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Advances in Research on the Composition of Dietary Fiber in Fruits

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Abstract

Dietary fibre means carbohydrate polymers which are not hydrolyzed by the endogenous enzymes in the small intestine of humans, including cellulose, hemicellulose, lignin, pectin, resistant starch and oligosaccharide, which was divided into two types as soluble dietary fiber and insoluble dietary fiber according to the solubility. This article summarizes the "high fiber", "fiber source" fruit and high quality dietary fiber. The research progress of dietary fiber composition in fruits was reviewed from the aspects of oligosaccharides, resistant starch and cell wall component. The monosaccharide composition of total dietary fiber, soluble dietary fiber and insoluble dietary fiber was also reviewed.

Keywords

Fruits, Dietary Fibre, Monosaccharide Composition, Oligosaccharide, Cell Wall Component

果实膳食纤维组成研究进展

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摘　要

膳食纤维指抗人体小肠消化吸收，但在大肠中能部分或全部发酵的可食用植物性成分——碳水化合物及类似物质，包括纤维素、半纤维素、木质素、果胶、抗性淀粉、寡糖等，按溶解性分为可溶性膳食纤维和不溶性膳食纤维两类。本文综述了“高纤维”、“纤维源”果品及高品质膳食纤维，从寡糖、抗性淀粉及细胞壁组分等方面综述了果实膳食纤维组成的研究进展，并进一步挖掘了果实总膳食纤维、可溶性膳食纤维和不溶性膳食纤维的单糖组成。

关键词

果实，膳食纤维，单糖组成，寡糖，细胞壁组分

1. 引言

自 Hipsley [1]初步认定膳食纤维是“纤维素、半纤维素和木质素”以来，历经半个多世纪的发展，虽然其间一直争议不断，但膳食纤维的内涵始终得到补充和完善，目前国内外普遍认同的膳食纤维定义为：“抗人体小肠消化吸收，但在大肠中能部分或全部发酵的可食用植物性成分——碳水化合物及类似物质，包括纤维素、半纤维素、木质素、果胶、抗性淀粉、寡糖等”[2] [3]。作为人体“第七大营养素”，膳食纤维具有改善肠道功能，调节血糖及血糖耐受度，降低血液胆固醇等多种健康效应[4] [5] [6]。

果树果实是人类摄取膳食纤维的重要途径之一。按溶解性可将果树果实总膳食纤维(TDF)分为两类：可溶性膳食纤维(SDF)和不溶性膳食纤维(IDF)，可溶性膳食纤维包括寡糖类、抗性淀粉以及水溶性果胶；不溶性膳食纤维包含不溶性果胶、纤维素、半纤维和木质素，具体如图 1 所示。而果实发育及贮藏过程中纤维素、半纤维素、木质素及果胶等细胞壁组分的变化是引起果实膳食纤维组成改变的主要因素，因此，果实膳食纤维组分的研究很大程度得益于研究者们对于植物细胞壁代谢的关注[7]，为方便总结叙述，文中将细胞壁组分水溶性果胶列入不溶性膳食纤维进行描述。

2. 总膳食纤维(TDF)

2.1. “高纤维”和“纤维源”果实

按照欧盟委员会标准，食品中膳食纤维含量超过 3%可认为是“纤维源”食品，超过 6%即可认定为“高纤维”食品[8]。“高纤维”鲜果如人心果(*Achras sapota*, 10.9%) [9]、番石榴(*Psidium guajava*, 8.5%) [9]、余甘子(*Phyllanthus emblica*, 7.3%) [9]、木橘(*Aegle marmelos*, 6.40%) [10]，西梅(6%~7%) [11]；干果如板栗(*Castanea sativa*, 13.7%) [12]，“纤维源”鲜果如番荔枝(*Anona squamosa*, 5.5%) [9]、无花果(*Ficus carica*, 5.0%) [9]、刺梨(*Rosa roxburghii*, 4.2%) [13]、酸枣(*Zizyphus jujube*, 3.8%) [9]、蒲桃(*Syzygium cumini*, 3.5%) [9]、树菠萝(*Artocarpus heterophyllus*, 3.5%) [9]等。

芒果鲜果属“高纤维”食品，四种芒果果肉的膳食纤维的含量：“金芒果”(23.07%) > “凯特芒”(9.69%) > “大金煌芒”(7.78%) > “吕宋芒”(6.54%) [14] [15]；另有一种野生芒果 *Mangifera pajang* 总膳食纤维含量达到了鲜重的 83.50% [16]。海枣(*Phoenix dactylifera*)也是膳食纤维含量较高的果实，但不同品种差异较大，每 100 g 干质量果实中 TDF 含量从 7.81~93.46 不等[17] [18] [19] [20]。“Manzanilla”

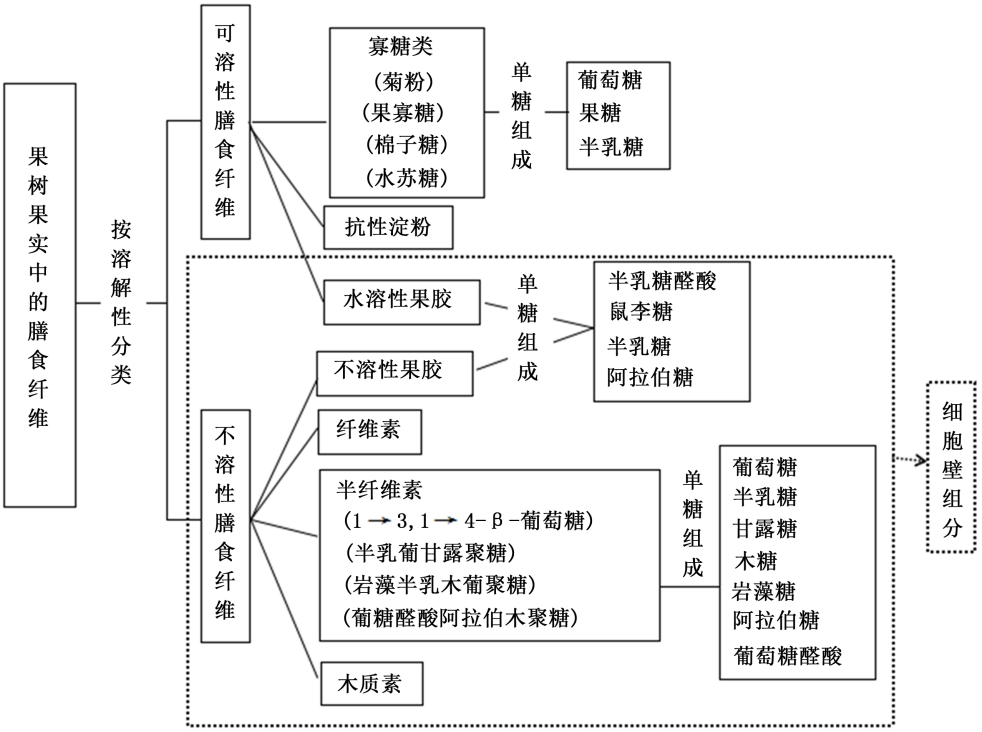

Figure 1. Composition of main dietary fibre in fruits
图 1. 果树果实中膳食纤维的组成

和“Gordal”橄榄品种每 100 g 鲜果肉中 TDF 含量约 5 g，为“纤维源”果品，而“Hojiblanca”中含量 > 6 g，为“高纤维”果品[21]。“长营”、“惠圆”、“自来圆”、“檀香”和“檀头”5 个橄榄品种的果实 TDF 含量为 37.40~50.36 g/hg DW，品种间差异显著，以“长营”和“自来圆”含量相对较高[22]。香蕉属“纤维源”果实，TDF 含量为 3.54%~5.08% [15] [23]。

2.2. 单糖组成

不同种类果实 TDF 单糖组成差异较大。北方 7 种水果中检测到 8 种单糖，草莓、山楂、苹果、桃、杏以半乳糖醛酸为主，梨以阿拉伯糖为主，桑椹中半乳糖醛酸与阿拉糖含量相当[24]。木瓜(*Chaenomeles speciosa*)中含 9 种单糖，分别为鼠李糖、岩藻糖、阿拉伯糖、木糖、甘露糖、半乳糖、纤维素葡萄糖、非纤维素葡萄糖、半乳糖醛酸，9 种单糖中以纤维素葡萄糖含量最高，每 100 g TDF 含纤维素葡萄糖 28.6 g，其次为半乳糖醛酸 25.3 g，岩藻糖含量最低，仅 0.6 g。日本木瓜(*Chaenomeles japonica*)与木瓜单糖组成基本一致，只是“NV1944”、“NV1410”和“NV152”3 种基因型半乳糖醛酸含量稍高于纤维素葡萄糖[25]。海枣果肉中含 6 种单糖，以葡萄糖含量最高(2 g/100g TDF)，其次为木糖、半乳糖、阿拉伯糖，鼠李糖含量最低(0.06 g/100g TDF)，中性糖含量(3.63 g/100g TDF)大于醛酸类含量(2.04 g/100g TDF) [17]。芒果果肉中含 4 种单糖，以甘露糖含量最大(0.59%)，其次是山梨糖、半乳糖、鼠李糖(0.07%) [14]。

3. 可溶性膳食纤维(SDF)

3.1. 高品质膳食纤维

SDF 含量是影响膳食纤维生理功能的重要因素，高品质膳食纤维应达到 SDF 含量 ≥10%的要求，SDF 与 IDF 最佳比例为 1:3 [26]。如表 1 所示，结合 Ramulu 和 Udayasekhara Rao [9]对印度 25 种果实，

Table 1. SDF/IDF in ripen flesh of different fruit species (%)
表 1. 不同种类果实成熟果肉中可溶性膳食纤维(SDF)含量(%)

果树种类	SDF/TDF	参考文献
板栗(*Castanea sativa*)	7.09	[12]
灯笼果(*Physalis peruviana*)	12.20	[27]
木瓜(*Chaenomeles speciosa*)	23.26	[25]
宽皮柑橘(*Citrus reticulata*)	23.26	[28]
柚(*Citrus grandis*)	25.00	[28]
柠檬(*Citrus Limon*)	29.41	[28]
猕猴桃(*Actinidia chinensis*)	30.30	[29] [30]
刺梨(*Rosa roxburghii*)	31.51	[13]
榴莲(*Durio zibethinus*)	33.33	[31]
火龙果(*Hylocereus polyrhizus*)	34.48	[32]
木橘(*Aegle marmelos*)	55.56	[10]
海枣(*Phoexix dactylifera*)	1.17 - 43.48	[9] [17] [18] [19] [20]
橄榄(*Canarium album*)	14.71 - 27.03	[22]
芒果(*Mangifera indica*)	14.71 - 66.67	[9] [15] [33]
梨(*Pyrus communis*)	16.39 - 28.57	[34]
菠萝(*Ananas comosus*)	17.86 - 25.00	[9] [35]
甜橙(*Citrus sinensis*)	23.81 - 52.63	[9] [28]
苹果(*Malus domestica*)	25.00 - 66.67	[36] [37] [38]
蛇皮果(*Salacca edulis*)	28.57 - 32.26	[29] [31]
番石榴(*Psidium guajava*)	3.58 - 16.39	[9] [39]
山竹(*Garcinia mangostana*)	33.33 - 50.00	[31] [40]
李(*Prunus domestica*)	38.46 - 55.56	[9] [41]

吕明霞等[24]对北方 7 种水果的描述，除板栗和少数几种海枣、番石榴外，几乎所有果实都满足高品质膳食纤维的要求，其中 SDF 在芒果和苹果果实中最高可占到 66.67%，山楂 75.0%，桃 86.3%。

3.2. 寡糖类和抗性淀粉

火龙果新鲜果肉中含有寡糖类约 90 g/kg [42]。草莓中也含微量寡糖，分别为：蔗果三糖(40 μg/g FW)，新科斯糖(10 μg/g FW)，蔗果四糖(5 μg/g FW)，kestopentaose (菊粉的一种，3 μg/g FW) [43]。杨桃和番橄榄中含有的微量果寡糖为蔗果三糖和蔗果四糖[44]。苹果果实中含有棉子糖和水苏糖，水苏糖随着果实发育降低，棉子糖较水苏糖含量低，但在果实发育过程中保持不变[45]。桃和猕猴桃中含有微量棉子糖[46] [47]。抗性淀粉主要存在于香蕉和板栗中，随着香蕉果实的发育，抗性淀粉含量呈直线上升趋势，断蕾后 50 d，抗性淀粉含量达到最大值，为 402.96 mg/g FW [48]。生板栗中抗性淀粉含量为 27.44%，占总淀粉的比例为 68.93% [49]。

3.3. 单糖组成

果实 SDF 单糖组成以醛酸类为主，不同种类果实在中性糖的组成上具有一定的特异性。北方 7 种水

果 SDF 均以半乳糖醛酸为主[24]。木瓜(*Chaenomeles speciosa*)果实 SDF 含 8 种单糖，以半乳糖醛酸含量最高，每 100 g SDF 含 71.6 g 半乳糖醛酸，其次为阿拉伯糖 9.9 g，甘露糖 8.0 g，半乳糖 4.7 g，鼠李糖 2.2 g，葡萄糖 1.5 g，木糖 1.1 g，岩藻糖含量最低，仅 0.3 g。日本木瓜(*Chaenomeles japonica*)与木瓜 SDF 单糖组成基本一致，区别之处在于葡萄糖与鼠李糖的含量，日本木瓜中葡萄糖含量较高，而木瓜中鼠李糖含量更高[25]。野生芒果 *Mangifera pajang* SDF 含 8 种单糖，依次为甘露糖(1.51%)、阿拉伯糖、葡萄糖、鼠李糖、赤藓糖(0.14%)、半乳糖、木糖、岩藻糖(0.01%)，醛酸类含量(5.83%)大于中性糖含量(3.02%)，赤藓糖是这种野生芒果单糖的独特组成[15]。海枣果肉中含 6 种单糖，以葡萄糖含量最高(0.41 g/100g SDF)，鼠李糖含量最低(0.03 g/100g SDF)，醛酸类含量(1.80 g/100g SDF)大于中性糖含量(0.84 g/100g SDF) [14]。苹果 SDF 中含有 6 种单糖，以半乳糖醛酸含量最高(42.3%)，其次为阿拉伯糖(25.7%)，含量最低的为岩藻糖(1.9%)，未检测到甘露糖和葡萄糖[37]。

4. 不溶性膳食纤维(IDF)

4.1. 细胞壁组分

柑橘类果实膳食纤维以果胶，尤其是水溶性果胶为主，其次为纤维素或原果胶，木质素含量最低；在柠檬、柚、椪柑、脐橙、温州蜜柑、胡柚五种果实中，果胶、水溶性果胶、纤维素和木质素以柠檬中含量最高，原果胶以温州蜜柑中含量最高[28]。菠萝中以纤维素为主，其次为半纤维素[35]。刺梨果实以纤维素为主，其次为半纤维素、原果胶、木质素，水溶性果胶含量最低[13]。海枣果实以木质素为主，其次为纤维素、半纤维素[37]。枇杷果实生长发育过程中，水溶性果胶含量呈上升趋势，离子结合果胶、共价结合果胶、纤维素、半纤维素呈下降趋势[50]。而梨果实生长过程中纤维素、半纤维素含量在整个生长周期中的变化无明显规律，木质素含量先增后减，水溶性果胶含量递增[51]。嘎拉苹果发育期共价结合果胶含量最高，纤维素含量远高于半纤维素，采后共价结合果胶快速降低，水溶性果胶含量开始增加，纤维素和半纤维素含量降低[51]。枣果实发育过程中，果皮中原果胶、纤维素含量降低，水溶性果胶含量增加[53]。

4.2. 单糖组成

果实 IDF 单糖组成以中性糖为主，大多以葡萄糖含量最高，不同种类果实间差异较大。北方 7 种水果中检测到 8 种单糖，草莓、山楂、苹果、桃、杏以半乳糖醛酸为主，梨以阿拉伯糖为主，桑椹中半乳糖醛酸与阿拉糖含量相当[24]。桃中的果胶多糖主要为半乳糖醛酸、半乳糖和阿拉伯糖，半纤维素多糖主要为木糖和半乳糖，纤维素多糖分主要为阿拉伯糖和半乳糖[54]。杏水溶性果胶的单糖组成主要为半乳糖醛酸，其次为半乳糖、阿拉伯糖、葡萄糖[55]。木瓜(*Chaenomeles speciosa*)中含 9 种单糖，其组成与含量变化趋势与 TDF 相同，其中纤维素葡萄糖含量最高，其次为半乳糖醛酸、木糖，含量最低的仍然为岩藻糖。日本木瓜与木瓜单糖组成基本一致，仅“NV1597”果实中木糖含量高于半乳糖醛酸含量[25]。海枣果肉中含 6 种单糖，以葡萄糖含量最高(1.57 g/100g IDF)，鼠李糖含量最低(0.03 g/100g IDF)，中性糖含量(3.02 g/100g TDF)远大于醛酸类含量(0.14 g/100g TDF) [14]。野生芒果 *Mangifera pajang* SDF 含 7 种单糖，以阿拉伯糖含量为主(18.47%)，其次为葡萄糖(4.46%)、甘露糖(3.15%)，岩藻糖(0.01%)含量最低，中性糖含量(30.18%)约为醛酸类含量(15.51%)的 2 倍[15]。苹果 IDF 中含有 8 种单糖，以葡萄糖含量最高(33.5%)，其次为半乳糖醛酸(27.1%)、阿拉伯糖(16.5%)，含量最低的为岩藻糖(1.2%) [37]。

5. 结语

膳食纤维作为一类生物活性物质对人体的健康起着重要的作用，既可促进健康又可预防疾病。膳食

纤维组分的研究是进行膳食纤维改性技术研究及功能评价与应用的基础。如前所述，果实膳食纤维组分的研究很大程度得益于研究者们对于植物细胞壁代谢的关注，则关注点主要为纤维素、半纤维素、木质素、果胶等中高分子量膳食纤维，对于果实低分子量膳食纤维如寡糖类的研究还相对较少。今后果实膳食纤维的研究将在功能食品的开发，膳食纤维组分的积累与调控机制等方面得到长足发展。

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