± 0.87 g	7.49± 0.55 f	1.70± 0.79 hi	2 032.34± 138.38 efg	145.63± 7.71 cde	321.58± 7.66 e	92.02± 5.33 e	87.05± 10.52 cd
平度 Pingdu	51.74± 0.80 ab	18.89± 0.66 d	19.85± 4.01 b	6.88± 0.78 bc	3 579.45± 89.01 a	157.83± 6.23 cd	516.04± 12.60 b	88.84± 10.83 ef	67.52± 2.66 ef
坊子 Fangzi	48.43± 2.15 bcd	16.73± 1.26 def	14.73± 0.72 c	2.62± 0.87 gh	2 764.43± 151.29 b	151.63± 10.33 cd	426.29± 47.04 cd	128.36± 9.10 cd	112.50± 7.07 b
即墨 Jimo	49.09± 2.45 bcd	17.96± 0.91 d	15.00± 0.93 c	2.74± 0.19 fgh	2 383.18± 291.39 cd	140.72± 9.02 def	460.88± 28.73 c	71.32± 19.77 fg	72.96± 3.06 cdef
万荣 Wanrong	52.64± 0.51 ab	19.50± 0.54 cd	13.31± 0.64 cd	4.36± 0.80 def	2 540.23± 131.39 bc	97.31± 8.71 i	464.56± 9.49 c	82.95± 2.63 ef	40.71± 7.51 g
黄三角 Huangsanjiao	55.08± 3.57 a	21.91± 1.24 bc	4.11± 0.62 g	8.33± 1.16 b	3 765.18± 90.71 a	180.96± 5.02 ab	516.61± 8.41 b	151.92± 10.80 b	64.10± 2.89 f
界首 Jieshou	43.40± 1.35 def	17.06± 0.37 d	11.09± 0.57 de	5.63± 0.29 cd	2 171.64± 338.74 def	200.85± 10.84 a	429.96± 15.95 cd	120.32± 4.45 d	73.74± 6.29 cdef
固安 Gu'an	44.84± 3.85 cde	17.70± 1.06 d	11.87± 1.09 d	4.26± 0.40 def	1 972.03± 51.50 efgh	57.90± 2.45 j	549.44± 33.18 ab	83.74± 7.67 ef	71.31± 4.45 def
阳谷 Yanggu	49.70± 3.31 bcd	21.95± 0.87 bc	8.65± 0.40 ef	2.74± 0.76 fgh	2 733.14± 113.21 b	157.72± 14.86 cd	542.12± 22.89 ab	180.76± 21.03 a	257.76± 17.32 a
均值 Average	46.17± 6.24	18.05± 4.19	10.88± 5.18	4.64± 3.63	2 547.81± 610.13	138.01± 36.20	468.64± 73.21	107.09± 33.08	85.57± 47.83

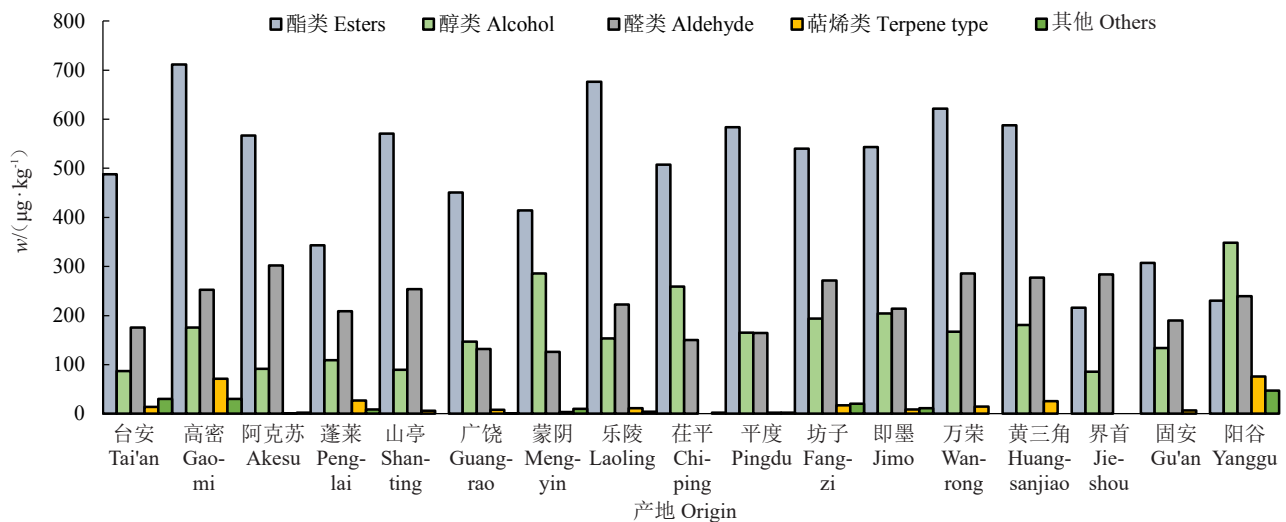


图 1 不同地区鲁丽果实香气成分种类及含量

Fig. 1 Aroma components and content of Luli apple fruits in different regions of China

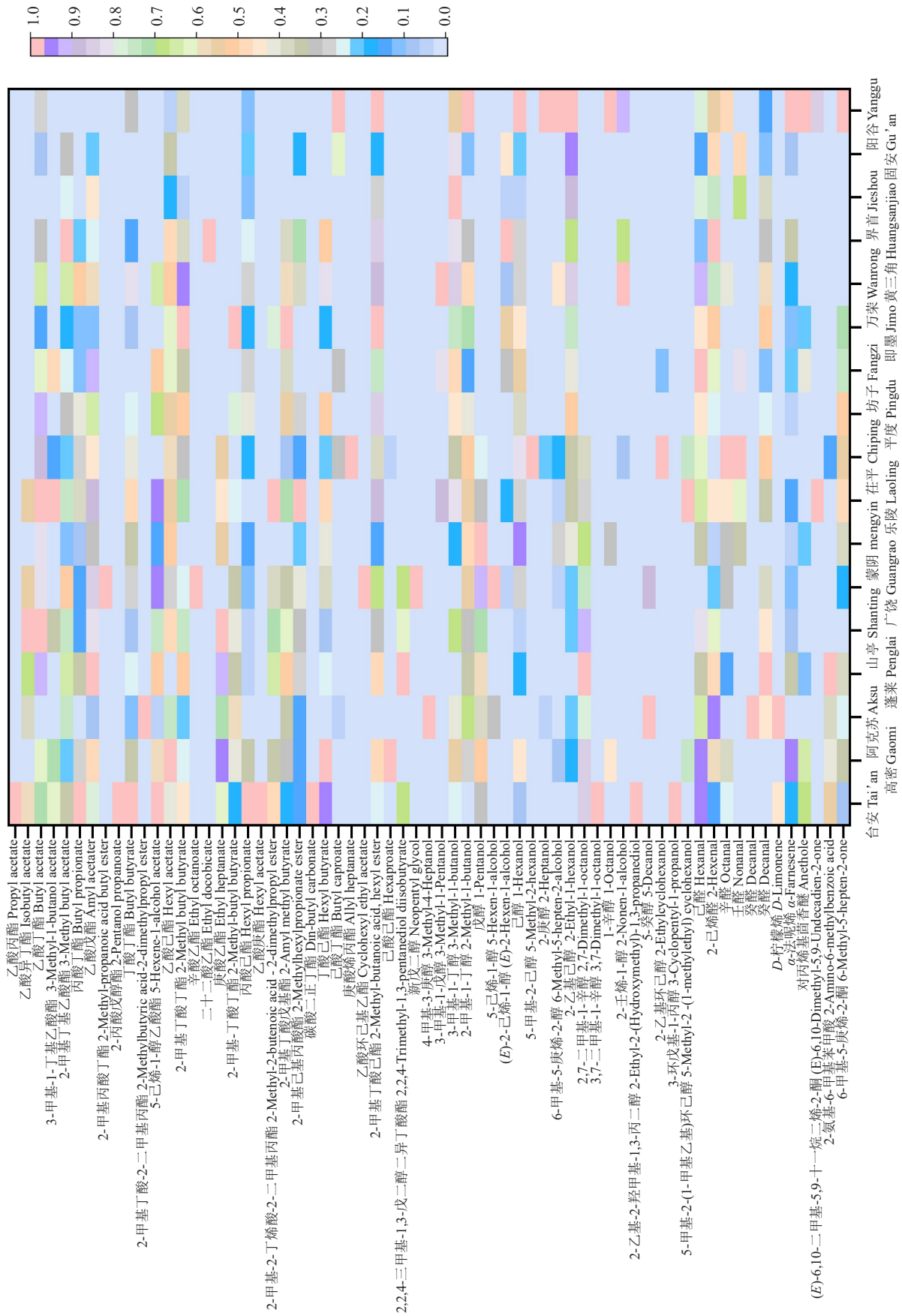


图 2 17 个地区鲁丽苹果香气成分热图

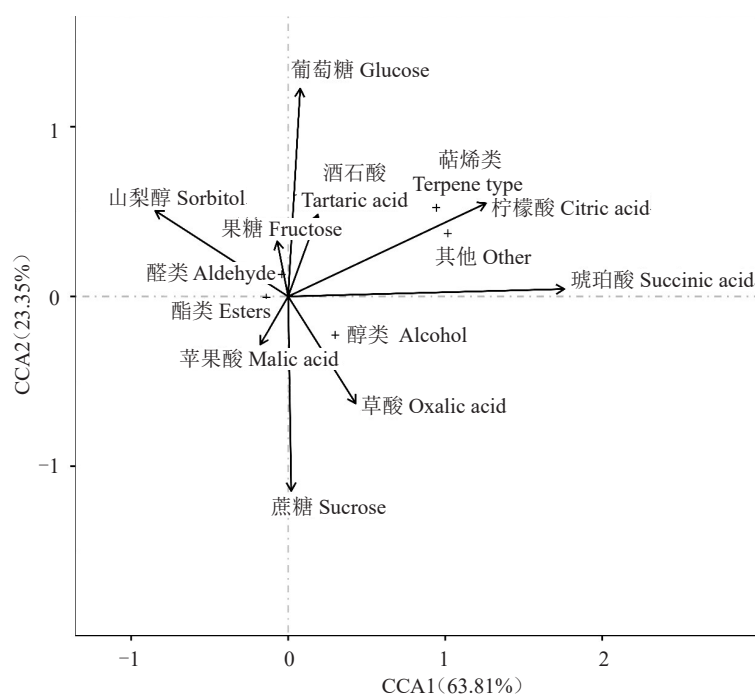
Fig. 2 Heatmap of fruit aroma components of Luli apple fruits in 17 regions of China

低;醇类成分以2-甲基-1-丁醇和己醇为主,阳谷己醇含量最高,占其所含醇类含量的72.24%,阿克苏含量最低,为阳谷的18.23%;醛类主要有己醛和2-己烯醛,其平均含量分别为 $86.91 \mu\text{g}\cdot\text{kg}^{-1}$ 和 $126.69 \mu\text{g}\cdot\text{kg}^{-1}$;萜烯类主要有D-柠檬烯和 α -法尼烯;此外果实香气中还检测出少量醚类、酸类、酮类等成分。

2.4 不同产地果实糖酸与香气相关性分析

糖酸是众多代谢反应的前体和关键物质,其种类和含量与果实挥发性物质有明显相关性^[20]。将果

实香气成分与糖酸含量进行典型关联分析,初步分析了不同地区鲁丽果实糖酸含量和香气种类的相关性(图3)。由箭头方向及长短可知,不同的糖酸组分对香气种类的作用效果不同,葡萄糖、柠檬酸、琥珀酸和蔗糖箭头较长,说明这几种组分与香气关联性较高,果糖和苹果酸箭头最短,说明这两种组分对香气的作用比较有限。葡萄糖、山梨醇、果糖、酒石酸、柠檬酸与萜烯类呈正相关,与醇类呈负相关,柠檬酸和琥珀酸对酯类和醛类影响较大,均呈负相关,而与醇类、萜烯类呈正相关。



箭头代表糖酸组分;+代表香气成分种类。
Arrows are shown in different sugar and acid components; aroma components are marked with +.

图3 果实糖酸与香气典型关联分析

Fig. 3 Canonical correlation analysis between fruit sugar acid and aroma

3 讨 论

苹果果实品质包括外观品质和内在品质,其中,外观品质包括果个大小、果形、颜色等,内在品质包括可溶性固形物、糖、酸、香气等。研究发现由于海拔、光照、气温、降雨量及土壤条件等生长环境的不同,果实品质在不同产地存在显著差异^[21-22]。本研究对17个产地鲁丽果实外观性状和内在品质进行了较全面的研究。从外观性状看,鲁丽果实果形指数的变异系数 $<10\%$,离散程度小,说明地域差别对果实果形指数影响不大,这与张蕊芬等^[23]的研究结果一致,产地环境无法改变果实形状,果实形状主要受植物内在基因调控^[23-24]。前人^[25]研究结果显示,可溶

性固形物含量、含糖量与日照时数呈正相关。本研究中,万荣和阿克苏产地果实可溶性固形物、可溶性糖等的含量较高,这与当地日照时间长、昼夜温差大,有利于果实中糖分的积累有关,而台安由于纬度偏北,日照时数较少,其含糖量较低。

糖和酸参与果实发育过程多种物质的代谢,其含量和种类是影响果实风味的关键因素^[26-27]。苹果中主要的可溶性糖是果糖、葡萄糖、蔗糖和山梨醇,4种糖组分决定果实的甜度^[28]。本研究得到与前人一致的结论,果实中含量最高的糖是果糖,其次是葡萄糖和蔗糖,山梨醇发现较晚,含量低,但在阿克苏产地山梨醇含量显著高于其他产地,这可能是当地长日照导致作为光合产物的山梨醇含量明显提

升^[29-30]。此外,本研究发现在聊城的茌平和阳谷糖分含量差异较大,其原因可能与果园土壤性质差异有关。苹果中的有机酸可以稳定花青素,延长新鲜水果新鲜度及货架期,并且在苹果着色中发挥重要作用^[31]。本研究结果表明,鲁丽果实有机酸以苹果酸为主,占总酸含量的67.72%~81.17%,属苹果酸型,这与冯娟等^[17]、李娅楠等^[32]在富士、金冠等品种的检测结果一致。不同于广饶,黄三角苹果酸和柠檬酸含量的显著提高,可能是由于其处于黄河滩涂区,海水侵袭严重,土壤盐分含量高,致使该地果实含酸量增加^[33]。而在阿克苏产地含酸量高,则由海拔高、积温少导致^[34-35]。

水果的风味除了味觉的差异外,另一个主要的区别是由于嗅感的不同。苹果的香气成分复杂,已鉴定出的香气成分超过300种^[36]。研究表明,苹果香气主要由酯类、醛类和醇类物质构成^[37],特征性香气有20多种。笔者在本试验中对17个产地鲁丽果实香气物质进行测定分析,共检测到的挥发性物质65种,香气成分中酯类、醛类和醇类物质的含量占总香气含量的86%以上。其中共有成分中己醛、乙酸己脂、2-甲基丁酸己酯、丙酸乙酯、2-己烯醛、2-甲基乙酸丁酯、 α -法尼烯等在之前的研究中均有报道^[38-39]。根据嗅感和香气阈值,大多数产地鲁丽果实呈“果香型”(乙酸己酯)^[40]。虽然在不同产地鲁丽果实中酯类物质含量的占比不同,但从特征香气的含量和组成上来看,乙酸己酯的贡献更大,因此可将鲁丽苹果归为“果香型”苹果品种。果实在不同的栽培条件和环境条件下香气成分也会存在一定的差异,卜万锁等^[41]研究结果显示过强或过弱的光强都会导致果实“果香型”成分积累量的降低, Jia等^[42]得出进一步结论,苹果果实在光照度为53%全日光时,“果香型”的酯类形成最多,而纬度位置与光照直接相关。在本研究中纬度较高的台安、固安以及纬度较低的界首产地果实酯类含量均处于较低水平,除个别地区外,其余地区均位于中间纬度,光照度适中,适度光照促进了酯类成分的合成和积累。阿克苏虽纬度较高但高海拔果园有利于酯类的积累^[43]。

4 结 论

笔者在本文中针对不同产地鲁丽苹果果实外观品质和糖、酸、香气等风味品质指标进行了对比分析,结果表明,烟台蓬莱产地果实单果质量最大,硬度及

可溶性固形物含量等指标均超过《鲜苹果》(GB/T 10651—2008)中早熟苹果指标;东营黄三角农高区、运城万荣、东营广饶等地含有较多的果糖,阿克苏、平度、黄三角含有较多的苹果酸;鲁丽苹果香气物质丰富,共检测到65种,可划分为“果香型”。本研究初步探析了鲁丽在我国不同产地的主要果实品质表现,对确定鲁丽苹果在我国的适生区有一定的参考意义。

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