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Application of Natural Amino Acid Anionic Surfactants

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Abstract. Global sensitive skin care demand has grown rapidly, reaching over $50 billion in 2024, but traditional surfactants like SLS often cause skin barrier irritation, creating an urgent need for mild, safe alternatives—making natural-source amino acid-based anionic surfactants (NSAAS) critical for the development of the personal care industry. This paper focuses on NSAAS derived from oat and wheat protein hydrolysates, systematically organizing their molecular design, synthesis technologies, performance regulation, and application potential while supplementing core research results. In molecular design, selecting neutral amino acid residues and C12-C14 coconut acyl chains enhances NSAAS's skin affinity by 22% and foam stability by 15% compared to other derivatives. In synthesis, the weak alkali chemical acylation method achieves a 98.5% conversion rate and over 95% product purity, while enzymatic acylation has higher selectivity but a 2-3 times longer reaction cycle. For performance, NSAAS reduces transepidermal water loss by 28% and skin barrier damage by over 25%, exhibits a 27° contact angle, and improves cleansing cream stability by 30%. In applications, it lowers crystalline amino acid cleansing cream setting temperature to 55℃ and achieves a 2% irritation rate in infant care, though facing industrial scaling-up and stability challenges. This paper provides theoretical references for developing mild, green personal care raw materials, effectively promoting the advancement of safe and high-performance sensitive skin care products.

Keywords: NSAAS, performance regulation mechanism, sensitive skin care application

1. Introduction

According to Euromonitor International, the global market for sensitive skincare products has rapidly expanded in recent years, with a market size exceeding $50 billion by 2024 [1]. Consumers' demand for the "mildness" and "safety" of basic care products such as cleaning agents has significantly increased. Traditional surfactants such as sodium dodecyl sulfate have strong cleaning power, but they can easily damage the stratum corneum barrier of the skin, causing dryness, itching, and even redness, which seriously conflicts with the needs of sensitive skin care [2]. In this context, naturally derived amino acid based anionic surfactants have gradually become a core alternative direction due to their structural similarity with skin components, low irritation, and easy biodegradability [3].

International scholars have conducted extensive research on nonsteroidal anti-inflammatory drugs. Kim et al. prepared NSAAS using oat protein hydrolysate and found that compared to sodium

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cocoyl glycinate, the surfactant can reduce transdermal dehydration of sensitive skin by 28%, confirming its superior skin barrier protection effect [4]. Zhang et al. focused on the acylation technology of nonsteroidal anti-inflammatory drugs and compared the performance of chemical acylation and enzymatic acylation. The results showed that the chemical acylation method achieved a conversion rate of 98.5% under lower equipment requirements, while the enzymatic acylation method had higher product selectivity, but the reaction period was extended by three times [5].

In terms of performance tuning, Lee et al. investigated the effect of acyl chain length on the foaming performance of NSAAS. They found that the volume of foam of coconut acyl modified surfactant was 15% higher than that of lauroyl derivatives, and the attenuation rate of foam within 5 minutes was only 8% [6]. In terms of application research, Park et al. applied NSAAS to a crystalline amino acid facial cleanser. The results showed that adding 8% oat protein-derived NSAAS could reduce the setting temperature of face cream from 65℃ to 55℃, and improve the high-temperature stability [7].

However, there are still gaps in existing research. Firstly, the quantitative relationship between the types of amino acid residues in plant protein hydrolysates and the mildness of surfactants is not yet clear. Secondly, the interaction mechanism between NSAAS and the skin barrier lacks in-depth analysis based on in vitro models. Thirdly, the continuous flow synthesis and other industrial production technologies of NSAAS have not been fully validated [4-8].

The above-mentioned research gaps limit the further application of NSAAS in sensitive skincare products. Therefore, this paper clarifies the direction of structural optimization by reviewing the molecular design elements of NSAAS, including amino acid residues and acyl chains, as well as synthesis techniques, including acylation methods and molecular weight regulation. In addition, this paper provides an in-depth analysis of the regulatory mechanisms of low irritation, wettability, foaming, and emulsifying properties. Based on in vitro and in vivo experimental data, a structure performance correlation is established. The specific applications of nonsteroidal anti-inflammatory drugs in sensitive skin cleansing and infant care, as well as existing bottlenecks such as long-term stability and cost control, are discussed, providing a reference for practical product development.

2. Molecular design and synthesis of natural amino acid anionic surfactants

2.1. Molecular structural elements

The performance of naturally derived amino acid-based anionic surfactants fundamentally depends on molecular design, while synthesis techniques affect their industrial feasibility. The coordination between these two aspects supports the application value of NSAAS. Amino acid residues are the basis of molecular design and directly affect the biocompatibility and mildness of surfactants. The current research mainly uses oat protein and wheat protein hydrolysate as raw materials. Oat protein is rich in neutral amino acids such as glutamic acid and proline. After hydrolysis, it forms small-molecule peptides, reducing skin charge irritation and providing hydrophilic groups for surfactants. Kim et al. confirmed through atomic force microscopy that glutamic acid residues in oat protein hydrolysate can bind to keratin through hydrogen bonding. Compared with synthetic amino acid-derived surfactants, NSAAS showed a 22% increase in skin affinity [4].

The length and type of acyl chain determine the hydrophobicity and interfacial activity of surfactants. Most studies choose short-chain acyl groups, such as coconut acyl and lauroyl. Cocoonyl group has moderate chain length, which ensures enough hydrophobic interaction to generate decontamination and foam, and avoids skin dryness caused by long-chain acyl group [6]. Lee et al. compared the coconut acyl and lauroyl derivatives and found that the foam stability of the

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coconut acyl-modified NSAAS increased by 15%, and the skin degreasing rate decreased by 8%, making it more suitable for cleaning products [6].

2.2. Synthesis technology

Acylation reaction is the core step in the preparation of nonsteroidal anti-inflammatory drugs, and there are two mainstream techniques: the weak base chemical method and enzymatic acylation. The weak alkaline chemical method uses organic solvents/water as a mixed solvent to achieve the binding of acyl chlorides and amino acids under weak alkaline conditions. This method has mild reaction conditions, high conversion rates, and low equipment requirements, making it suitable for laboratory and pilot production [5]. Zhang et al. used this method to prepare wheat protein-derived NSAAS with a purity of over 95%, although ethanol recrystallization was required to remove unreacted acyl chlorides [5].

Enzymatic acylation uses lipase as a catalyst, which is environmentally friendly and has high product selectivity, reducing the pollution of chemical reagents to the environment [5]. However, this method also has drawbacks, as the reaction cycle is 2-3 times longer than chemical methods, and the cost of enzyme preparation accounts for about 30% of the raw material cost, so it has not yet been applied in industry [5]. In addition, directional hydrolysis technology is key to controlling the molecular weight of amino acid residues. By adjusting the hydrolysis temperature and enzyme dosage, the molecular weight of plant protein hydrolysis products can be controlled within a specific range, ensuring that small molecule peptides can be absorbed by the skin while providing sufficient hydrophilic sites to maintain interfacial activity [4]. Kim et al.'s study showed that when the molecular weight is below a certain value, the wetting and emulsifying properties of NSAAS are significantly improved, which is closely related to the enhanced dispersibility of small molecule peptides [4].

3. Performance regulation mechanism of natural amino acid anionic surfactants

3.1. Low stimulus regulation mechanism

The core advantage of naturally derived amino acid-based anionic surfactants lies in the balance between "high performance" and "low irritation". The mechanism of performance regulation is analyzed from four aspects, including low irritation, wettability, foaming, and emulsification, each of which is directly related to the molecular structure. The low irritancy of NSAAS mainly stems from two aspects: pH compatibility with the skin and the skin protective film formed by coconut acyl groups. The pH value of the human skin surface is about 4.5-6.5, while the pH value of NSAAS is usually controlled at 5.0-6.0, which is highly compatible with the skin pH value and avoids damage to the stratum corneum by strong alkaline surfactants [9]. Wang et al. conducted skin irritation tests on 50 volunteers with sensitive skin and confirmed that nonsteroidal anti-inflammatory drugs with pH values of 5.0-6.0 can reduce skin barrier damage by more than 25% and significantly reduce transdermal water loss [9].

On the other hand, coconut acyl (the hydrophobic part of the molecule) diffuses on the surface of the skin, forming a dense hydrophobic protective film that prevents external pollutants from directly contacting the skin, while reducing the dissolution of skin lipids by the surfactant itself [4]. Kim et al. observed through confocal laser scanning microscopy that the use of NSAAS derived from oat protein increased the orderliness of lipid arrangement in the stratum corneum by 18%, and this protective film effect is an important support for its mildness [4].

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3.2. Wettability regulation mechanism

The wettability of NSAAS depends on its ability to reduce solid-liquid interfacial tension, with amphiphilic structure and sodium salt form being key regulatory factors. The hydrophilic part contains a large number of polar groups, such as hydroxyl and amino groups, which can form hydrogen bonds with water molecules; the Hydrophobic parts can adsorb onto solid surfaces, altering their hydrophilicity [8]. Meanwhile, the sodium salt form can achieve high ionization in water, forming a negatively charged region that further enhances the interaction with water molecules and significantly reduces the solid-liquid interfacial tension [8].

Chen et al. conducted interfacial tension tests and found that a 0.5% concentration of oat protein-derived NSAAS solution reduced the surface tension of water from 72 mN/m to 32 mN/m, while the same concentration of synthetic amino acid surfactants only reduced it to 38 mN/m [8]. In the contact angle test, the contact angle of this surfactant on the quartz surface was about 27°, lower than that of sodium cocoyl glycinate and NSAAS derived from wheat protein, confirming its superior wettability [8]. This characteristic enables it to quickly spread in cleaning products, achieving uniform cleaning.

3.3. Bubble regulation mechanism

The foaming performance of NSAAS depends on its ability to orient itself at the gas-liquid interface. When air is introduced into the solution, the hydrophilic groups of NSAAS face the aqueous phase and the hydrophobic groups face the gas phase, forming a dense monolayer. This reduces the interfacial tension between gas and liquid, and lowers the energy barrier for bubble formation [6]. The medium chain length of the acyl group makes the hydrophobic interaction at the interface stable, prevents bubble coalescence and rupture, and extends the life of the foam [6].

Lee et al. conducted foaming performance experiments, and the results showed that the volume of 0.1 g/L coconut acyl oat protein-derived NSAAS solution after shaking exceeded 160 mL, and the attenuation rate of foam within 5 minutes was only 8%, significantly lower than that of sodium coconut acylglycine [6]. This property enables it to form rich cream foam in cleaning products, improve user experience, and ensure cleaning efficiency - bubbles can wrap oil and dirt on the skin surface and be washed away during washing.

3.4. Emulsification regulation mechanism

The emulsifying performance of nonsteroidal anti-inflammatory drugs is mainly regulated by the hydrophilic lipophilic balance index and critical micelle concentration. The HLB value of NSAAS is about 12-14, classified as a water-in-oil emulsifier, which can disperse the oil phase into tiny droplets and uniformly suspend them in the water phase [10]. Meanwhile, its low CMC can form micelles at low concentrations. These micelles can further wrap oil droplets, prevent oil droplets from accumulating and maintain the long-term stability of the lotion [10]. Yang et al. studied the crystalline amino acid facial cleanser and found that adding 5% oat protein-derived NSAAS could improve the emulsifying stability of face cream by 30%, and there was no stratification after storage at 45 °C for 1 month [10]. This feature solves the problem of "easy layering and poor stability" in traditional amino acid cleansers, providing technical support for extending product shelf life.

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4. Application of natural amino acid anionic surfactants in the care of sensitive skin

4.1. Application of sensitive skin cleansing products

Based on the balance between mildness and high performance, naturally derived amino acid-based anionic surfactants have broad potential for application in sensitive skin care. Currently, they are mainly focused on sensitive skin cleansing products and infant care products, but they also face certain application bottlenecks. The core function of NSAAS in sensitive skin cleansing products is to improve the performance defects of crystalline amino acid cleansing creams. The traditional crystalline amino acid facial cleanser mainly uses sodium coconut glycine, which is mild in nature, but when used alone, it is easy to produce high coagulation temperature, low foam content and poor stability [7]. The addition of NSAAS derived from oat protein solves two problems through synergistic effects. On the one hand, oat protein peptides form hydrogen bonds with sodium cocoyl glycinate in their molecules, reducing the solidification temperature from 65 ℃ to 55 ℃ and simplifying the production process; On the other hand, its excellent foaming and emulsifying properties improve the foam volume and stability of facial cleanser, while maintaining the mildness [7].

In actual formulations, non-steroidal anti-inflammatory drugs derived from oat protein are often mixed with multiple ingredients. Glycerol enhances moisturizing performance and reduces tightness after cleaning. EDTA-2Na chelates metal ions in water to avoid interfering with the performance of surfactants. Sodium dodecyl benzene sulfonate further reduces irritation and improves foam fineness [9]. Wang et al. conducted a formula optimization experiment, which showed that the irritation score of the cleaning solution containing 8% oat protein-derived NSAAS on sensitive skin was only 0.3, significantly lower than the cleaning solution containing 5% sodium cocoyl glycinate [9].

4.2. Application of infant and toddler care products

The thickness of the stratum corneum of infant skin is only one-third of that of adult skin, with weak barrier function and high sensitivity to surfactant irritation. Therefore, NSAAS has become an ideal raw material for infant care products [3]. Its low irritation and moisturizing properties can reduce redness and dryness of infants' skin, while its excellent cleaning ability can remove sweat, sebum, and fecal residue from the skin surface. At present, research has applied NSAIDs to infant cleaning foam and bath gel, and further improved the gentleness and barrier protection by controlling the concentration and composition [3]. Park et al. conducted a 4-week safety test on 100 infants using a shower gel containing 4% wheat protein-derived nonsteroidal anti-inflammatory drugs. The results showed that only 2 infants had mild redness on their skin, which recovered within 24 hours, with an overall irritation rate of 2%, significantly lower than the 8% irritation rate of bathing with sodium lauroyl ether sulfate. This confirms the high safety of NSAAS in infant care products [7].

4.3. Application bottlenecks

Despite its enormous potential for application, NSAAS faces two core bottlenecks: first, insufficient long-term stability - under high or low temperature storage conditions, NSAAS is prone to crystal precipitation or performance degradation, affecting product quality [10]. Yang et al. found that the foaming performance of NSAAS solution derived from oat protein decreased by 12% after storage at 50 ℃ for one month, and crystal precipitation occurred at -5℃ [10]. Secondly, the high cost of industrialization - the complexity of directional hydrolysis and acylation processes leads to product

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costs that are 2-3 times higher than traditional synthetic surfactants, limiting their application in mid to low-end products [5]. Zhang et al. pointed out that adding stabilizers or optimizing continuous flow synthesis processes can improve stability and cost issues to a certain extent, but related technologies still need further validation [5].

5. Conclusion

Amino acid-based anionic surfactants from natural sources are derived from plant protein hydrolysates and have shown significant advantages as mild cosmetic ingredients in the sensitive skincare field. Their molecular design achieved a balance between biocompatibility and interfacial activity by optimizing the amino acid residues in oat protein and acyl chains. In synthetic technology, the weak base chemical method achieves high conversion rates, and directional hydrolysis precisely controls molecular weight. In terms of performance regulation mechanism, pH compatibility and skin protective film ensure low irritation, while amphiphilic structure and sodium salt form improve wetting, foaming, and emulsifying properties-all of which have been validated by in vitro and in vivo experimental data in British literature. In application, NSAAS has effectively improved the stability and foam performance of sensitive skin cleaning cream, which is suitable for baby care products. However, long-term stability and industrialization costs remain the main bottlenecks. Future research should focus on the following three aspects. Firstly, establishing a quantitative correlation model between molecular structure and properties to provide theoretical support for precise design. Secondly, optimizing enzyme synthesis technology and the continuous flow production process to reduce costs and improve stability. The third is to develop a multifunctional composite system to further enhance the added value of the product. In summary, NSAAS plays an irreplaceable role in addressing the irritation issues of traditional surfactants and promoting the upgrade of sensitive skincare products. Its research and application will provide important impetus for the green and moderate development of the cosmetics industry.

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