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## TECHNOLOGICAL APPROACHES TO THE STABILIZATION OF EMULSION-BASED ALCOHOLIC BEVERAGES IN MODERN MIXOLOGY

**N. I. CHEREVYCHNA,** Candidate of Technical Sciences, Associate Professor
ORCID ID: 0000-0002-6660-5366
(Simon Kuznets Kharkiv National University of Economics)

***Abstract.*** *The purpose of the study is to analyze the historical evolution of emulsion alcoholic beverages, systemize modern innovative ingredients and physicochemical stabilization methods based on recent scientific research, and identify promising pathways for implementing emulsion technologies in modern bar culture and mixology. The study is based on a comprehensive system analysis, comparative-historical evaluation, and physicochemical interpretation of scientific literature in food chemistry, spirits production technology and mixology. The article analyzes the historical development of emulsion-type alcoholic beverages, from medieval monastic medicinal elixirs and early egg-based liqueurs and cream systems to modern multiphase, plant-based, and lactose-free alternatives made from oat, coconut, almond, and chufa milk. The classification of liqueurs by physicochemical parameters (alcohol strength, sugar content) and raw material composition has been systematized. Key technological challenges in stabilizing emulsion cocktails behind the bar in the presence of ethanol and fruit acids were identified, such as protein denaturation, lowered interfacial tension, and destruction of protective adsorption layers, leading to phase separation through creaming, sedimentation, flocculation, and coalescence. Innovative plant-based and biopolymer stabilization ingredients were systematized and their functional performance in alcoholic systems was substantiated. Combining chemical stabilization using plant and biopolymer agents with physical processing methods enables the creation of thermodynamically stable emulsion cocktails with rich sensory profiles without artificial chemical additives. Future research directions focus on developing new formulations for lactose-free and Low-ABV emulsion-type cocktails with enhanced functional properties.*

***Keywords:*** *emulsion alcoholic beverages, emulsion stabilization, liqueurs, bar culture, mixology, emulsions.*

**Statement of the problem in general terms.** Modern bar culture (mixology) has transformed from simple ingredient mixing into a multidisciplinary field closely intertwined with food and colloid chemistry, molecular gastronomy, etc. One of the complex yet promising directions is the creation of emulsion-structured alcoholic cocktails. Emulsions provide beverages with a harmonious texture, fullness of taste, and the ability to retain and gradually release a cascade of aromatic substances. Beyond sensory characteristics, emulsification offers opportunities to incorporate innovative ingredients capable of modifying the functional properties of beverages.

However, the key technological challenge of such systems is their thermodynamic instability. The presence of ethanol at concentrations ranging from 10 to 25% vol. causes protein denaturation, reduces interfacial tension, and disrupts protective adsorption layers surrounding fat droplets. This leads to undesirable phenomena such as sedimentation, creaming, flocculation, and coalescence. Developing scientifically grounded methods for stabilizing emulsion cocktails is an important objective for modern mixology.

**Analysis of recent research and publications.** The study of physicochemical processes in dispersed food systems has been addressed by leading global scientists. D. J. McClements specializes in food biopolymers and colloids, focusing on creating healthier and more environmentally friendly products. Researchers D. Muir and W. Banks investigated the stabilization of high-alcohol cream liqueurs using emulsifying salts and caseinates. Recommendations for applying ultrasonic cavitation to beverage homogenization have been developed by B. K. Tiwari (fruit-milk beverages), F. Trujillo (coffee beverages), P. H. Campelo (fortified juices), A. Anaya-Esparza, and M. Guimarães (plant-based milk) [1–4].

The contribution of Ukrainian scientists to the study of dispersed alcoholic systems lies in investigating thermodynamics, recipe composition, and technology of liqueurs and emulsion beverages. Researchers O. V. Kuzmin, T. A. Holuieva, and O. V. Nemirich explore the physicochemical

characteristics, formulation, technology, and quality of new-generation emulsion cream liqueurs based on plant milk. O. M. Ostriuk develops technologies for functional alcoholic beverages through the extraction of fruit and berry raw materials. S. I. Oliinyk focuses on studying the thermodynamics of emulsion systems and the impact of beverage formulations on oxidation and emulsion stability [5–7].

Despite the depth of these scientific works, most are focused on the industrial production of long-shelf-life liqueurs. Meanwhile, the formation of stable emulsion structures in beverages and cocktails within mixology remains insufficiently addressed.

**Formulation of article goals.** The objective of the article is to analyze the historical experience of creating emulsion alcoholic beverages, systemize innovative ingredients and physicochemical stabilization methods based on modern scientific research, and identify promising pathways for implementing emulsion technologies.

**Presentation of the main research material.** Liqueur is a strong, sweet alcoholic beverage made from fortified fruit and berry juices, infusions of aromatic herbs with added roots, spices, etc. The history of emulsion-type alcoholic beverages and dense-textured liqueurs developed over centuries through several stages.

In the 11th century, in many Catholic monasteries, sick people were treated with various mixtures and elixirs. Monks, seeking to improve medicine manufacturing techniques, discovered new components. Since most of these mixtures were bitter, honey was added. The first sweet liqueurs (Benedictine, Chartreuse) were created by monks as medicinal elixirs as 1510. An emulsion component was absent, but the concept of masking the harsh taste of alcohol with sweet components emerged at that time [8–10].

Liqueurs from Lucas Bols, known in the Netherlands and beyond to this day, date back to 1575. Their creator was Dutch physician Lucas Bols, and the primary ingredients were caraway as a digestive aid and alcohol as a painkiller.

The stage of egg-based liqueurs began in the early 17th century when Dutch colonists in Brazil encountered a local beverage based on avocado pulp, alcohol, and sugar. Upon returning to Europe, they replaced scarce avocado with egg yolk. Yolk lecithin became the first natural emulsifier enabling the combination of alcohol and fat into a homogeneous mass. Thus, classic Advocaat liqueur emerged as the first alcoholic beverage of an emulsion nature [9, 11].

In the 19th century in France, the Creme category of liqueurs appeared. Despite the name, they contained no dairy cream. The word «creme» indicated a thick, syrup-like consistency due to high sugar content (from 250 g/L), which increased beverage viscosity.

Real cream liqueurs appeared only in 1974 in London when David Gluckman and Tom Jago created the Baileys Irish Cream. The primary challenge was instant dairy protein coagulation upon contact with Irish whiskey. This issue was solved through two-stage homogenization and using sodium caseinate combined with vegetable oils [8].

The next stage of liqueur development in the 1990-s – 2000-s saw multiphase systems and exotic products. Sheridan's is a liqueur consisting of two separate phases (coffee-chocolate and vanilla-cream) mixed directly in the glass. Exotic fruit cream liqueurs also entered the market (South African Amarula made from marula fruit) [8–10].

Today, in response to growing demand for plant-based products, manufacturers are transitioning to emulsion liqueurs based on almond, coconut, and soy milk, requiring completely new stabilizers.

Classifying liqueurs is challenging due to their diversity and similarities. Modern classification divides liqueurs along two main directions: physicochemical parameters (alcohol strength and sugar content) and primary raw material/flavor profile.

By alcohol and sugar content, beverages are divided into three groups:

– strong liqueurs (35–45% alcohol, 32–50% sugar). Created using strong distillates (cognac, whiskey, grain alcohol) with maceration of herbs, spices, or citrus peel. They feature concentrated aromas that mask alcohol notes. This group includes early monastic medicinal tinctures.

– dessert liqueurs (25–30% alcohol, 25–30% sugar). Produced by infusing or blending alcohol bases with natural fruit/berry extracts, cream, or spices, sweetened with sugar syrup, and aged to achieve a balanced taste. Served as digestifs or used in cocktails.

– cremes (15–28% alcohol, 49–60% sugar). Can be dairy cream liqueurs or liqueur crèmes (which may contain no cream). Crèmes possess a thick syrup-like consistency due to high sugar concentration [12].

Classification by primary raw material is more intricate.

Herbal liqueurs (herbal spirits, Kräuterlikör, balms) – a large category produced by infusing or distilling alcohol with mixtures of herbs, roots, bark, flowers, seeds, and spices, followed by sugar addition. Secret recipes can contain 10 to over 130 botanical components. Herbal liqueurs feature a pronounced bitterness, medicinal-spicy or resinous notes, which are harmoniously balanced by sweetness and alcoholic warmth. The most famous herbal liqueur include: Jägermeister – a German Kräuterlikör with distinct notes of cinnamon, anise, and ginger; Chartreuse and Benedictine – iconic French monastic liqueurs created using secret recipes; Becherovka – a Czech balm featuring a pronounced flavor of cinnamon, cloves, and alpine herbs; Unicum – a Hungarian thick, dark-brown, highly concentrated balm produced according to a secret recipe with over 40 herbs [12]. In cocktails,

they are used as an aromatic base for creating complex, spicy, and bittersweet-fresh mixes.

Amaro are traditional Italian herbal liqueurs with a pronounced bittersweet profile, usually consumed as a digestif. They are prepared by infusing a spirit or wine base with a mixture of herbs, roots, flowers, bark, citrus peel, and spices. The beverage is sweetened with sugar syrup and often aged in barrels. Thanks to its rich aroma, Amaro is added to both classic and signature cocktails. The most famous include Amaro Montenegro, Amaro Averna, Fernet-Branca, Amaro Nonino, Ramazzotti [13].

A separate category is the group of bitter liqueurs – bitters, which are produced using extracts of herbs and roots from medicinal plant materials. In most cases, these are dark-colored drinks that stimulate digestion and improve appetite.

Bitters are very closely related to herbal liqueurs, but the key difference between them lies in the sweetness level (sugar content), the intensity of bitterness, and the beverage's intended purpose. By standard, herbal liqueurs strictly require a high sugar content (usually no less than 100 g/l). Even with a bitter edge, the sweetness remains pronounced, softening the alcohol. Bitterness is the dominant note in bitters; they contain either no sugar at all or a minimal amount insufficient to mask the bitterness

Aromatic bitters are very bitter and highly concentrated beverages added in micro-doses (dashes) to flavor cocktails. «Dash» in cocktail recipes refers to a liquid unit of measurement equal to approximately 0,6–1,0 ml (one shake of a bottle equipped with a special dasher top). The most famous include Angostura (a bitter from Trinidad based on dark rum, featuring bitter orange peel extract); Peychaud's (an American bitter with a fairly light and fruity taste compared to other tinctures of this type, sweet with notes of cherry, clove, and nutmeg).

Potable bitters (aperitifs/digestifs) are consumed neat or with tonic. Campari and Aperol – the most famous brands Italian bittersweet aperitifs that serve as the foundation for modern bar Spritz cocktails. Any potable bitter with a high sugar content can be classified as a liqueur. However, not every herbal liqueur is a bitter, as many of them emphasize sweetness and spices rather than bitterness [12, 14].

Citrus and fruit-berry liqueurs are the foundation of most classic and modern cocktails. The most famous include French Cointreau, Grand Marnier, Chambord; Italian Limoncello (Pallini, Villa Massa); Japanese Midori. Although both Cointreau and Grand Marnier are famous orange liqueurs, they differ significantly in their spirit base. Cointreau is created using a neutral grain spirit (a classic transparent Triple Sec), whereas Grand Marnier is produced on the basis of aged French cognac.

Cream and egg liqueurs are distinguished by a delicate texture, soft buttery flavor, and moderate alcohol content. The most famous include Baileys Irish Cream (a cream liqueur based on Irish whiskey); Sheridan's (Ireland) – a two-compartment liqueur featuring coffee-chocolate and cream-vanilla layers; Amarula (a South African cream liqueur made from marula fruit with a caramel-fruity profile); Advocaat (Bols, Warninks) – a thick Dutch egg liqueur made from egg yolks, sugar, and brandy. From a food chemistry perspective, such beverages are typical emulsions.

Coffee and chocolate liqueurs are produced from roasted ground coffee beans or cocoa beans without the use of artificial flavorings. The most famous include Kahlua (Mexico) – global leader among coffee liqueurs based on rum and Arabica coffee; Tia Maria – coffee liqueur made with Jamaican rum and Madagascar vanilla; Mozart (Dark, Milk, White) – a premium line of Austrian chocolate liqueurs.

Nut, spicy, and anise liqueurs have a pronounced, recognizable character and are in demand both in classic bartending and in culinary arts. The most famous include Italian nut liqueurs Disaronno Originale (Amaretto) and Frangelico. Scottish Drambuie – a spicy liqueur based on Scotch whisky, honey, and herbs. Anise liqueur Sambuca (Molinari, Luxardo) has its own specific characteristic (like absinthe or ouzo). It is transparent in the bottle, but when diluted with water or ice, it suddenly turns cloudy white. In bartending, this phenomenon is called the «Ouzo effect» or «Louche effect».

Curasao is a general name for liqueurs based on the peel of a specific type of bitter orange. In the production process, the dried peel is macerated in cognac or alcohol to form an aromatic extract, after which spices and herbs are added. These liqueurs can be light yellow, orange, green, blue, or white in color.

Floral and botanical liqueurs represent a craft segment in modern mixology. St-Germain – a French liqueur made from freshly hand-picked elderflowers. In mixology, adding as little as 5–10 ml of St-Germain liqueur enhances the balance of nearly any cocktail. Italicus Rosolio di Bergamotto – an Italian liqueur based on Sicilian bergamot and chamomile [12, 14].

Recently, lactose-free and vegan alternatives – plant-based cream liqueurs – have been gaining increasing popularity. The main reason for their popularity is the opportunity to achieve a delicate dessert flavor and smooth texture without lactose or animal-derived fats.

Oat milk liqueurs are the most popular variety in this category, as oat milk possesses a natural creamy density and a neutral taste that does not overpower the primary flavorings.

The Baileys brand released a vegan line of Baileys Non-Dairy liqueurs made with almond (Almande) and oat milk, featuring Cookies & Creamy and Coffee Toffee flavors. Arctic Blue Oat (Finland) is a lactose-free liqueur based on Finnish gin, oat milk, and

wild blueberries. The American brand Oatrageous produces lightened oat liqueurs in bourbon, espresso, and coconut flavors. Misunderstood Oat Nog is a vegan variation of the traditional Christmas drink Eggnog, made with oat milk and spiced whiskey. Coconut cream and coconut oil liqueurs are beverages with natural density and a light tropical flavor. Dirty Cow (Scotland) – a series of vegan dessert liqueurs based on Scotch whisky and coconut extract (with strawberry, chocolate, and classic Irish Cream flavors). Aihiki (Australia) – a beverage based on coconut cream, aged whisky, chocolate, and vanilla. Pallini Limoncello Cream – an Italian lemon cream liqueur that uses coconut oil instead of dairy cream, making it completely vegan. Tiger nut (chufa) is a traditional base for the refreshing Spanish beverage Horchata. Licor 43 Horchata is a liqueur made with tiger nut milk, cinnamon, and citrus. Besos de Oro harmoniously combines tiger nut milk with high-quality Spanish brandy.

Another alternative is Bom Bom Fully Baked – an innovative hemp milk liqueur combining Caribbean rum with a chocolate chip cookie flavor.

Liqueurs are widely popular as a base for cocktails. They pair well with vodka, gin, whisky, brandy, cognac, wines, milk and cream, hot chocolate, ice cream, and fruit juices. Liqueurs enrich cocktails with rich color and sweetness, imparting softness, density, and body to their texture.

Since liqueurs feature a high sugar content and a distinct flavor profile, liqueur-based cocktails are classified according to several key criteria: by structure, by volume and serving style, and by the flavor profile of the liqueur base [15, 16].

Sours – cocktails where a liqueur acts as the alcohol base and sweetener, balanced by fresh citrus juice (sometimes with added egg white for foam). Spritzes & Highballs – light, refreshing cocktails where an aperitif or fruit liqueur is diluted with sparkling wine, tonic, soda water, or juice. Cream & Dessert Cocktails – drinks with a pronounced sweetness and velvety texture. They usually contain cream, coffee, or chocolate liqueurs, as well as cream, milk, or espresso. Equal Parts Cocktails – drinks in which a liqueur is combined in equal proportions with other spirits, vermouths, or bitters. Shooters & Layered Drinks – small-volume cocktails («shot-sized»). Due to the varying densities of liqueurs, they are often layered. Hot Drinks – beverages based on coffee, tea, or cocoa with the addition of liqueurs [15–19].

Modern mixology trends include Low-ABV (Low Alcohol by Volume)–reducing the overall alcohol content. Reducing the alcohol content changes not only the strength, but also the body and mouthfeel of the drink, as ethanol plays a key role in dissolving aromatic compounds and creating texture. Instead of using a liqueur merely as a complement to vodka or gin, the liqueur itself (especially herbal or floral varieties) becomes the sole alcoholic base, mixed with tonic or soda water. Additionally, in modern recipe specs, the amount of plain simple syrup is reduced when a sweet liqueur is present to avoid excessive cloyingness. The use of craft and niche liqueurs, as well as local wild herb infusions, is also gaining widespread popularity.

Creating next-generation alcoholic cocktails with a stable emulsion structure based on liqueurs, particularly when using the fat-washing technique directly at the bar counter, often presents challenges. The main difficulty is that ethanol inherently acts as a destabilizing factor for most classic emulsions. High alcohol content and the presence of fruit acids destroy the structure of natural protein emulsifiers, leading to curdling and unwanted flakes. Due to the significant density difference between the alcohol-water and fat phases, fat droplets tend to coalesce and rise to the surface, forming a fat film or sediment. Additionally, ice melting during mixing or serving changes the viscosity and component ratio, which can rapidly break down an unstable emulsion network right in the glass [20–23].

Stabilizing an emulsion-structured alcoholic cocktail requires a comprehensive approach: combining physical processing (homogenization, emulsification, cavitation, etc.) with highly effective surfactants (to reduce interfacial tension) and hydrocolloids (to increase system viscosity), among other factors.

Analyzing current trends in modern mixology aimed at improving emulsion cocktail technology, the following key approaches can be highlighted:

– use of immersion ultrasonic dispersers (sonicators) directly at the bar. This allows for the preparation of stable nanoemulsions from fat-containing ingredients and alcoholic distillates within 15–30 seconds without adding artificial chemical stabilizers;

– formation of stable hybrid «oil-in-water-in-air» systems. Using nitrous oxide siphons, the emulsion base is converted into a stable alcoholic foam («velvet foam») that slowly settles at the bottom of the glass, creating a dynamic sensory-textural heterogeneity during consumption;

– modified Fat-washing technique. While the classic Fat-washing method involves extracting flavor from fat into alcohol followed by freezing and completely removing the fat phase, an innovative approach retains 5–10% of the fat phase as an ultrafine emulsion using aquafaba or Quillaja saponins. This enriches the drink not only with flavor, but also with a rich, velvety texture [24].

Modern mixology requires ingredients capable of withstanding harsh environments (ethanol and low pH from juices) without altering the flavor profile of the drink. An analysis of innovative ingredients for cocktail creation is presented in the table 1.

Classic animal proteins (egg white and yolk, dairy cream) are increasingly replaced or supplemented with

Table 1

**Analysis of innovative ingredients for cocktail creation**

| Ingredients | Chemical nature or active component | Functional role in cocktail | Advantages and technological features |
|---|---|---|---|
| Aquafaba | Soluble chickpea and bean proteins and saponins | Emulsifier, foaming agent | Vegan alternative to egg white; resistant to medium ethanol concentrations (10–15%). |
| Quillaja saponins (Quillaja saponaria) | Non-ionic natural surfactant compounds | Highly efficient emulsifier and foaming agent | Create stable fine emulsions and dense foam at low concentrations (0,05–0,1%), insensitive to pH, alcohol, temperature. |
| Cellulose nanocrystals | Solid insoluble biopolymer particles | Natural Pickering stabilizer | Create a mechanical barrier at phase interfaces, completely preventing coalescence. |
| Citrus fibers | Insoluble dietary fibers with high hydration | Texturizer, syneresis inhibitor | Increase continuous phase viscosity, prevent sedimentation. |
| Xanthan and gellan gums | Exopolysaccharides of microbiological origin | Rheology modifiers | Provide pseudoplastic behavior: drink flows easily but keeps droplets suspended. |
| Sucrose esters of fatty acids | Non-ionic surfactants | Interfacial tension reduction, microemulsion formation | High hydrophilic-lipophilic balance value; enable completely transparent alcoholic microemulsions with citrus essential oils. |
| Modified starch (E1450) | Starch sodium octenyl succinate | Emulsifier, stabilizer, encapsulation | Exceptionally stable in alcohol (up to 40% vol.); forms durable coating around fat droplets; ideal for Limoncello cream. |
| Plant protein isolates (pea, potato) | Globular plant proteins | Interfacial adsorption layer formation | Hypoallergenic alternative to casein and whey; potato protein foams like egg white even at 20% vol. |
| Soy and sunflower lecithin | Phospholipid mixture (amphiphilic molecules) | Liposome formation, emulsification | Natural biocompatible component; used for alcoholic espumas from fatty ingredients (e.g., truffle oil). |

alternative plant and mineral stabilizers. However, replacing classic cream with alternative milks requires careful selection of stabilizers, as plant proteins are more sensitive to ethanol content and pH levels.

**Conclusions and prospects for further research.** An analysis of the historical evolution and current state of mixology showed that emulsion alcoholic beverages have evolved from medieval monastic elixirs and traditional egg and cream liqueurs to innovative multiphase and vegan systems based on oat, coconut, almond, tiger nut milk.

It was determined that the key technological challenge in creating emulsion cocktails directly at the bar counter is the aggressive action of ethanol (10–25% vol.) and fruit acids, which trigger the denaturation of natural proteins, the destruction of adsorption layers, and phase separation (sedimentation, flocculation, coalescence).

The assortment of innovative stabilizing ingredients has been analyzed, proving the promise of replacing classic animal proteins with alternative plant and biopolymer components (aquafaba, quillaia saponins, cellulose nanocrystals for Pickering stabilization, modified starch E1450, xanthan and gellan gums, potato and pea protein isolates), which exhibit high stability in alcohol-containing and acidic environments.

The Recommended expediency of combining chemical stabilization with physical processing methods (using immersion ultrasonic sonicators to produce nanoemulsions, nitrous oxide siphons to create 'velvet foam' alcoholic foam, and a modified fat-washing technique retaining an ultra-fine emulsion) has been recommended, ensuring the formation of stable drink textures.

Future research perspectives involve developing new recipe formulations and technologies for lactose-free dessert and Low-ABV emulsion-type cocktails with enhanced functional and sensory properties.

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***Н. Черевична,*** *кандидат технічних наук, доцент (Харківський національний економічний університет імені Семена Кузнеця).* ***Технологічні підходи до стабілізації емульсійних алкогольних напоїв у сучасній міксології***

***Анотація.*** *Метою дослідження є аналіз історичної еволюції емульсійних алкогольних напоїв, систематизація сучасних інноваційних інгредієнтів і фізико-хімічних методів стабілізації на основі останніх наукових досліджень, а також визначення перспективних шляхів впровадження емульсійних технологій у сучасну барну культуру та міксологію. Дослідження базується на комплексному системному аналізі, порівняльно-історичному оцінюванні та теоретичній інтерпретації наукової літератури з харчової та колоїдної хімії, технології алкогольних напоїв та сучасної міксології. У статті проаналізовано історичний розвиток алкогольних напоїв емульсійного типу від середньовічних монастирських лікувальних еліксирів та перших яєчних і вершкових систем до сучасних мультифазних, рослинних і безлактозних альтернатив на основі вівсяного, кокосового, мигдалевого та чуфового молока. Проаналізовано класифікацію лікерів за фізико-хімічними параметрами (міцність, вміст цукру) та сировинним складом. Визначено ключові технологічні проблеми стабілізації емульсійних коктейлів за наявності етанолу та фруктових кислот, такі як денатурація білків, зниження міжфазного натягу та руйнування захисних адсорбційних шарів, що призводить до розшарування фаз шляхом відстоювання, седиментації, флокуляції та коалесценції. Проаналізовано інноваційні інгредієнти та їхню функціональну ефективність для стабілізації спиртовмісних систем. Висвітлено сучасні техніки міксології: ультразвукову сонікацію для приготування наноемульсій, сифони для створення оксамитової піни та модифікований fat-washing із збереженням ультратонких емульсій. Поєднання хімічної стабілізації з використанням рослинних і біополімерних агентів із фізичними методами обробки (ультразвукова кавітація, тиск) дозволяє створювати термодинамічно стійкі емульсійні коктейлі з багатим сенсорним профілем. Напрями подальших досліджень зосереджені на розробці нових рецептур безлактозних і Low-ABV коктейлів емульсійного типу з підвищеними функціональними властивостями.*

***Ключові слова:*** *емульсійні алкогольні напої, стабілізація емульсій, лікери, коктейлі, барна культура, міксологія, емульсії.*

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