

干燥方式对黄桃果脯品质的影响

Effects of drying methods on the quality of preserved yellow peach

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摘要:目的:筛选合适的黄桃果脯干燥方式。方法:采用热风干燥(HAD)、微波—热风干燥(MHD)、真空冷冻干燥(VFD)3种方式制成黄桃果脯,并对其物理特性、营养成分、感官及香气等指标进行分析。结果:相较传统HAD,MHD的效率提高了56.1%,且果脯色泽、营养成分、感官品质、香气成分和含量均显著优于HAD($P < 0.05$);VFD黄桃果脯色泽最好、复水性最强,产品组织结构完整性最好,营养物质维生素C、总酚、可滴定酸含量最高,感官评分最高为91.58,香气成分及含量最多且独具有2-己烯醇和反式2-己烯醛两种香气成分。结论:与HAD相比,MHD的黄桃果脯各方面较优,更适于普通黄桃果脯生产;VFD的黄桃果脯品质最佳,但能耗大,成本高,推荐用于高品质果脯生产。

关键词:黄桃果脯;干燥方式;物理特性;营养成分;香气

Abstract: Objective: This study aimed to select a suitable drying method for preserved yellow peach. Methods: Preserved yellow peach was prepared by hot air drying (HAD), microwave-hot air drying (MHD) and vacuum freeze drying (VFD). Its physical properties, nutritional components, sensory and aroma indexes were studied. Results: Compared with traditional HAD, the efficiency of MHD was increased by 56.1%, and the preserved fruit

was significantly better than HAD in color, nutritional composition, sensory evaluation, aroma components and content; The preserved yellow peach fruit by VFD has the best color, the strongest rehydration, the best tissue structure integrity of the product, the highest contents of nutrients vitamin C, and total phenol and titratable acid, and the highest sensory score is 91.58. It has the most aroma components and contents, and uniquely has two aroma components: 2-hexenol and trans-2-hexenal. Conclusion: Compared with HAD, the preserved yellow peach fruit prepared by MHD is better in all aspects, and MHD is more suitable for the production of common preserved yellow peach fruit. The quality of preserved yellow peach fruit prepared by VFD is the best. However, due to the high-energy and -cost consumption, it is recommended to produce high-quality preserved fruit.

Keywords: preserved yellow peach fruit; drying method; physical characteristics; nutritional composition; aroma

黄桃(*Amygdalus persica* L.),营养丰富,含水量高,常温下极易出现萎蔫、褐变、腐烂变质等现象,市场价值严重降低^[1-3]。因此,精加工成为延长黄桃贮藏期、增加经济效益的重要方式。

干燥是最古老的保存技术之一,可去除果实大量水分,减少贮藏过程中物理化学变化,从而抑制微生物生长延长其保质期,同时,干燥可减少食品重量和体积、降低包装、贮藏和运输成本^[4-5]。热风干燥(HAD)操作简单、成本低^[6],但干燥速度慢、热效率低,而微波干燥速率快,迅速脱水硬化,不易控制;微波—热风干燥(MHD)可在

基金项目:上海市科技兴农项目(编号:沪农科推字[2021]第4-1号)

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收稿日期:2022-03-16 **改回日期:**2022-07-12

保持产品质量前提下提高能源效率,克服单一干燥方式的不足^[7-8];真空冷冻干燥(VFD)在真空条件下通过升华作用脱水,可有效保存食品色泽和形态而成为干燥的热点^[8]。干燥是果脯加工过程中的重要环节,不同的干燥工艺对其品质有较大影响^[9],而目前关于此方面的研究尚未见报道。研究拟采用HAD、MHD、VFD技术制备黄桃果脯,分析其物理性质、营养成分及感官品质,并采用气相色谱—质谱联用仪评价其香气成分,以期为黄桃果脯的最佳干燥方式筛选提供依据。

1 材料与方法

1.1 材料

“锦绣”黄桃:七八成熟,肉质厚实、大小均一、无腐烂损伤,市售。

1.2 主要试剂、仪器

草酸、氢氧化钠、没食子酸:分析纯,国药集团化学试剂有限公司;

2-辛醇(优级纯)、EDTA-2Na溶液:上海源叶生物科技有限公司;

氯化钙:分析纯,上海秋爽生物科技有限公司;

电热恒温鼓风干燥箱:101-2型,绍兴市苏珀仪器有限公司;

微波炉:EV923MF-7-NRH型,广东美的电器制造有限公司;

真空冷冻干燥箱:TF-LFD型,上海田枫实业有限公司;

全自动色差仪:SPECTROPHOTOMETER CM-5型,柯盛行仪器有限公司;

质构仪:TA.XT plus型,英国SMS公司;

紫外—可见分光光度计:UV2450型,日本岛津公司;

气相色谱—质谱联用仪:Aglient7890-5975 GC-MS型,安捷伦科技有限公司。

1.3 试验方法

1.3.1 黄桃果脯制备工艺流程 根据文献^[10]并修改。

(1) 原料处理:黄桃经清洗去皮,切成厚度约为8 mm的果坯。

(2) 护色硬化:配制2%柠檬酸和1%氯化钙溶液,按 $V_{\text{柠檬酸溶液}}:V_{\text{氯化钙溶液}}=1:1$ 混合加入黄桃片中(以浸没黄桃片为准),常温下浸泡4 h。

(3) 糖渍、糖煮:一层果坯一层糖并按下层到上层糖量逐渐增加的方法糖渍4 h,加入40%糖液,煮沸30 min,沥干。

(4) 热风干燥(HAD):将果坯均匀摆放至烘盘中,每4 h翻面以防糊化,50℃烘干32 h。

(5) 微波—热风干燥(MHD):果坯于616 W微波干燥30 min,50℃热风干燥20 h。

(6) 真空冷冻干燥(VFD):果坯于-80℃预冻4 h,

真空温度-50℃,真空压力60 Pa,真空冷冻干燥18 h。

1.3.2 物理特性测定

(1) 色泽:根据文献^[10]。

(2) 复水率:根据文献^[11]。

(3) 质构特性:根据文献^[12]略修改。P2探头,测前速率1.0 mm/s,测中速率2.0 mm/s,测后速率10 mm/s,触发力0.004 9 N,穿透距离5.0 mm。每组试验测定6次取平均值。

1.3.3 营养成分分析

(1) 维生素C含量:根据文献^[13]。

(2) 可滴定酸含量:根据文献^[14]。

(3) 总酚含量:根据文献^[15]。

1.3.4 香气成分测定 根据文献^[16]并修改。将黄桃果脯用液氮研磨成粉,取5 g于20 mL顶空瓶,加入5 mL CaCl₂溶液和5 mL EDTA-2Na溶液,加入质量浓度为0.7 mg/mL的2-辛醇并以此为内标计算各香气成分含量。

1.3.5 感官评价 选10名经培训过的感官评价人员,参照表1盲品3种黄桃果脯。

表1 黄桃果脯感官评分标准

Table 1 Sensory scoring standard of preserved yellow peach fruit

项目	产品品质	分值
色泽	色泽金黄透亮且均一	16~20
	色泽金黄偏暗,较均一	10~15
	色泽偏暗不均一	0~9
滋味	酸甜适口、淡淡果香,硬度适中,有一定咀嚼性	21~30
	略酸或略甜,淡淡果香,口感质地较软或较硬	10~20
	过酸或过甜,果脯质地过硬或难以咀嚼	0~9
香气	有浓厚的桃香味,无异味	16~20
	有桃的清香味,无异味	10~15
	香气不足或存在异味	0~9
组织状态	无结晶返砂,果肉饱满,形态均一	21~30
	无结晶返砂,形态较饱满,结构略有不均	10~20
	返砂,外观干瘪或部分干瘪,略微粘手	0~9

1.3.6 数据分析 采用Origin 2018软件作图,SPSS 22软件检验差异显著性, $P<0.05$ 表示差异显著。

2 结果与分析

2.1 干燥方式对黄桃果脯色泽的影响

由表2可知,VFD的 L^* 值最大,MHD与VFD的黄桃果脯亮度差异不显著,但均显著高于HAD($P<0.05$);VFD的 b^* 值显著高于其他两种干燥方式($P<0.05$),是由于HAD干燥时间长,延长了物料与氧气的接触时间,

表 2 不同干燥方式下黄桃果脯色泽[†]

Table 2 The color of preserved yellow peach fruit under different drying methods

干燥方式	<i>L</i> *	<i>a</i> *	<i>b</i> *	Δ <i>E</i>
鲜果	65.092±0.41 ^c	8.514±0.13 ^d	38.824±0.56 ^c	
HAD	46.545±0.24 ^a	6.525±0.38 ^a	11.001±0.40 ^a	33.501±0.83 ^c
MHD	55.865±0.56 ^b	7.318±0.21 ^b	11.023±0.13 ^a	27.322±0.52 ^b
VFD	56.005±0.15 ^b	8.103±0.27 ^c	16.801±0.18 ^b	18.831±0.17 ^a

† 同列字母不同表示差异显著($P<0.05$)。

褐变严重,亮度偏暗;MHD可提高黄桃果脯的干燥速率,使褐变率降低;VFD的氧气浓度较低,可有效抑制果脯褐变。 ΔE 大小为VFD<MHD<HAD,由于MHD和HAD发生不同程度褐变,与鲜果相比,其*L**、*a**、*b**值变化较大,导致 ΔE 显著增加($P<0.05$),VFD的 ΔE 最小,较好地保留了鲜果色泽。因此VFD的黄桃果脯色泽更加金黄透亮,与张群等^[17]的研究结果相似,此外,郑悄然等^[18]发现HAD的牛肝菌色泽优于MHD,与试验相反,可能是由于不同原料和温度差异导致的。

2.2 干燥方式对黄桃果脯复水性的影响

由图1可知,复水初期,3种干燥方式的黄桃果脯迅速吸水,此时果脯含糖量高,形成高渗环境,有利于水分子渗入,加速复水。2~14 min时,VFD的复水速率和复水率均高于HAD和MHD,与猕猴桃果脯^[10]的类似。14 min后复水速率均逐渐趋于稳定,但VFD复水率仍最高,可能是VFD的黄桃果脯内部结构疏松,利于复水,HAD与MHD的黄桃果脯表面产生一定程度硬化,阻碍了水分子渗入,复水率较低,与Guo等^[19]的结果一致。

2.3 干燥方式对黄桃果脯质构特性的影响

由表3可知,HAD的果脯硬度和咀嚼性最大,其次是MHD,由于HAD和MHD受热时间长、温度高,组织细胞破坏较大,干燥后水分含量少,导致果脯质地较硬;VFD的硬度和咀嚼性均较小,可能是由于VFD的果脯预先冷冻,且在低温、低氧、真空环境下,表面不易硬化,此

表 3 不同干燥方式下黄桃果脯质构特性[†]

Table 3 The texture characteristics of preserved yellow peach fruit under different drying methods

干燥方式	韧性/(N·s ⁻¹)	硬度/N	咀嚼性/(N·s)
HAD	0.839 5±0.003 3 ^a	16.728 2±0.006 4 ^c	31.146 7±0.008 0 ^c
MHD	1.583 0±0.008 0 ^c	12.016 4±0.007 0 ^b	14.994 9±0.006 0 ^b
VFD	1.037 1±0.002 1 ^b	2.979 6±0.003 7 ^a	3.370 3±0.004 0 ^a

† 同列字母不同表示差异显著($P<0.05$)。

外,VFD的香芋片硬度也低于HAD^[20]。MHD的韧性最大且显著高于其他两种干燥方式($P<0.05$),可能是由于微波处理水分快速流失,韧性加强。总体来说,HAD与MHD的黄桃果脯硬度和咀嚼性过大影响口感,VFD的黄桃果脯口感较佳。

2.4 干燥方式对黄桃果脯营养成分的影响

由表4可知,VFD的维生素C(*V_C*)含量最高,可能是VFD中*V_C*与氧气接触时间较短,氧化损失较少^[21],与宋悦等^[22]的结论一致。同时,VFD处于低温环境,能最大限度保护*V_C*^[23]。可滴定酸对果实的酸度、质地和风味起重要作用^[24],不同干燥方式下黄桃果脯可滴定酸含量为VFD>MHD>HAD,可能是高温条件下加速了可滴定酸的流失^[25]。多酚是植物的次生代谢产物,有降血糖、抗氧化、抗菌、抗炎等生物活性^[26-27]。3种干燥方式下的黄桃果脯总酚含量差异显著($P<0.05$),主要是由于HAD时间长,溶质迁移,总酚流失较多;MHD直接与果脯细胞中的水分子相互作用,短时间内脱水,可能会减少多酚含量^[9];相对来说,VFD更有利于总酚的保留^[28],此外,

表 4 不同干燥方式下黄桃果脯营养成分[†]

Table 4 The nutritional composition of preserved yellow peach fruit under different drying methods

干燥方式	<i>V_C</i> 含量/ (10 ⁻² mg·g ⁻¹)	可滴定酸含量/ (10 ⁻² g·g ⁻¹)	总酚含量/ (mg·kg ⁻¹)
HAD	1.62±0.34 ^a	0.41±0.31 ^a	286.84±0.36 ^a
MHD	3.14±0.27 ^b	0.82±0.09 ^b	348.26±0.24 ^b
VFD	4.81±0.20 ^c	1.23±0.21 ^c	410.43±0.11 ^c

† 同列字母不同表示差异显著($P<0.05$)。

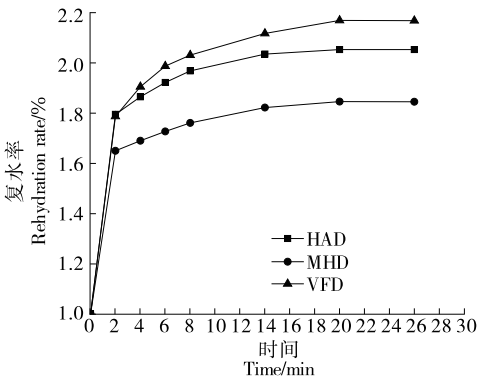


图 1 不同干燥方式下黄桃果脯复水率

Figure 1 The rehydration rate of preserved yellow peach fruit under different drying methods

VFD 的柿子片总酚含量高于 MHD 和 HAD^[23]。

2.5 干燥方式对黄桃果脯挥发性化合物的影响

由表 5 可知,3 种干燥方式下,黄桃果脯中检测到 15 种主要香气化合物,包括烷(2 种)、醇(4 种)、醛(3 种)、酯(5 种)、酮(1 种),其中醇类、酯类占主导地位。研究^[29]表明,风华桃中主要的香气物质包括醛类、醇类、酯类等。黄桃果脯中风味化合物含量为 VFD>MHD>HAD。醛醇类化合物构成了桃的主要特征香气成分^[29],C₆醛和醇具有清香味,主要是(E)-2-己烯醛和(E)-2-己烯醇^[30],苯甲醛、苯乙醛具有果香和奶油香味^[31],仅 VFD 的黄桃果脯含有香气成分(E)-2-己烯醛和(E)-2-己烯醇,且香气成分正己醛、壬醛含量均显著高于其他两种干燥方式。酯通常由醇和脂肪氧化产生的游离脂肪酸相互作用形成,主要呈果味、甜味^[32],3 种干燥方式的黄桃果脯酯类物质含量为 VFD>MHD>HAD,说明 MHD 与 HAD 在加热过程中酯类物质损失较多,VFD 的黄桃果脯

具有更好的果味和甜味。烷类、酮类占比小且 VFD 中的含量均显著高于其他两种干燥方式。综上,真空冷冻干燥的黄桃果脯的香气物质及含量保留最多。

2.6 干燥方式对黄桃果脯感官品质的影响

由表 6 可知,VFD 的黄桃果脯在色泽、滋味、香气、组织状态、总分上均显著高于其他两种干燥方式,其酸甜适口,硬度适中,无结晶返砂,果肉饱满,主要是由于 MHD 过程中表面硬化,影响口感;HAD 加热时间长且与氧气接触久,导致色泽更暗,滋味、香气和组织状态均较差,与付龙威等^[33]的结果类似。

3 结论

试验表明,热风干燥因生产率高,成为最常用的干燥方法,但在高温、长时有氧环境下,果脯中的营养成分和其他生物活性物质含量显著降低。微波-热风干燥可缩短干燥时间,提高能源效率,果脯在色泽、营养成分、感

表 5 不同干燥方式下黄桃果脯主要的挥发性化合物[†]

Table 5 Main volatile compounds of preserved yellow peach fruits under different drying methods					
化合物 种类	保留时 间/min	香气成分	含量/($\mu\text{g} \cdot \text{kg}^{-1}$)		
			HAD	MHD	VFD
烷类	17.920	十二烷	49.952 4 ^a	57.055 2 ^b	61.385 5 ^c
	22.609	十三烷	59.648 6 ^a	64.446 3 ^b	76.172 2 ^c
醇类	25.259	正己醇	—	5.905 5 ^a	12.226 4 ^b
	27.214	2-己烯醇	—	—	20.921 8
	29.967	2-乙基己醇	140.162 0 ^a	150.956 0 ^b	162.828 0 ^c
	31.629	芳樟醇	39.988 8 ^a	40.845 4 ^a	81.336 8 ^b
醛类	13.319	正己醛	18.225 4 ^a	22.875 7 ^a	50.956 7 ^b
	19.317	反式 2-己烯醛	—	—	2.706 6
	26.674	壬醛	90.516 2 ^a	120.006 0 ^b	138.953 0 ^c
酯类	21.696	乙酸己酯	32.596 8 ^b	26.002 5 ^a	47.837 8 ^c
	24.361	乙酸顺式-3-己烯酯	—	52.828 7 ^a	179.211 0 ^b
	24.361	2-己烯-1-醇乙酸酯	12.995 6 ^a	11.026 0 ^a	32.465 1 ^b
	36.112	γ -己内酯	11.825 2 ^a	10.824 2 ^a	22.704 8 ^b
酮类	45.664	丙位癸内酯	54.712 2 ^a	64.938 7 ^b	134.164 0 ^c
	38.894	大马酮 1-(2,6,6-三甲基-1,3-环己二烯-1-基)-2-丁烯-1-酮	20.654 2 ^a	24.122 1 ^b	40.047 8 ^c

† 同行字母不同表示差异显著($P<0.05$);“—”未检出。

表 6 干燥方式对黄桃果脯感官品质的影响[†]

Table 6 Effects of different drying methods on the sensory quality of preserved yellow peach fruit

干燥方式	色泽	滋味	香气	组织状态	总分
HAD	10.98±0.25 ^a	19.56±0.19 ^a	10.87±0.17 ^a	18.87±0.13 ^a	60.28±0.74 ^a
MHD	14.61±0.19 ^b	24.48±0.23 ^b	15.18±0.21 ^b	22.98±0.14 ^b	77.25±0.77 ^b
VFD	18.83±0.24 ^c	28.78±0.13 ^c	18.62±0.15 ^c	25.35±0.09 ^c	91.58±0.61 ^c

† 同列字母不同表示差异显著($P<0.05$)。

官品质、香气成分和含量方面显著高于热风干燥,因此,微波—热风干燥更适于普通黄桃果脯的生产。相对来说,真空冷冻干燥不仅能够最大限度保持果脯的组织结构、色泽,还能有效减少营养物质流失,较好地保留果脯香气成分及其含量,产品质量较高,但真空冷冻干燥成本较高,适用于高价值产品,如婴儿食品,提供给军事和户外运动等特殊食品。后续可结合多种干燥方式从多方面探讨果脯的品质。

参考文献

- [1] 余意, 张鑫, 张丽平, 等. 采收成熟度和贮藏温度对锦绣黄桃成熟品质的影响[J]. 食品工业科技, 2015, 36(4): 334-338.
YU Y, ZHANG X, ZHANG L P, et al. Effects of harvest maturity and storage temperature on the ripening quality of Jinxiu yellow peach[J]. Food Industry Science and Technology, 2015, 36(4): 334-338.
- [2] 张洪礼, 马玉华, 王宇, 等. 锦绣黄桃品质的影响因素及贮藏保鲜技术研究进展[J]. 贵州农业科学, 2019, 47(7): 91-95.
ZHANG H L, MA Y H, WANG Y, et al. Research progress on influencing factors and storage and preservation technology of Jinxiu yellow peach[J]. Guizhou Agricultural Science, 2019, 47(7): 91-95.
- [3] HK A, AT B, MG C. Evaluation of biochemical changes and quality in peach fruit: Effect of putrescine treatments and storage [J]. Journal of Food Composition and Analysis, 2021, 102: 104048.
- [4] GOKCE D, ELICIN D, BELMA Ö. Effect of drying conditions on rehydration kinetics of microwave dried spinach[J]. Food and Bio-products Processing, 2008, 86(4): 235-241.
- [5] CHUA K J, MUJUMDAR A S, HAWLADER M, et al. Batch drying of banana pieces: Effect of stepwise change in drying air temperature on drying kinetics and product colour [J]. Food Research International, 2001, 34(8): 721-731.
- [6] REN Z F, YU X J, YAGOUR A E A, et al. Combinative effect of cutting orientation and drying techniques (hot air, vacuum, freeze and catalytic infrared drying) on the physicochemical properties of ginger (*Zingiber officinale* Roscoe)[J]. LWT, 2021, 144: 111238.
- [7] OZKAN K, KARADA A, SAGDIC O. The effects of different drying methods on the in vitro bioaccessibility of phenolics, antioxidant capacity, minerals and morphology of black 'Isabel' grape[J]. LWT, 2022, 158: 113185.
- [8] AM A, VSA B, SATA B. A systematic review on the recent advances of the energy efficiency improvements in non-conventional food drying technologies[J]. Trends in Food Science & Technology, 2020, 100: 67-76.
- [9] PARAMANANDAM V, JAGADEESAN G, MUNIYANDI K, et al. Comparative and variability analysis of different drying methods on phytochemical, antioxidant and phenolic contents of *Ficus auriculata* Lour. Fruit[J]. Phytomedicine Plus, 2021, 1(3): 100075.
- [10] 雷炎, 李华佳, 望诗琪, 等. 不同干燥方式对猕猴桃果脯品质的影响[J]. 食品研究与开发, 2020, 41(24): 103-108.
- LEI Y, LI H J, WANG S Q, et al. Effects of different drying methods on the quality of preserved kiwifruit[J]. Food Research and Development, 2020, 41(24): 103-108.
- [11] 潘莹瑛. 芒果果脯热风干燥及组合干燥对比研究[D]. 南宁: 广西大学, 2013: 64-70.
PAN Y Y. Comparative study on hot air drying and combined drying of preserved mango[D]. Nanning: Guangxi University, 2013: 64-70.
- [12] ZHAO W, FANG Y, ZHANG Q A, et al. Correlation analysis between chemical or texture attributes and stress relaxation properties of 'Fuji' apple[J]. Postharvest Biology and Technology, 2017, 129: 45-51.
- [13] 徐朝阳. 2,6-二氯酚酞酚滴定法与碘量法测定蔬菜水果中维生素 C 方法的准确度比较[J]. 食品安全导刊, 2021(25): 100-101.
XU Z Y. Comparison of accuracy between 2,6-dichlorophenol indophenol titration and iodometry for the determination of vitamin C in vegetables and fruits[J]. Food Safety Guide, 2021(25): 100-101.
- [14] RB A, SP A, GA B, et al. Changes in the activity of proline-metabolising enzymes is associated with increased cultivar-dependent chilling tolerance in mangos, in response to pre-storage melatonin application [J]. Postharvest Biology and Technology, 2021, 182: 111702.
- [15] WANG L, SHAN T, XIE B, et al. Glycine betaine reduces chilling injury in peach fruit by enhancing phenolic and sugar metabolisms[J]. Food Chemistry, 2019, 272(30): 530-538.
- [16] 张琴, 周丹丹, 韩璐, 等. 鲜切火龙果低温贮藏期间游离态和结合态香气物质的变化[J]. 食品科学, 2021, 42(14): 144-150.
ZHANG Q, ZHOU D D, HAN L, et al. Changes of free and bound aroma substances in fresh cut pitaya during low temperature storage[J]. Food Science, 2021, 42(14): 144-150.
- [17] 张群, 舒楠, 张维, 等. 不同采收期黄桃的品质特性和微观结构变化[J]. 保鲜与加工, 2021, 21(4): 29-34.
ZHANG Q, SHU N, ZHANG W, et al. Quality characteristics and microstructure changes of yellow peach at different harvest times[J]. Preservation and Processing, 2021, 21(4): 29-34.
- [18] 郑俏然, 周凤, 邢洁, 等. 干燥方式对牛肝菌干燥特性、品质及抗氧化能力的影响[J]. 食品与机械, 2018, 34(11): 45-49.
ZHENG X R, ZHOU F, XING J, et al. Effects of drying methods on drying characteristics, quality and antioxidant capacity of Boletus[J]. Food & Machinery, 2018, 34(11): 45-49.
- [19] GUO H Q, ZHANG M, HUA D W, et al. Effect of different drying methods on the quality changes of the granular fruits and vegetables[J]. Journal of Food Science and Biotechnology, 2006(2): 28-32.
- [20] 杨玉, 肖婷, 孙雪, 等. 不同干燥方法对香芋片品质特性的影响[J/OL]. 食品与发酵工业. (2021-12-12) [2022-02-12]. DOI:10.13995/j.cnki.11-1802/ts.028982.
- YANG Y, XIAO T, SUN X, et al. Effects of different drying meth-

- ods on the quality characteristics of taro slices[J/OL]. Food and Fermentation Industry. (2021-12-12) [2022-02-12]. DOI:10.13995/j.cnki.11-1802/ts.028982.
- [21] VIEIRA D S J E, LINS D M, BATISTA D M. Influence of ultrasound and vacuum assisted drying on papaya quality parameters[J]. LWT-Food Science and Technology, 2018, 97: 317-322.
- [22] 宋悦, 金鑫, 毕金峰, 等. 超声辅助渗透处理对热风干燥及真空冷冻干燥黄桃片品质的影响[J]. 食品科学, 2020, 41(15): 177-185.
- SONG Y, JIN X, BI J F, et al. Effect of ultrasonic assisted osmotic treatment on the quality of hot air drying and vacuum freeze-drying yellow peach slices [J]. Food Science, 2020, 41(15): 177-185.
- [23] JIA Y Y, KHALIFA I, HU L L, et al. Influence of three different drying techniques on persimmon chips' characteristics: A comparison study among hot-air, combined hot-air-microwave, and vacuum-freeze drying techniques[J]. Food and Bioproducts Processing, 2019, 118: 67-76.
- [24] WANG L, FU H, WANG W, et al. Analysis of reducing sugars, organic acids and minerals in 15 cultivars of jujube (*Ziziphus jujuba* Mill.) fruits in China [J]. Journal of Food Composition and Analysis, 2018, 73: 10-16.
- [25] WU Z F, TU M M, YANG X B, et al. Effect of cutting and storage temperature on sucrose and organic acids metabolism in postharvest melon fruit[J]. Postharvest Biology and Technology, 2020, 161: 111081.
- [26] SAMSONOWICZ M, REGULSKA E, KARPOWICZ D, et al. Antioxidant properties of coffee substitutes rich in polyphenols and minerals[J]. Food Chemistry, 2019, 278(25): 101-109.
- [27] ZHANG H, QI R L, MINE Y. The impact of oolong and black tea polyphenols on human health[J]. Food Bioscience, 2019, 29: 55-61.
- [28] BOZKIR H, RAYMAN E A, SERDAR E, et al. Influence of ultrasound and osmotic dehydration pretreatments on drying and quality properties of persimmon fruit [J]. Ultrasonics Sonochemistry, 2019, 54: 135-141.
- [29] NIU Y W, DENG J M, XIAO Z B, et al. Characterization of the major aroma-active compounds in peach (*Prunus persica* L. Batsch) by gas chromatography-olfactometry, flame photometric detection and molecular sensory science approaches[J]. Food Research International, 2021, 147: 110457.
- [30] 张琴, 周丹丹, 彭菁, 等. 油桃采后结合态香气变化规律及其与可溶性糖的关联性[J]. 食品科学, 2021, 42(6): 206-214.
- ZHANG Q, ZHOU D D, PENG J, et al. Changes of post harvest bound aroma of nectarine and its correlation with soluble sugar[J]. Food Science, 2021, 42(6): 206-214.
- [31] YAO L M, ZHANG Y, QIAO Y J, et al. A comparative evaluation of nutritional characteristics, physical properties, and volatile profiles of sweet corn subjected to different drying methods[J]. Cereal Chemistry, 2021, 99(2): 406-420.
- [32] OZKARA K T, AMANPOOUR A, GUCLU G, et al. GC-MS-olfactometric differentiation of aroma-active compounds in turkish heat-treated sausages by application of aroma extract dilution analysis[J]. Food Analytical Methods, 2019, 12(3): 729-741.
- [33] 付龙威, 连建梅, 叶淑贤, 等. 不同干燥工艺对燕窝品质特性的影响[J/OL]. 食品工业科技. (2022-03-17) [2022-04-11]. DOI: 10.13386/j.issn1002-0306.2021110300.
- FU L W, LIAN J M, YE S X, et al. Effects of different drying processes on quality characteristics of bird's nest[J/OL]. Science and Technology of Food Industry. (2022-03-17) [2022-04-11]. DOI:10.13386/j.ssn1002-0306.2021110300.

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- [18] 李国友, 杨梦琪, 杭丙鹏, 等. 基于模糊粗糙集和鲸鱼优化支持向量机的化工过程故障诊断[J]. 振动与冲击, 2022, 41(2): 177-184.
- LI G Y, YANG M Q, HANG B P, et al. Fault diagnosis of chemical processes based on the SVM optimized by fuzzy rough sets and a whale optimization algorithm[J]. Journal of Vibration and Shock, 2022, 41(2): 177-184.
- [19] MIN X Y, XU X F, WANG Z J. Combining vonneumann neighborhood topology with approximate-mapping local search for ABC-based service composition [C]// 2014 IEEE International Conference on Services Computing. Anchorage: IEEE, 2014: 187-194.
- [20] 王峒钧, 邢凯, 库斌, 等. 布谷鸟马尔科夫链蒙特卡罗混合高斯地质统计学随机反演[J]. 地球物理学报, 2021, 64(7): 2 540-2 553.
- WANG Y J, XING K, SHE B, et al. Mixed Gaussian stochastic inversion based on hybrid of cuckoo algorithm and Markov chain Monte Carlo [J]. Chinese Journal of Geophysics, 2021, 64(7): 2 540-2 553.
- [21] 徐岩. 基于改进引力搜索算法的高速并联机器人轨迹优化[J]. 食品与机械, 2022, 38(5): 82-86.
- XU Y. Trajectory optimization of high speed parallel robot based on improved gravity search algorithm[J]. Food & Machinery, 2022, 38(5): 82-86.
- [22] 姚学峰, 李超. 基于改进 NURBS 曲线插补算法的食品分拣机器人轨迹规划[J]. 食品与机械, 2022, 38(3): 80-85.
- YAO X F, LI C. Trajectory planning method of food sorting robot based on improved NURBS curve interpolation algorithm[J]. Food & Machinery, 2022, 38(3): 80-85.
- [23] 赖啸. 基于抖动和时间的码垛食品机器人轨迹优化算法研究[J]. 食品与机械, 2020, 36(12): 74-78.
- LAI X. Research on trajectory optimization algorithm of palletizing robot based on jitter and time[J]. Food & Machinery, 2020, 36(12): 74-78.