牛乳的凝固特性及其影响因素研究进展

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摘　要: 本文综述了近年来有关牛乳凝固特性的研究进展, 重点针对影响牛乳凝固能力的遗传和非遗传因素的研究进展进行了分析论述, 包括不同来源牛乳的凝固特性、乳蛋白组分和工艺条件等对牛乳凝固能力的影响。旨在厘清影响牛乳凝固能力的主要因素。

关键词: 牛乳凝固能力; 乳蛋白组分; 发酵乳凝乳质量

Research advances on milk coagulation properties and influencing factors

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ABSTRACT: This paper mainly reviewed the research progress on the milk coagulation properties and the influencing factors, including the milk coagulation ability of different sources of milk, and the effects of milk protein components and processing technology on the milk coagulation ability, aiming to clarify the main factors affecting the milk clotting ability.

KEY WORDS: milk coagulation ability; milk protein components; fermented milk; curd quality

1　引　言

牛乳凝固过程是生产酸奶和干酪等发酵乳制品的关键步骤。在发酵乳制品生产过程中, 乳酸发酵时或牛乳添加凝乳酶后, 牛乳凝固特性差或不凝固现象严重地影响了产品的品质和产率。在过去的 20~30 年里, 随着奶牛单产逐渐增加, 牛乳中蛋白质组成随之变化, 导致原料乳凝固能力显著下降, 研究发现约有 13%的奶牛所产牛乳凝乳时间显著增加, 并且约有 2~4%的奶牛所产牛乳不凝固[1]。现阶段, 我国乳制品企业主要是通过控制原料乳抗生素残留来改善牛乳的凝固特性。但在乳品企业对抗生素残留控制十分严格的情况下, 乳不凝固的情况仍时有发生, 造成诸如酸奶持水力差、乳清严重析出、酸奶品质下降、干酪产量显著降低。造成这种现象的主要原因是牛乳中存在不利于乳凝固的成分以及乳蛋白基因的多态性。

2　不同来源牛乳的凝固能力及其影响因素

自从上世纪 20 年代, 有关发酵乳制品生产过程中发生的原料乳不凝固的现象就受到了一些学者的关注, 芬兰、瑞典和意大利等乳业发达国家陆续开展此方面的研究。不同来源的牛乳的 MCA 差别很大, MCA 受多种因素影响, 包括遗传因素如品种差异; 非遗传因素如奶牛胎次、泌乳阶段、季节、牛群管理和饲养条件等[2-4]; 加工条件如 pH、$CaCl_2$、凝乳酶、温度等对 MCA 都有直接影响[5-7]。在此基础上, Tervala[8-11]等发现不同奶牛品种或同一品种不同个体之间的遗传差异可导致牛乳 MCA 差别很大, 约

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20%-40%表型上的差异实质上是遗传因素造成的。近年来研究者希望尝试通过奶牛遗传改良来改善牛乳的 MCA, 选用意大利荷斯坦牛和芬兰黑白花奶牛作为实验对象, 发现 κ-酪蛋白的存在对牛奶凝乳有较大影响[12-14]。Macheboeuf 等[15]发现一些特殊的奶牛品种, 如芬兰本地一种奶牛可产出干物质含量很高的牛乳, 其 MCA 要优于其它高产奶牛品种如 Holstein- Friesian 所产的乳, 说明不同品种奶牛即使牛乳产量相差不多但是 MCA 差别很大。进一步研究发现, 这种干物质含量较高的乳中酪蛋白含量高, κ-酪蛋白的 B-等位基因多出现于这类奶牛的基因型当中[16, 17]。

奶牛产犊胎次对其所产牛乳 MCA 的影响, 目前有关研究结论并不一致。Lindström 等[18]的实验结论表明牛乳 MCA 随着胎次的增加而变差。但是, Schaar 等[19]发现奶牛胎次的增加可以改善 MCA。还有一些学者的研究认为胎次对 MCA 没有影响[20,21]。泌乳阶段对 MCA 的影响比较明显, 泌乳初期和泌乳末期牛乳的 MCA 差异较大。Macheboeuf 等[15,22]研究表明在牲畜吃青草的季节牛乳 MCA 较好; 但是 Schaar 等[19]研究表明秋季乳的 MCA 最好。

研究发现牛群管理方式及饲养条件对牛乳 MCA 的影响主要体现在奶牛日粮的能量水平上。奶牛日粮的能量低, 则 MCA 差; 日粮均衡能量高, 则 MCA 好。日粮能量低的奶牛群中产凝乳能力差的乳的奶牛比例较高[23]。此外, 体质好的奶牛要比体质差的奶牛 MCA 高。乳房的健康状况对 MCA 的影响显著; Bergère 等[24]研究结果表明乳房炎对牛乳 MCA 影响很大。进一步实验研究发现乳房炎会改变乳的矿物质平衡, 降低钙含量, 使乳的 pH 值升高, 酪蛋白含量降低, 从而影响酪蛋白胶束结构和形成结实凝块的能力[25-27]。乳房炎乳对干酪的产量和质构也有很大影响。

3　乳蛋白组分对牛乳凝固能力的影响

近年研究表明, 乳的凝固能力在很大程度上受牛乳中乳清蛋白含量和组成的影响。β-乳球蛋白基因型对凝乳时间有明显影响: 研究发现含 β-乳球蛋白基因型 AA 的牛乳要比含基因型BB或AB的牛乳更适于加工干酪, 前者可以加快凝乳速度并且能够获得更高的干酪产量[28-30], 这可能是由于β-乳球蛋白AA的牛乳通常酪蛋白含量较高所致, 同时含A等位基因β-乳球蛋白的牛乳要比含B等位基因β-乳球蛋白的牛乳凝乳速度更快。对于 α_{s1}-CN 各基因型而言: 基因型 CC 牛乳生产的干酪产量(20.26%)高于 AA 型(18.65%)和 DD 型(18.35%), 并且基因型 CC 比 BC 凝乳形成的凝块更为结实; 基因型 CC 的酪蛋白含量较高, 因而凝乳时间也更长; 与基因型 CC 相比较, 含基因型 DD 的牛乳酪蛋白含量低, 因而形成凝胶慢, 凝块硬度低[31]。Allmere 等[32,33]的研究发现, A 和 B 等位基因型的 κ-酪蛋白的酸凝乳效果没有区别。E 等位基因 κ-酪蛋白对酸凝乳的影响目前未见报道。各种乳蛋白的基因型对干酪的产量和质量也有影响。生产 Manchego 干酪时, β-乳球蛋白 AA 牛乳加工的干酪产量最高, β-乳球蛋白 AA 牛乳生产的 Ricotta 干酪产量较高, 生产的 Tuma 干酪的脂肪含量较低[34,35]。

β-乳球蛋白是鲜乳中蛋白质中由乳腺上皮细胞合成分泌的一种特有乳清蛋白, 占鲜乳蛋白质的 7%~12%, 是牛和其他反刍动物乳中乳清蛋白的重要组分。研究已确定β-乳球蛋白在牛乳中存在多种遗传变构体, 不同变构体对奶牛牛乳的组分、性质和产量有一定的影响[36,37]。自发现β-乳球蛋白存在两种(A 和 B)遗传变构体以来, 研究者开始对 β-乳球蛋白的多态性给予重视和关注。随着分子生物学技术和核酸技术的引入和发展, 大量基于 β-乳球蛋白基因的研究报道显示该基因多态性显著, Aschaffenburg 等[38,39]在该基因座上发现 A、B、C、D、E、F、G、H 和 W9 种变构体。

4　原料乳的选择及工艺条件对牛乳凝固能力的影响

近年来对原料乳在酸性条件下凝乳特性的研究发现, β-乳球蛋白的基因型对酸凝乳过程有很大影响, 原料乳加热过程中B等位基因β-乳球蛋白与κ-酪蛋白的结合效率要高于 A 等位基因 β-乳球蛋白[40-42]。在牛乳蛋白含量相同的条件下, 使用含有 B 等位基因 β-乳球蛋白的牛乳生产的酸化牛乳凝胶的弹性模量(G′)明显高于含有 A 和 B 等位基因的β-乳球蛋白或只含有A等位基因的β-乳球蛋白牛乳生产的酸化凝胶。与富含 A 等位基因 β-乳球蛋白的牛乳相比, 含有B等位基因β-乳球蛋白的牛乳总β-乳球蛋白的含量比较低, 因此后者不适于加工发酵乳制品[43,44]。

通过调控加工技术条件可以改善牛乳的 MCA。酸奶加工过程中原料乳适宜的热处理(如 90~95 ℃, 5~10 min)可促进乳清蛋白变性, 改善凝乳质构。加热过程使乳清蛋白, 尤其是 β-乳球蛋白变性, 并与酪蛋白胶束表面的 κ-酪蛋白通过分子内二硫键和疏水作用而聚合在一起。随着发酵过程的进行, pH 值下降, 变性的乳清蛋白进一步与酪蛋白胶束聚合, 使酪蛋白胶束之间的交联度增加而形成致密的凝胶结构[45]。

乳的凝固能力是评估干酪加工用原料乳品质的重要标准。在干酪加工过程中发现, 通过添加发酵剂降低乳的 pH 值, 添加氯化钙, 增加凝乳酶的用量, 或者升高凝乳温度都可以改善牛乳的 MCA[46,47]。但是, 对这些加工条件的调控必须有所限制, 如果过度则会产生负面影响[48,49]。

5　研究展望

综上所述, 至今有关乳不凝固问题的研究主要集中在不同因素对酸凝乳或酶凝乳过程中牛乳凝固能力的影响

[50,51]，而较少研究这些因素如何通过改变牛乳组分，尤其是不同乳蛋白组分的含量及其相对比例变化规律的影响，以及乳蛋白基因型的改变，从而影响牛乳的凝固能力。

随着我国乳业的快速发展，年增长20%以上的发酵乳制品已成为我国发展最快的乳制品种类，与此同时，奶牛单产水平的进一步提高可能导致原料乳凝固特性的改变，从而影响发酵乳产品的品质和产量。因此有必要进一步研究造成牛乳凝固能力变差或不凝固的内源性因素如奶牛品种差异、品种内的遗传因素、泌乳阶段等对牛乳凝固能力影响的机制，建立原料乳组分与凝乳特性之间的相关性，确定影响凝乳的主要乳蛋白质组分，研究不同等位基因乳蛋白对牛乳凝固特性的影响，探讨酶凝乳和酸凝乳时的牛乳凝固作用分子机制。在此基础上提出基于牛乳凝固能力的原料乳分级方法，对于原料乳的品质评价和合理利用，提高原料乳资源的利用率，改善发酵乳品质，增加乳品企业经济效益，具有重要的理论和应用价值。

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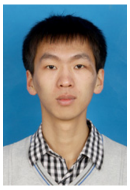

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