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FLAXSEED (LINUM USITATISSIMUM L.) AS A POTENTIAL NATURAL SOURCE OF NIACINAMIDE: EXTRACTION, CHARACTERIZATION AND PHARMACEUTICAL APPLICATIONS

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ABSTRACT :

Flaxseed (Linum usitatissimum L.) is a nutritionally important oilseed containing alpha-linolenic acid, dietary fibre, proteins, lignans, minerals and other bioactive constituents. Vitamin B3, particularly niacinamide or nicotinamide, is an essential water-soluble vitamin involved in cellular metabolism and is widely used in pharmaceutical and cosmetic preparations. Although flaxseed is known to contain niacin and other B-group vitamins, the specific presence and concentration of niacinamide in flaxseed require direct analytical confirmation. This review examines the potential of flaxseed as a herbal source of niacinamide and discusses its botanical characteristics, nutritional composition, biological relevance, extraction, purification, characterization and possible pharmaceutical and cosmetic applications. A proposed workflow includes authentication, cleaning, drying, pulverization, optional defatting, polar solvent extraction, filtration, concentration, purification and chromatographic analysis. Thin-layer chromatography, UV-visible spectroscopy, Fourier-transform infrared spectroscopy and high-performance liquid chromatography may be used as complementary techniques for identification and quantification. Important extraction variables include solvent selection, particle size, solvent-to-sample ratio, temperature, extraction time, pH and extraction cycles. The review highlights the limited flaxseed-specific evidence, the need for validated analytical methods and the importance of experimental confirmation before considering flaxseed an established source of niacinamide. Future research should address optimization, structural confirmation, safety, formulation, stability, scale-up and economic feasibility. and sustainability.

Keywords: Flaxseed, Linum usitatissimum, Niacinamide, Vitamin B3, Extraction, Isolation, Phytochemicals, Nutraceuticals, Antioxidant, Skin Care.

Introduction

Vitamin B3 is an essential water-soluble vitamin that is present primarily in two forms, namely nicotinic acid and nicotinamide [1,11]. Nicotinamide, also known as niacinamide, is the amide form of vitamin B3 and plays an important role as a precursor of nicotinamide adenine dinucleotide (NAD^+) and nicotinamide adenine dinucleotide phosphate ($NADP^+$) [2-5,12]. These coenzymes participate in numerous oxidation–reduction reactions and are essential for energy metabolism, cellular signalling, DNA repair and maintenance of normal cellular functions [5-13,14].

Niacinamide has gained considerable importance in pharmaceutical and dermatological research because of its broad biological and topical applications [15]. Topical niacinamide has been reported to support skin-barrier function, improve epidermal hydration, regulate sebum production and reduce the appearance of hyperpigmentation [16]. Its ability to influence melanosome transfer and improve the appearance of uneven skin pigmentation has further increased its use in cosmetic and dermatological formulations [17].

Consequently, niacinamide is widely incorporated into creams, gels, lotions, serums and other topical preparations [15,18].

The increasing pharmaceutical and cosmetic importance of niacinamide has created interest in its analytical determination and in the investigation of alternative natural sources of vitamin B3 [19]. Plant materials are particularly attractive for such investigations because they contain a wide range of nutritional and bioactive molecules that may be recovered using suitable extraction and purification techniques [20]. However, the presence of a particular vitamin in a plant should be established through appropriate analytical evidence rather than inferred only from the general nutritional composition of the plant [21].

Flaxseed is therefore an interesting candidate for investigation because it possesses a complex nutritional matrix containing both major and minor constituents [2,8]. Although extensive research has been conducted on its fatty acids, lignans, fibre and proteins, comparatively less attention has been directed toward the targeted extraction and characterization of individual vitamin B3 forms from flaxseed [9,22]. This provides a potential research opportunity for investigating whether niacinamide can be recovered from flaxseed using an appropriate extraction and analytical workflow.

The extraction of niacinamide from flaxseed is expected to present an analytical challenge because the seed contains a considerable lipid fraction together with proteins, carbohydrates, mucilage, lignans, phenolic compounds and other phytochemicals [3,8]. These matrix components may interfere

with extraction efficiency, purification and chromatographic determination of the target compound [23]. Therefore, selection of a suitable solvent system and optimization of extraction conditions are essential for obtaining an extract with adequate recovery and minimum matrix interference [24].

Because niacinamide is a polar and water-soluble compound, polar extraction systems such as water or aqueous alcohol may be considered during method development [12,24]. The suitability of an extraction solvent should be determined experimentally on the basis of extraction recovery, selectivity, stability and compatibility with subsequent analytical procedures [25]. Parameters such as particle size, solvent-to-sample ratio, extraction time, temperature, agitation and number of extraction cycles can significantly influence the recovery of compounds from plant matrices [24,26].

Sample preparation is another important consideration in the proposed investigation. Proper drying, grinding and homogenization of flaxseed can improve the reproducibility of the extraction process and increase the contact between the plant material and extraction solvent [24]. Since the high lipid content of flaxseed may interfere with the extraction and chromatographic analysis of polar compounds, an appropriate defatting or sample-cleanup step may be investigated where necessary [27]. Such pretreatment should be optimized carefully to avoid loss of the target compound during sample processing.

Following extraction, purification or separation may be required because the crude flaxseed extract is expected to contain numerous compounds with different physicochemical properties [23]. Chromatographic techniques can be used to separate the target compound from co-extracted constituents and to obtain a fraction suitable for further characterization [28]. Thin-layer chromatography (TLC) can provide a preliminary qualitative assessment by comparing the chromatographic behaviour of the sample with an authentic niacinamide standard [29].

High-performance liquid chromatography (HPLC) can provide more specific information regarding the separation, identification and quantitative estimation of niacinamide in the extracted fraction [30]. Comparison of the retention time of the sample with that of an authentic reference standard can provide important evidence for the possible presence of niacinamide [31]. Quantitative determination can subsequently be performed using an appropriate calibration procedure after development and validation of the analytical method [32].

Spectroscopic techniques can provide complementary evidence for characterization of the extracted compound [33]. UV–Visible spectroscopy may be used to compare the absorption characteristics of the extracted fraction with those of an authentic niacinamide standard [34]. Fourier-transform infrared spectroscopy (FTIR) can provide information regarding characteristic functional groups and can support the identification of the isolated or enriched fraction when interpreted together with chromatographic results [35]. Advanced analytical techniques such as liquid chromatography–mass spectrometry (LC–MS) may provide additional structural confirmation when available [36].

The use of more than one analytical technique is particularly important when investigating a compound within a complex herbal matrix [28]. A single analytical parameter may not be sufficient to establish the identity of niacinamide because other compounds present in flaxseed may produce overlapping spectral or chromatographic responses [23]. Therefore, comparison with an authentic reference standard combined with chromatographic and spectroscopic characterization can provide stronger evidence for compound identification [31,35].

The proposed research is consequently focused on determining whether flaxseed can serve as a potential herbal source of niacinamide through a reproducible extraction, purification and characterization process. The objective is not to assume that flaxseed is already an established rich source of niacinamide, but rather to experimentally investigate its presence and determine its concentration using appropriate analytical methods [21]. Such an approach is particularly relevant because the actual occurrence and concentration of free niacinamide in flaxseed need to be distinguished from the general presence of vitamin B3 or related nutritional compounds.

The investigation of flaxseed as a potential niacinamide source may also have pharmaceutical and cosmetic significance. If the presence of niacinamide is experimentally confirmed and a reproducible extraction procedure is established, the recovered fraction may provide a basis for further investigation of plant-derived vitamin B3 ingredients [20]. The isolated or enriched fraction could subsequently be evaluated for purity, stability, compatibility and suitability for pharmaceutical or cosmetic formulation development [15,18]. Therefore, the present review focuses on flaxseed (Linum usitatissimum L.) as a potential herbal source of niacinamide, with particular emphasis on extraction, purification, characterization and pharmaceutical applications. The review discusses the botanical profile and nutritional composition of flaxseed, vitamin B3 and niacinamide, the available evidence regarding vitamin B3 in flaxseed, extraction and purification strategies, analytical characterization using TLC, UV–Visible spectroscopy, FTIR and HPLC, factors affecting extraction efficiency, potential applications, limitations, research gaps and future prospects. The overall objective is to provide a scientific framework for experimentally evaluating whether flaxseed can be developed as a reproducible plant-derived source of niacinamide

Botanical Profile of Flaxseed (Linum usitatissimum L

Taxonomical Classification Flaxseed is obtained from the cultivated flax plant, Linum usitatissimum L., which belongs to the family Linaceae. [1]

The accepted botanical name of the species is Linum usitatissimum L. [1]

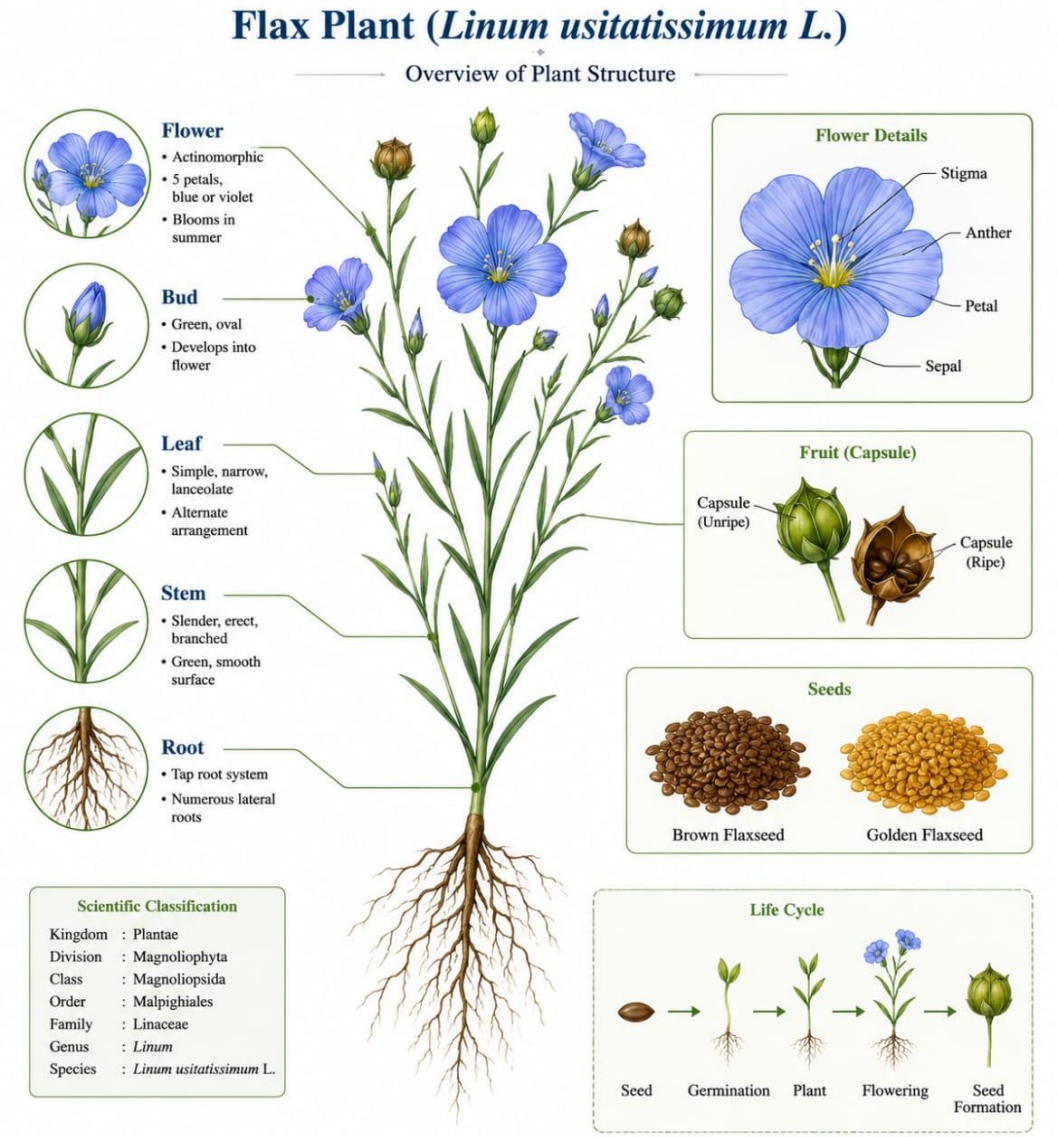
The commonly used taxonomic classification places flax under Kingdom Plantae, Family Linaceae, Genus Linum and Species Linum usitatissimum. [1,2]

The species is an annual herb and is mainly associated with temperate environments. [1] Cultivated flax is the principal commercially important species of the genus Linum. [2] Common Names and Vernacular Names Linum usitatissimum is commonly known as flax or linseed, depending on its intended use. [2]

Taxonomical hierarchy:	Kingdom
Plantae	Division
Magnoliophyta	Class
Magnoliopsida	Order
Malpighiales	Family
Linaceae	Genus
Linum	Species

Linum usitatissimum L.	

The seeds are commonly referred to as flaxseed when used primarily as food, whereas the term linseed is frequently used in relation to oil and industrial applications. [2] The plant is also known by several regional names in different parts of the world. [3] In India, flaxseed is commonly known by names such as Alsi, Jawas and Tisi. [3]



2.3 Origin and Geographical Distribution

The exact wild origin of cultivated flax is uncertain, although its historical origin has been associated with regions extending from southern Europe and the Near East to Central Asia. [2]

The accepted native range currently listed for L. usitatissimum is Türkiye to Iran, while the species is now extensively cultivated beyond this range. [1]

Flax is cultivated mainly in temperate and subtropical regions because its growth and development are strongly influenced by environmental conditions. [2,4]

The crop has been cultivated for thousands of years for both its fibre and seed-derived oil. [2]

Modern flax cultivation includes both fibre-type and oilseed-type forms, which differ in several morphological and agronomic characteristics. [5]

2.4 Habit and Habitat

Linum usitatissimum is an annual herbaceous plant with an erect and slender growth habit. [1,4]

The plant generally develops a relatively narrow and upright architecture, although plant height and branching can vary according to genotype and growing conditions. [5]

Reported plant height may range approximately from 20 to 100 cm, with considerable variation among cultivars and environments. [4]

Flax can be cultivated under a range of temperate agricultural conditions and is generally adapted to well-drained soils. [2,4]

Morphological variation among flax genotypes is associated with different breeding objectives, particularly fibre production and seed/oil production. [5]

2.5 Root

The flax plant develops a taproot system with lateral roots that contribute to anchorage and absorption of water and nutrients. [4]
The root system supports the relatively slender aerial portion of the annual plant during vegetative and reproductive growth. [4]
Root development can be influenced by soil characteristics, water availability and genotype. [5]

2.6 Stem

The stem of L. usitatissimum is generally erect, slender and cylindrical, with a smooth or slightly ridged surface. [1,4]
The stem may remain largely unbranched in the lower region and produce branches towards the upper portion, particularly in flowering plants. [4]
Stem morphology differs between fibre flax and oilseed flax because these types have been selected for different agricultural and industrial purposes. [5]
Fibre-type flax generally emphasizes tall, slender stems with desirable fibre characteristics, whereas oilseed types are selected primarily for seed production. [5]

2.7 Leaves

The leaves of flax are simple, sessile and generally arranged alternately along the stem. [1,4]
The leaf blades are typically linear to linear-lanceolate, narrow and relatively small. [4] The leaves are generally glabrous and possess entire or nearly entire margins. [1,4] Leaf morphology may vary slightly among cultivars and environmental conditions. [5]

2.8 Inflorescence

The flowers are generally borne towards the terminal region of the aerial shoots. [1,4] The inflorescence is described as an open cyme or panicle-like arrangement, with individual flowers borne on slender pedicels. [1,4]
The open floral arrangement contributes to the characteristic delicate appearance of the flax plant during flowering. [4]

2.9 Flower

Flax flowers are generally five-petalled and are usually blue, although white flowers may also occur. [1,4]
The flowers possess five sepals and five petals, together with five stamens and a superior ovary. [1]
The petals are generally obovate and may show variation in colour depending on genotype. [4]
The ovary is divided into multiple locules and develops into the characteristic flax capsule following fertilization. [1]
Flower morphology and colour can also show diversity among species and varieties within the genus Linum. [6]

2.10 Fruit

The fruit of flax is a dry capsule, generally globose to ovoid or subglobose in shape. [1,4] The mature capsule contains several seeds and may reach approximately 6–10 mm in diameter, although dimensions vary with genotype. [4]
The capsule undergoes dehiscence at maturity and releases the mature seeds. [1,4]

2.11 Seed

The seed is the most economically important part of the flax plant for oilseed production and nutritional applications. [2,5]
Flaxseeds are generally flattened, smooth, glossy and oval to elongated in shape. [6] Typical seed dimensions are approximately 4–6 mm in length and 2–3 mm in width, although considerable variation occurs among flax types. [6]
Seed colour may range from golden-yellow to brown or dark brown, depending on genotype and other factors. [5,6]
Oilseed varieties generally produce relatively larger and rounder seeds than many fibre-type varieties. [6]

2.12 Seed Morphology

Macroscopic examination of flaxseed generally reveals a flat, smooth and glossy seed surface. [6]
The seed is characterized by a distinct seed coat surrounding the internal storage tissues and embryo. [6,7]
The seed coat contains mucilaginous material that can swell when exposed to water. [7] This mucilage-producing property contributes to the characteristic mucilaginous behaviour of hydrated flaxseed. [1,7]
The internal seed tissues contain storage compounds including fixed oil and proteins, which contribute substantially to the nutritional value of the seed. [7]

2.13 Microscopic Characteristics of Flaxseed

Microscopic examination shows that the flaxseed coat contains an outer mucilaginous epidermal layer. [7]
Beneath the epidermal region, several tissue layers including parenchymatous and stone-cell regions can be observed. [7]
A pigment-containing layer contributes to the characteristic colour of the seed coat. [7] The endosperm surrounds the embryo and contains storage materials including fixed oil and proteinaceous components. [7]
The embryo contains two prominent cotyledons that serve as important storage tissues during seed development and germination. [7]

2.14 Anatomical Organization of Flaxseed

The major anatomical regions of flaxseed include the seed coat, endosperm and embryo/cotyledonary tissues. [7]
The seed coat provides a protective external layer and also contains mucilage-producing cells. [7]
The internal storage tissues contain substantial quantities of fixed oil and other nutrients. [7] The anatomical organization of the seed is important when considering extraction because different compounds may be distributed preferentially within different seed tissues. [6,7]

2.15 Flaxseed Varieties and Morphotypes

Cultivated flax exhibits substantial morphological diversity because of long-term selection and breeding for different end uses. [5]
The two major agricultural types are broadly described as fibre flax and oilseed flax. [5,6] Fibre flax is primarily selected for desirable stem and fibre characteristics, whereas oilseed flax is selected for high seed and oil production. [5]
Oilseed types commonly produce larger and relatively rounder seeds, whereas fibre types may produce smaller, flatter and more elongated seeds. [6]
Genetic diversity among flax accessions also influences seed colour, seed size, plant height, branching and biochemical composition. [5]

2.16 Golden and Brown Flaxseed

Flaxseed colour is an important visible morphological characteristic and can vary from golden-yellow to brown and darker shades. [5,6]
Golden and brown flaxseeds represent commonly encountered colour types of cultivated flax. [6]
Differences in seed colour are associated with genetic variation and may also be influenced by growing conditions. [5,6]
Because seed colour can correlate with genotype and biochemical characteristics, it may be useful as one preliminary descriptor when selecting plant material for experimental studies. [5]

2.17 Major Chemical Constituents of the Seed

Flaxseed is a chemically complex plant material containing lipids, proteins, dietary fibre, carbohydrates, lignans and other bioactive constituents. [6]
The lipid fraction is particularly important because flaxseed is recognized as a rich plant source of α-linolenic acid (ALA). [6]
The seed also contains lignans, with secoisolariciresinol diglucoside (SDG) being a characteristic flaxseed lignan. [6]
Flaxseed proteins and polysaccharides contribute to its nutritional and functional properties. [6]
This complex chemical matrix is important when developing extraction and purification procedures for any specific target compound. [6]

2.18 Botanical and Pharmacognostic Significance

Flaxseed is considered an important medicinal, nutritional and functional-food plant because of its diverse chemical composition. [6]
Its biological value is associated with the combined presence of fatty acids, dietary fibre, lignans, proteins and other constituents rather than a single compound alone. [6] The seed therefore represents a complex natural matrix that requires appropriate extraction and analytical procedures for investigation of individual constituents. [6]

2.19 Relevance of Flaxseed to Niacinamide Research

For the proposed study, flaxseed is considered a potential herbal source rather than an already established rich source of niacinamide.
Because flaxseed contains a complex mixture of lipids, proteins, polysaccharides, lignans and other minor constituents, selective extraction of a water-soluble vitamin such as niacinamide would require suitable sample preparation and purification. [6,7]
The presence of niacinamide should therefore be established experimentally rather than inferred only from the general nutritional importance of flaxseed.
A suitable analytical workflow may involve extraction, clarification, chromatographic separation and comparison with an authentic niacinamide standard.
HPLC or another validated quantitative analytical method would be particularly useful for confirming identity and estimating the concentration of a suspected niacinamide fraction.

NUTRITIONAL COMPOSITION OF FLAXSEED

Flaxseed (Linum usitatissimum L.) is considered a nutritionally valuable oilseed because it contains lipids, proteins, dietary fibre, carbohydrates, vitamins, minerals and several biologically active phytochemicals.[1] The nutritional composition of flaxseed varies depending on the cultivar, geographical origin, environmental conditions, maturity stage, cultivation practices and processing conditions.[1,2] Flaxseed is particularly recognized for its high content of α-linolenic acid (ALA), dietary fibre and lignans, which contribute significantly to its nutritional and functional properties.[2,3]

3.1 Macronutrient Composition

The major macronutrients present in flaxseed are lipids, proteins, dietary fibre and carbohydrates.[1,2] Flaxseed generally contains approximately 35–45% lipid, 18–30% protein and 25–35% dietary fibre, although the exact values may differ among varieties.[1,3] The high concentration of these macronutrients makes flaxseed an important functional food and a potential source of nutritionally valuable compounds.[2]

3.2 Lipid Content

Lipids represent one of the most abundant components of flaxseed and generally account for approximately 35–45% of the seed weight.[2,4] Flaxseed oil is characterized by a high proportion of polyunsaturated fatty acids, particularly α-linolenic acid (ALA), an essential omega-3 fatty acid.[3,4] ALA may constitute approximately 50–60% of the total fatty acid content of flaxseed oil, depending on cultivar and growing conditions.[4] Linoleic acid, oleic acid, palmitic acid and stearic acid are also present in smaller proportions.[2,4] The high concentration of omega-3 fatty acids is one of the major characteristics responsible for the nutritional importance of flaxseed.[3]

3.3 Protein Content

Flaxseed contains approximately 18–30% protein, making it a useful plant-based source of dietary protein.[1,2] The major protein fractions of flaxseed include globulins and albumins.[2] Flaxseed proteins contain several essential and non-essential amino acids, with arginine, glutamic acid and aspartic acid being among the predominant amino acids.[2,5] The protein fraction may also contribute to the functional and nutritional properties of flaxseed-derived food products.[5]

3.4 Dietary Fibre

Dietary fibre is an important component of flaxseed and generally represents approximately 25–35% of the seed.[1,3] Flaxseed contains both soluble and insoluble dietary fibre.[3] The soluble fibre fraction is associated mainly with mucilage present in the outer layers of the seed, whereas insoluble fibre consists predominantly of cellulose, hemicellulose and lignin-related structural components.[3,6] The presence of both soluble and insoluble fibre contributes to the functional-food value of flaxseed.[3]

3.5 Carbohydrate Content

Flaxseed contains approximately 20–30% carbohydrate, although the exact value depends on the analytical method used.[2,3] A considerable proportion of the carbohydrate fraction is represented by dietary fibre rather than simple carbohydrates.[3] The carbohydrate fraction includes structural polysaccharides and mucilage components that may contribute to the water-holding and functional properties of flaxseed.[6]

3.6 Fatty Acid Composition

The fatty acid profile of flaxseed is dominated by polyunsaturated fatty acids.[2,4] α-Linolenic acid (ALA; C18:3, omega-3) is the major fatty acid, followed by linoleic acid (LA; C18:2, omega-6) and oleic acid (C18:1, omega-9).[4] Smaller amounts of saturated fatty acids such as palmitic acid and stearic acid are also present.[2] The characteristic fatty acid profile distinguishes flaxseed from many other commonly consumed oilseeds.[4]

3.7 Vitamin Content

Flaxseed contains several vitamins, including B-group vitamins and vitamin E.[2,3] Reported B-group vitamins include thiamine (vitamin B1), riboflavin (vitamin B2), niacin (vitamin B3), pyridoxine (vitamin B6), pantothenic acid and folate.[3] Vitamin E occurs mainly in the form of tocopherols and contributes to the antioxidant properties of flaxseed oil.[2,4] The presence of B-group vitamins is particularly relevant to the present review because the proposed study focuses on the investigation of vitamin B3-related compounds in flaxseed.[3]

3.8 Vitamin B3 Content and Its Relevance to the Present Study

Niacin is one of the B-group vitamins reported in the nutritional composition of flaxseed.[3] Vitamin B3 occurs mainly in two nutritionally important forms, namely niacin (nicotinic acid) and niacinamide (nicotinamide).[7] Although nutritional databases may report the total or available niacin content of foods, the specific chemical form present in a plant matrix should not be assumed without appropriate analytical confirmation.[7,8] Therefore, the reported presence of vitamin B3 in flaxseed provides a rationale for investigating whether niacinamide can be specifically detected, extracted, purified

and characterized from flaxseed.[3,8]

3.9 Mineral Composition

Flaxseed is also a source of several essential minerals, including potassium, phosphorus, calcium, magnesium, iron and zinc.[1,3] Potassium and phosphorus are among the relatively abundant minerals found in flaxseed.[3] The mineral content may vary depending on soil composition, geographical location, cultivar and agricultural practices.[1] These minerals contribute to the overall nutritional value of flaxseed.[2]

3.10 Lignans

Flaxseed is one of the richest dietary sources of plant lignans.[2,9] Secoisolariciresinol diglucoside (SDG) is considered the major lignan present in flaxseed.[9] Other lignans, including pinoresinol, lariciresinol, isolariciresinol and matairesinol, have also been reported.[2,9] These compounds contribute to the biological and functional properties associated with flaxseed.[9]

3.11 Phenolic Compounds

Flaxseed contains several phenolic compounds that contribute to its antioxidant potential.[2,9] Phenolic acids, flavonoids and other phenolic constituents have been identified in different parts and fractions of the seed.[2] The concentration of these compounds depends on cultivar, environmental conditions and processing methods.[2,9]

3.12 Tocopherols and Phytosterols

Tocopherols are naturally occurring lipid-soluble compounds present in flaxseed and flaxseed oil.[4] They contribute to the antioxidant protection of lipids and may help reduce oxidative deterioration of flaxseed oil during storage.[4] Flaxseed also contains phytosterols such as β-sitosterol, campesterol and stigmasterol.[2] These minor lipid components further contribute to the nutritional and functional characteristics of flaxseed.[2]

3.13 Nutritional Importance of Flaxseed

The combined presence of omega-3 fatty acids, proteins, dietary fibre, vitamins, minerals, lignans, phenolic compounds and other phytochemicals makes flaxseed a nutritionally important functional food.[1,2] The diverse chemical composition of flaxseed also makes it an interesting plant matrix for the investigation and recovery of specific bioactive and nutritionally important compounds.[2,9] In the context of the present review, the reported occurrence of vitamin B3 in flaxseed provides a scientific basis for further investigation of its individual forms, particularly niacinamide.[3]
However, the presence of reported vitamin B3 or niacin in flaxseed should not be interpreted as direct evidence that niacinamide has already been isolated from flaxseed.[7,8] Therefore, a systematic extraction, purification and analytical characterization procedure is required to establish the presence and concentration of niacinamide specifically in flaxseed.[8] **Approximate Nutritional Composition of Flaxseed**

Component	Approximate content per 100 g
Energy	530–535 kcal
Protein	18–21 g
Total fat	37–45 g
Dietary fibre	25–29 g
Carbohydrates	28–30 g
Potassium	750 mg
Phosphorus	370 mg
Calcium	170 mg
Iron	2.7 mg
Niacin (Vitamin B3)	1 mg
Magnesium	390 mg
Thiamine (Vitamin B1)	0.2 mg
Riboflavin (Vitamin B2)	0.07 mg
Vitamin B6	0.6 mg
Folate	110 µg

VITAMIN B3 / NIACINAMIDE

Vitamin B3 water soluble of important epidermal lipids such as ceramides.[7] Improvement of the skin barrier can contribute to better moisture retention and overall skin condition.[7] Niacinamide has also been investigated for its potential to reduce the appearance of hyperpigmentation through effects on melanosome transfer.[8]

4.6 Importance of Niacinamide as a Target Compound

Niacinamide is widely used as an active pharmaceutical and cosmetic ingredient because of its nutritional and dermatological significance.[4,7] Its established analytical methods and well-characterized chemical properties make it a suitable target compound for extraction and characterization studies.[3,4] However, the detection of niacin or total vitamin B3 in a plant material does not automatically establish the presence of niacinamide specifically.[1,2]

ROLE OF NIACINAMIDE

5.1 Role in Skin Barrier Function

Niacinamide can enhance the synthesis of important epidermal barrier components including ceramides, sphingolipids, free fatty acids and cholesterol. [6] These effects may contribute to improved structural and functional integrity of the skin barrier. [6]

5.2 Role in Skin Hydration

Improvement of epidermal barrier function can support moisture retention and reduce excessive transepidermal water loss. [6] Therefore, niacinamide is frequently incorporated into formulations intended for dry or barrier-impaired skin. [6,7]

5.3 Role in Hyperpigmentation

Niacinamide has been investigated extensively for its effect on cutaneous pigmentation. [6,7] Experimental studies have shown that niacinamide can inhibit melanosome transfer from melanocytes to keratinocytes without directly inhibiting melanogenesis in melanocyte monoculture models. [7,8]

5.4 Role in Sebum Regulation

Topical niacinamide has been investigated for its ability to reduce excessive facial sebum production. [6] This property contributes to its usefulness in formulations intended for oily and acne-prone skin. [6]

5.5 Anti-inflammatory Role

Niacinamide has anti-inflammatory properties and may support the management of inflammatory skin conditions. [6,7] Its anti-inflammatory effects may contribute to its broader dermatological applications. [6]

5.6 Role in Skin Repair

By supporting epidermal lipid synthesis and cellular processes, niacinamide can contribute to maintenance and restoration of skin-barrier function. [6] This makes it relevant to formulations designed for compromised or stressed skin. [6]

5.7 Cellular Metabolism

Nicotinamide contributes to the formation of NAD and NADP, which are essential cofactors in cellular metabolism. [4,5] Through these pathways, vitamin B3 compounds participate in energy metabolism and redox reactions. [4,5]

5.8 Role in Skin Aging

Clinical and mechanistic evidence indicates that topical niacinamide may improve several features associated with photoaged skin, including uneven pigmentation, redness, texture and other visible signs of aging. [6,7]

5.9 Pharmaceutical and Cosmetic Applications

Because of its multifunctional properties, niacinamide is used in creams, lotions, gels, serums, moisturizers and other topical preparations. [4,6] Its multifunctionality makes it a valuable active ingredient for pharmaceutical and cosmetic formulation development. [6,7]

EVIDENCE OF VITAMIN B3 IN FLAXSEED

6.1 Current Scientific Basis

Flaxseed is extensively documented as a source of lipids, proteins, dietary fibre, lignans and phenolic compounds. [1–3] However, the occurrence of a

specific vitamin in a plant matrix should be established using validated analytical methods and appropriate reference standards. [8–10]

6.2 Research Hypothesis

The present review proposes that flaxseed may be investigated as a potential herbal source of niacinamide or related vitamin B3 compounds. [1,8] This proposal should be treated as a research hypothesis rather than an established fact until direct analytical evidence is obtained. [8–10]

6.3 Need for Experimental Confirmation

The detection of niacinamide should involve comparison of the flaxseed extract with an authenticated niacinamide reference standard. [8–10] Retention time, spectral characteristics and chromatographic behaviour should be evaluated before assigning a positive identification. [8–10]

6.4 Quantitative Determination

If niacinamide is detected, its concentration should be quantified using a validated analytical method such as HPLC. [8–10] Validation should include parameters such as specificity, linearity, accuracy, precision, limit of detection and limit of quantification. [8–10]

6.5 Importance of Negative Findings

If niacinamide is not detected under validated experimental conditions, the result should also be reported because it would help define the actual vitamin B3 profile of flaxseed. [8–10] Scientific confirmation should therefore be based on experimental evidence rather than the proposed outcome of the study. [8]

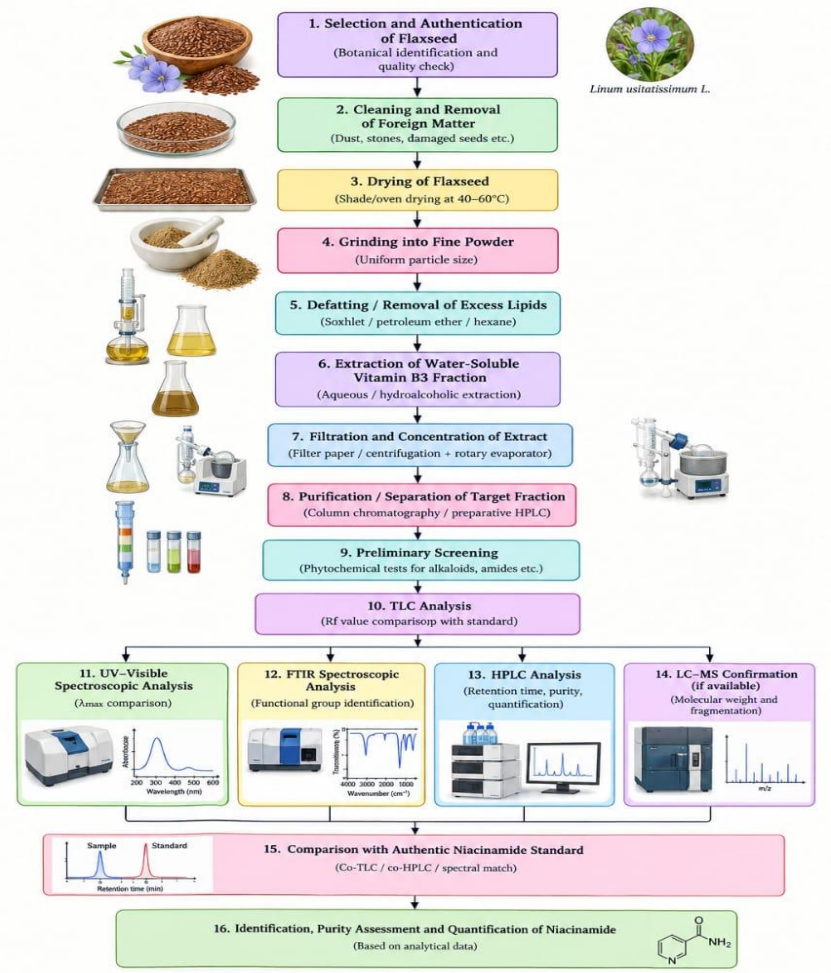


Figure 2. Complete extraction and analytical workflow for the proposed isolation and identification of niacinamide from flaxseed.

EXTRACTION OF NIACINAMIDE FROM FLAXSEED

7.1 Selection and Authentication of Flaxseed

Flaxseed (Linum usitatissimum L.) should be collected from an authenticated source and botanically identified before extraction to ensure the identity and quality of the plant material. [1,2]
The seeds should be free from visible contamination, fungal growth and foreign materials before further processing. [1,2]

7.2 Cleaning and Preparation

The collected flaxseeds should be cleaned to remove dust, stones, plant debris and other foreign matter. [1,2]
The cleaned seeds may be dried under controlled conditions to reduce moisture before pulverization. [1,8]
Controlled drying is important because excessive heat may affect the stability of some constituents present in the plant material. [8]

7.3 Pulverization

The dried flaxseeds should be powdered using a suitable laboratory grinder or mill. [8] Reduction of particle size increases the surface area of the plant material available for contact with the extraction solvent and may improve mass transfer during extraction. [8,9] The powdered material should preferably be passed through a suitable sieve to obtain a relatively uniform particle size. [8]

7.4 Selection of Extraction Solvent

Solvent selection is one of the most important factors influencing the recovery of a target compound from plant material. [8,9]

PURIFICATION AND SEPARATION

8.1 Need for Purification

Flaxseed is a chemically complex plant matrix containing lipids, proteins, carbohydrates, lignans, phenolic compounds and other minor constituents. [1,2]
Therefore, the crude extract may contain several interfering substances along with the target compound. [3]
Purification and separation are consequently important steps before reliable characterization and quantification of niacinamide. [3,4]

8.2 Preliminary Separation

The crude extract may first be subjected to filtration and concentration to remove insoluble plant material and reduce the extraction volume. [3]
Because flaxseed contains a high proportion of lipids, a suitable sample-cleanup or defatting step may be investigated before analysis of a polar target compound. [1,3]
Liquid–liquid partitioning or solid-phase extraction may subsequently be explored to reduce matrix interference and enrich the target fraction. [3,4]

8.3 Chromatographic Separation

Chromatographic techniques can separate compounds according to differences in their physicochemical properties and interactions with stationary and mobile phases. [4] TLC may be used for preliminary separation and screening, whereas HPLC can provide more selective separation and quantitative analysis. [4,5]

9. CHARACTERIZATION OF NIACINAMIDE

9.1 UV-VISIBLE SPECTROSCOPY

UV-visible spectroscopy can be used as a preliminary spectroscopic technique for investigating the isolated or enriched fraction. [4,5]
The absorption spectrum of the sample can be compared with that of an authentic niacinamide reference standard under identical conditions. [4]
Similarity in the spectral profile can provide supportive evidence for the presence of the target compound. [4,5]
However, UV-visible spectroscopy alone generally does not provide sufficient specificity for definitive identification in a complex plant extract. [4,5]
Therefore, UV-visible analysis should preferably be combined with chromatographic and other spectroscopic techniques. [4,5]

9.2 FOURIER-TRANSFORM INFRARED SPECTROSCOPY (FTIR)

FTIR spectroscopy provides information about the functional groups present in a sample by measuring characteristic infrared absorption bands. [4,6]

The FTIR spectrum of an isolated fraction can be compared with the spectrum of an authentic niacinamide standard. [6]
Characteristic absorption regions associated with functional groups present in niacinamide can provide supportive evidence for compound identity. [6]
FTIR is particularly useful for assessing the chemical characteristics of a relatively purified fraction. [6]
Nevertheless, FTIR results should be interpreted together with chromatographic evidence when analyzing complex plant-derived samples. [4,6]

9.3 THIN-LAYER CHROMATOGRAPHY (TLC)

TLC is a simple and relatively inexpensive chromatographic technique that can be used for preliminary identification and monitoring of separation. [4]
The flaxseed extract, purified fractions and authentic niacinamide standard can be applied simultaneously on a suitable TLC plate. [4,5]
After development in an appropriate mobile phase, the migration behaviour of the sample can be compared with that of the reference standard. [4]
The retention factor (Rf) of the sample spot can be compared with the Rf of the standard under identical experimental conditions. [4]
A comparable Rf value provides preliminary evidence of similar chromatographic behaviour but should not alone be considered conclusive proof of identity. [4,5]

9.4 HIGH-PERFORMANCE LIQUID CHROMATOGRAPHY (HPLC)

HPLC is a powerful analytical technique for separation, identification and quantitative determination of compounds in complex samples. [4,5]
For the proposed flaxseed–niacinamide investigation, HPLC can be used to determine whether a chromatographic peak corresponding to niacinamide is present in the extract. [4,5] The retention time of the sample peak should be compared with that of an authenticated niacinamide reference standard under the same chromatographic conditions. [4,5]
A suitable HPLC method should provide adequate resolution between niacinamide and other components of the flaxseed matrix. [4,5]

9.4.1 HPLC Quantification

If niacinamide is confirmed in the flaxseed extract, its concentration can be estimated using a suitable calibration curve prepared from the reference standard. [5]
The calibration curve generally relates detector response to known concentrations of the reference compound. [5]
The concentration of niacinamide in the sample can then be calculated from the validated calibration model. [5]

9.4.2 HPLC Method Validation

Analytical validation is necessary to demonstrate that the HPLC method is suitable for its intended purpose. [5]
Important validation characteristics may include specificity, linearity, accuracy, precision, range, limit of detection, limit of quantification and robustness. [5]
A validated method provides greater confidence in the reliability and reproducibility of the analytical results Because niacinamide is a highly polar and water-soluble compound, aqueous or aqueous-alcoholic solvent systems may be investigated during method development. [3,4] Different solvent systems should be compared experimentally to determine the system providing the best recovery and minimum matrix interference. [8,9]

7.5 Defatting of Flaxseed

Flaxseed contains a relatively high amount of lipid, particularly triglyceride-rich oil. [1,2] Therefore, a preliminary defatting step may be considered when developing an extraction procedure for a polar target compound such as niacinamide. [8,9]
A suitable non-polar solvent may be used to remove a major proportion of the lipid fraction before extraction of the polar fraction, provided that the procedure does not cause loss of the target analyte. [8,9]

7.6 Primary Extraction

The powdered flaxseed may be subjected to solid–liquid extraction using a selected aqueous or aqueous-alcoholic solvent system. [8,9]
Maceration, reflux extraction or ultrasound-assisted extraction may be investigated as possible extraction techniques. [8,9]
The plant powder should be mixed with a predetermined volume of extraction solvent and maintained under controlled extraction conditions. [8]
Extraction time, temperature and solid-to-solvent ratio should be optimized experimentally to obtain maximum recovery of the target compound. [8,9]

7.7 Filtration

After completion of extraction, the extract should be separated from the residual plant material by filtration. [8]
The filtrate should be collected carefully to avoid loss of the target analyte. [8] Further membrane filtration may be performed before HPLC analysis to remove fine particulate matter that could interfere with chromatographic analysis. [9,10]

7.8 Concentration of Extract

The filtered extract may be concentrated under controlled conditions when necessary. [8] Concentration should preferably be performed using conditions that minimize thermal degradation or chemical alteration of the target compound. [8,9]

The concentrated fraction can then be subjected to purification and chromatographic analysis. [8–10]

7.9 Preliminary TLC Screening

Thin-layer chromatography (TLC) may be used as a preliminary screening technique for comparison of the flaxseed extract with an authentic niacinamide reference standard. [9] The sample and reference standard should be applied under identical chromatographic conditions. [9]
A comparable chromatographic migration pattern or retention factor may provide preliminary evidence for the presence of a similar compound, but TLC alone should not be considered definitive structural confirmation. [9]

7.10 Purification of Extract

Because flaxseed contains lipids, proteins, carbohydrates, lignans and phenolic compounds, crude extracts may contain substantial matrix components. [1,2]
Additional purification may therefore be required before quantitative analysis. [8,9] Liquid–liquid partitioning or solid-phase extraction may be investigated to reduce matrix interference and enrich the target fraction. [8,9]

7.11 HPLC Analysis

High-performance liquid chromatography (HPLC) may be used for specific detection and quantitative estimation of niacinamide in the purified flaxseed extract. [9,10]
The retention time and chromatographic response of the sample should be compared with those of an authenticated niacinamide standard. [9,10]
A validated HPLC method should demonstrate adequate specificity, linearity, accuracy, precision, sensitivity and robustness. [10,11]

7.12 Confirmation of Niacinamide

The identity of the suspected niacinamide peak should preferably be supported using more than one analytical technique. [9,10]
UV-visible spectroscopy and FTIR spectroscopy may provide complementary information regarding the isolated or enriched fraction. [9]
Where available, LC-MS/MS or another suitable hyphenated technique can provide stronger molecular confirmation of the detected compound. [9,10]

7.13 Proposed Extraction Workflow

Authenticated flaxseed → Cleaning → Controlled drying → Pulverization → Optional defatting → Polar solvent extraction → Filtration → Concentration → Purification → TLC**orresponding Author:** Manisha Babasaheb Ganje **(manishaganje021@gmail.com)** screening → HPLC analysis → FTIR/UV confirmation → Quantificatio Complete extraction and analytical work flow Factors Affecting Extraction of Niacinamide from Flaxseed

9.1 Solvent Selection

The choice of solvent is one of the most important factors affecting the extraction of niacinamide from flaxseed. Since niacinamide is a water-soluble vitamin B3 derivative, polar solvents such as water, aqueous ethanol, or aqueous methanol may provide better extraction efficiency than non-polar solvents. The solvent should efficiently penetrate the flaxseed matrix and dissolve the target compound while minimizing co-extraction of unwanted constituents. [1–3]

9.2 Solvent-to-Sample Ratio

The ratio of solvent volume to flaxseed powder affects the concentration gradient between the plant material and extraction solvent. Increasing the solvent-to-sample ratio can improve mass transfer and extraction yield up to an optimum level; excessive solvent, however, increases processing time and solvent consumption without necessarily producing a proportional increase in yield. [2,4]

9.3 Particle Size

Particle size of powdered flaxseed influences the surface area available for solvent contact. Smaller particles generally provide a larger surface area and shorter diffusion pathways, which can enhance extraction efficiency. Extremely fine powders may nevertheless cause filtration difficulties and may increase the extraction of undesirable matrix components. [3,5]

9.4 Extraction Temperature

Temperature influences the solubility and diffusion of compounds from the plant matrix. Moderate increases in temperature can improve solvent penetration and mass transfer; however, excessive heating may cause degradation of heat-sensitive components and may alter the chemical composition of the extract. Therefore, an optimum temperature should be established experimentally. [2,4]

9.5 Extraction Time

Extraction time affects the extent to which niacinamide can diffuse from the flaxseed matrix into the solvent. Increasing extraction time generally increases extraction during the initial stage, but after equilibrium is approached, further extraction may provide little improvement and may increase degradation or co-extraction of impurities. [3,4]

9.6 pH of Extraction Medium

The pH of the extraction medium can influence the stability, solubility, and recovery of the target compound as well as other matrix constituents. Maintaining a suitable pH may improve selective extraction and reduce unwanted degradation or interference during subsequent chromatographic analysis. [2,6]

9.7 Extraction Method

The extraction technique can significantly influence recovery. Conventional methods such as maceration, infusion, and Soxhlet extraction differ in solvent contact, temperature, extraction time, and energy consumption. For a heat-sensitive target, a mild aqueous or hydroalcoholic extraction may be preferable, whereas optimized assisted-extraction techniques may improve mass transfer. [3,5]

9.8 Moisture Content of Flaxseed

The moisture content of the raw material can affect solvent penetration, extraction efficiency, and the stability of the extracted constituents. Proper drying and controlled storage of flaxseed before extraction are therefore important for obtaining reproducible results. [1,5]

9.9 Flaxseed Matrix Composition

Flaxseed contains considerable amounts of oil, proteins, dietary fibre, mucilage, lignans, carbohydrates, and other phytoconstituents. These components can interfere with extraction and subsequent purification of a water-soluble target such as niacinamide. Therefore, appropriate pretreatment or defatting may be considered when required by the analytical workflow. [1,7]

9.10 Number of Extraction Cycles

Repeated extraction of the plant residue can improve recovery of compounds that remain trapped within the plant matrix after the first extraction. However, additional extraction cycles increase solvent consumption, processing time, and the possibility of extracting unwanted substances. An optimum number of cycles should therefore be established experimentally. [3,4]

9.11 Agitation

Continuous or intermittent agitation improves contact between the flaxseed particles and extraction solvent and can enhance mass transfer. Shaking, stirring, or mechanical mixing may therefore increase extraction efficiency compared with static extraction. [2,5]

9.12 Storage and Processing Conditions

Light, oxygen, humidity, and prolonged storage can influence the stability of bioactive compounds and the overall quality of plant material. Flaxseed should therefore be stored under controlled conditions and the extraction should preferably be performed using standardized raw material. [1,7]

9.13 Drying Conditions

The method and temperature used for drying flaxseed before extraction can influence the chemical composition and extraction performance. Excessive drying temperature should be avoided when the target compound or other relevant constituents may be affected by heat. [5,7]

9.14 Filtration and Clarification

After extraction, efficient filtration or centrifugation is necessary to remove suspended particles and matrix components. Inadequate clarification can interfere with TLC, UV-Visible analysis, HPLC, and other characterization techniques. [3,6]

9.15 Optimization of Extraction Conditions

For development of a reproducible method for niacinamide recovery from flaxseed, variables such as solvent composition, solvent-to-sample ratio, particle size, temperature, extraction time, pH, and extraction cycles should be optimized systematically. Experimental optimization can help maximize recovery while minimizing impurities, solvent consumption, and processing time. [2–6]

METHOD DEVELOPMENT AND VALIDATION FOR PHARMACEUTICAL AND COSMETIC APPLICATIONS

10.1 Method Development

Analytical method development is an essential step for establishing a reliable procedure for the identification and quantification of niacinamide potentially present in flaxseed extracts. [1] The complexity of the flaxseed matrix, which contains lipids, proteins, carbohydrates, mucilage, lignans and other phytoconstituents, makes appropriate sample preparation and selective analytical separation important. [2] The developed method should provide adequate sensitivity, selectivity, accuracy and precision for the intended analytical purpose. [3]

For the proposed investigation, a combination of chromatographic and spectroscopic techniques can be used for preliminary identification and quantitative determination of niacinamide. [1,3] Thin-layer chromatography (TLC) can be employed as a preliminary screening technique, whereas UV-Visible spectrophotometry can provide information regarding the absorption characteristics of the extracted compound. [3,4] High-performance liquid chromatography (HPLC) can subsequently be used for specific separation and quantitative estimation of niacinamide in the flaxseed extract. [3,5]

10.2 Sample Preparation

Sample preparation plays an important role in obtaining reproducible analytical results from plant-derived materials. [2] Flaxseeds should be properly cleaned, dried and powdered before extraction to obtain a relatively homogeneous sample. [2,6] An appropriate polar extraction solvent may then be selected according to the solubility and stability characteristics of niacinamide. [3] The obtained extract should be filtered or centrifuged before chromatographic analysis to remove suspended particles and insoluble matrix components. [5]

10.3 Preliminary Identification by TLC

TLC can be used as a simple preliminary method for comparing the flaxseed extract with an authentic niacinamide standard. [4] The sample extract and standard solution can be applied separately on a suitable stationary phase and developed using an optimized mobile phase. [4] The observed spot and corresponding retention factor (Rf) value of the sample can be compared with the standard to provide preliminary evidence for the presence of niacinamide. [4]

10.4 UV-Visible Spectrophotometric Analysis

UV-Visible spectrophotometry can be used to study the absorption characteristics of the extracted compound. [3] A standard solution of niacinamide can be scanned over a suitable wavelength range to determine its maximum absorption wavelength. [3] The absorption profile of the flaxseed extract can then be compared with that of the reference standard as supportive evidence for identification. [3,4]

10.5 HPLC Method Development

HPLC is an important analytical technique for the separation and quantitative determination of compounds in complex plant extracts. [5] During HPLC method development, parameters such as stationary phase, mobile-phase composition, flow rate, detection wavelength, injection volume, column temperature and run time should be optimized. [5,7] The optimized conditions should provide a well-resolved and symmetrical niacinamide peak with minimum interference from other flaxseed constituents. [5]

10.6 Analytical Method Validation

After development, the analytical procedure should be validated to demonstrate that it is suitable for its intended purpose. [7] Analytical validation generally evaluates characteristics such as specificity, linearity, range, accuracy, precision, detection limit, quantitation limit and robustness, as applicable to the analytical procedure. [7]

10.6.1 Specificity

Specificity refers to the ability of an analytical method to distinguish niacinamide from other components present in the flaxseed extract or finished formulation. [7] In HPLC analysis, specificity can be assessed by demonstrating adequate separation of the niacinamide peak from other matrix components. [5,7]

10.6.2 Linearity

Linearity evaluates the ability of the analytical method to produce a response that is proportional to the concentration of niacinamide within a specified range. [7] A series of standard niacinamide concentrations can be analyzed and a calibration curve can be prepared by plotting concentration against peak area or analytical response. [5,7]

10.6.3 Accuracy

Accuracy expresses the closeness of agreement between the measured value and the accepted reference value. [7] It can be evaluated by recovery studies in which known quantities of niacinamide standard are added to the sample matrix and subsequently analyzed. [7]

10.6.4 Precision

Precision indicates the closeness of agreement among a series of measurements obtained from multiple sampling of the same homogeneous sample. [7] Precision can be evaluated through repeatability and intermediate precision under specified analytical conditions. [7]

10.6.5 Limit of Detection

The limit of detection (LOD) represents the lowest amount of niacinamide in a sample that can be detected by the analytical procedure but may not necessarily be quantified with suitable accuracy and precision. [7]

10.6.6 Limit of Quantification

The limit of quantification (LOQ) represents the lowest amount of niacinamide that can be quantitatively determined with appropriate accuracy and precision under the specified analytical conditions. [7]

10.6.7 Robustness

Robustness describes the ability of an analytical procedure to remain unaffected by small deliberate variations in method parameters. [7] Parameters such as flow rate, mobile-phase composition, detection wavelength and column temperature may be varied within suitable limits during robustness evaluation. [5,7]

10.6.8 System Suitability

System-suitability testing is performed before or during chromatographic analysis to verify that the analytical system is functioning properly. [5] Parameters such as retention time, theoretical plate number, peak symmetry or tailing factor and repeatability of response may be evaluated according to the developed method. [5,7]

10.7 Pharmaceutical Applications

A validated analytical method can be applied to the evaluation of niacinamide in pharmaceutical preparations. [5,7] Such a method may support identification, assay determination, quality-control testing and stability evaluation of niacinamide-containing pharmaceutical formulations. [7]

10.8 Cosmetic Applications

Niacinamide is an important active ingredient used in several cosmetic preparations, including creams, gels, lotions and serums. [8] A reliable analytical method can be used to determine niacinamide content during cosmetic formulation development and quality-control studies. [8] The method can also assist in evaluating the stability of niacinamide during storage under specified conditions. [8]

10.9 Stability Studies

Stability assessment is important for determining whether niacinamide remains chemically stable during storage and formulation processing. [7,8] The validated analytical method can be used to monitor changes in niacinamide concentration over time under defined temperature, humidity and light conditions. [7]

Advantages Natural and Plant-Based Approach Flaxseed is a plant-derived material containing several nutritionally and pharmacologically relevant constituents, making it an interesting candidate for investigation as a botanical source of bioactive compounds. [1,2] The investigation of niacinamide from flaxseed may support the development of plant-based approaches for obtaining vitamin B3-related compounds.

11.2 Renewable Raw Material

Flaxseed is an agricultural crop that can be cultivated on a large scale and may therefore provide a renewable raw material for phytochemical investigation. [1,2] Utilization of plant materials can support the exploration of sustainable sources of pharmaceutical and cosmetic ingredients.

11.3 Nutritionally Valuable Plant Matrix

Flaxseed contains α-linolenic acid, dietary fibre, proteins, lignans, minerals and other bioactive constituents. [1,2] This complex nutritional profile makes flaxseed a valuable functional-food material and an attractive matrix for further investigation of minor bioactive compounds.

11.4 Potential Pharmaceutical Application

If niacinamide is successfully identified, isolated and quantitatively established in flaxseed, the purified fraction could be investigated for pharmaceutical applications. [3] A validated analytical method would be essential for determining the identity, purity and concentration of the isolated compound.

11.5 Potential Cosmetic Application

Niacinamide is widely investigated for topical applications related to skin barrier support, pigmentation, sebum regulation and overall skin appearance. [3,4] Therefore, a scientifically confirmed flaxseed-derived niacinamide fraction could potentially be explored for cosmetic formulations such as creams, gels and serums.

11.6 Multiple Analytical Approaches

The proposed study can employ complementary techniques such as TLC, UV-Visible spectrophotometry, FTIR and HPLC for screening, identification and quantitative evaluation. [5] The use of multiple analytical techniques can provide stronger evidence for the identity of the target compound.

11.7 Possibility of Green Extraction

The use of water or other relatively safer solvent systems may be investigated to reduce the environmental burden associated with conventional organic-solvent extraction. [5,6] Optimization of solvent quantity, extraction time and energy requirements may further improve the sustainability of the proposed process.

11.8 Value Addition to Flaxseed

Investigation of minor bioactive compounds in flaxseed may provide an opportunity for value addition beyond its conventional nutritional and oilseed applications. [1,2] Such research may contribute to the development of higher-value pharmaceutical, nutraceutical or cosmetic ingredients.

11.9 Scope for Method Optimization

Extraction parameters such as solvent composition, particle size, temperature, extraction time and solvent-to-sample ratio can be optimized to improve recovery and reproducibility. [5,6] This provides scope for developing a standardized analytical workflow for the proposed investigation.

11.10 Research and Development Potential

The proposed flaxseed–niacinamide investigation can generate a foundation for further studies involving extraction, purification, structural characterization, quantitative estimation, formulation development and stability testing. [5] This may provide opportunities for future pharmaceutical and cosmetic research.

11.11 Potential Cost-Effectiveness

If an efficient extraction and purification process is established, the use of an easily available agricultural raw material could potentially contribute to economical production. [6] However, actual cost-effectiveness would need to be demonstrated through comparative process and economic evaluation.

11.12 Scope for Sustainable Product Development

The combination of a renewable plant source, optimized extraction and appropriate analytical validation may support future development of sustainable botanical ingredients. [1,6] Nevertheless, the feasibility of obtaining commercially useful niacinamide from flaxseed must be established through experimental recovery, purity, yield and economic studies. Limited Flaxseed-Specific Evidence Although flaxseed is extensively studied for its nutritional and pharmacological properties, evidence specifically demonstrating flaxseed as a source of niacinamide is limited. [1,2] Therefore, the occurrence and concentration of niacinamide in different flaxseed varieties require systematic experimental investigation. [2,3]

12.2 Lack of a Standardized Extraction Method

A validated and standardized extraction procedure specifically designed for recovery of niacinamide from flaxseed has not been sufficiently established. [2,3] Differences in solvent composition, extraction temperature, extraction time, particle size and solvent-to-sample ratio may influence the recovery of the target compound. [3,4]

12.3 Complex Plant Matrix

Flaxseed contains oils, proteins, carbohydrates, mucilage, lignans, dietary fibre and other phytoconstituents that may interfere with extraction, purification and analytical determination. [1,4] Therefore, selective separation of niacinamide from the complex flaxseed matrix may be challenging. [4]

12.4 Low Concentration of Target Compound

If niacinamide is present in flaxseed at a relatively low concentration, its detection and quantification may require sensitive and selective analytical techniques. [3,5] Simple spectroscopic methods alone may not be sufficient to conclusively establish its presence in a complex plant extract. [5]

12.5 Need for Confirmatory Characterization

Preliminary identification using TLC or UV-Visible spectroscopy may provide supportive evidence but may not be sufficient for definitive structural confirmation. [5] Therefore, chromatographic and spectroscopic techniques such as HPLC, FTIR and, where available, LC-MS or NMR should be considered for comprehensive characterization. [5,6]

12.6 Lack of Comparative Studies

There is a need for comparative studies involving different flaxseed varieties, geographical sources, cultivation conditions and processing methods to determine their influence on niacinamide content. [1,2] Such studies could help identify raw materials with comparatively higher concentrations of the target compound.

12.7 Influence of Processing and Storage

Drying, grinding, heating, storage and other processing conditions may influence the stability and recovery of target compounds from plant materials. [4,7] Therefore, the effect of these factors on niacinamide recovery from flaxseed requires systematic evaluation.

12.8 Purification Challenges

Isolation of niacinamide from flaxseed extract may be complicated by the simultaneous extraction of other polar constituents. [3,4] Development of an efficient purification and separation strategy is therefore necessary to obtain a sufficiently pure fraction for subsequent characterization.

12.9 Lack of Complete Validation Data

A flaxseed-specific analytical method requires validation for parameters such as specificity, linearity, accuracy, precision, detection limit, quantification limit and robustness. [5] The absence of such validated data would limit the reliability of quantitative claims regarding niacinamide obtained from flaxseed.

12.10 Limited Formulation Studies

Although niacinamide has established relevance in pharmaceutical and cosmetic formulations, the direct application of a flaxseed-derived niacinamide fraction has not been adequately investigated. [6,8] Further studies are required to evaluate its purity, stability, compatibility with excipients and performance in pharmaceutical or cosmetic formulations.

12.11 Research Gap

The major research gap is the lack of a well-established, flaxseed-specific and experimentally validated workflow for extraction, purification, identification and quantification of niacinamide. [2,3] Existing literature provides substantial information regarding the nutritional and bioactive properties of flaxseed and the pharmaceutical and cosmetic importance of niacinamide, but these two research areas have not been sufficiently integrated into a validated flaxseed-to-niacinamide workflow. [1,2,6]

A systematic investigation is therefore required to determine whether niacinamide is genuinely present in flaxseed, at what concentration it occurs, and whether it can be reproducibly recovered using an optimized extraction process. [3,5] Such a study should include appropriate controls, authentic niacinamide reference standards, optimized extraction conditions, purification, chromatographic separation and confirmatory characterization. [5,6]

Future scope

Confirmation of Niacinamide in Flaxseed Future studies should first focus on experimentally confirming the presence of niacinamide in flaxseed using an authentic reference standard and validated analytical techniques. [1,2] HPLC coupled with suitable spectroscopic or mass-spectrometric techniques may provide stronger evidence for identification and quantification. [2,3]

13.2 Optimization of Extraction Conditions

Systematic optimization of solvent type, solvent-to-sample ratio, extraction time, temperature, particle size and extraction cycles may improve the recovery of niacinamide from flaxseed. [3,4] Design of experiments and response-surface methodology may be explored to identify optimum extraction conditions with minimum solvent consumption and processing time. [4]

13.3 Development of a Standardized Extraction Method

Future research can focus on developing a simple, reproducible and scalable extraction procedure specifically for niacinamide from flaxseed. [3,4] Standardization of raw-material quality, extraction conditions and purification steps would be essential for achieving batch-to-batch consistency.

13.4 Advanced Purification Techniques

Further investigations may employ chromatographic separation techniques such as preparative HPLC, solid-phase extraction or other suitable purification approaches to obtain a highly purified niacinamide fraction. [2,3] Purity assessment should be performed using appropriate analytical techniques before considering pharmaceutical or cosmetic applications.

13.5 Advanced Structural Characterization

Advanced analytical techniques such as LC-MS/MS and NMR spectroscopy may be employed in future studies to provide stronger structural confirmation of the isolated compound. [2,5] These techniques may also help differentiate niacinamide from other closely related vitamin B3 compounds or matrix components.

13.6 Comparative Study of Flaxseed Varieties

Future research should compare niacinamide content among different flaxseed varieties, geographical origins and cultivation conditions. [1,6] Such comparative studies may help determine whether genetic, environmental or agricultural factors influence the concentration of the target compound.

13.7 Green and Sustainable Extraction

Future work may investigate water-based, ethanol-based and other environmentally preferable extraction systems for reducing the use of hazardous organic solvents. [4,7] Energy-efficient extraction techniques may also be evaluated to improve the sustainability of the proposed process.

13.8 Pharmaceutical Formulation Development

If sufficient purity and reproducible recovery are established, future studies may investigate the incorporation of flaxseed-derived niacinamide into suitable pharmaceutical formulations. [3,8] Formulation studies should include compatibility, stability, dose uniformity and performance evaluation.

13.9 Cosmetic Formulation Development

The purified fraction may potentially be investigated for incorporation into cosmetic products such as face serums, creams, gels, lotions and moisturizers. [8,9] Future studies should evaluate formulation stability, skin compatibility, microbiological quality and the effectiveness of the final preparation.

13.10 Stability Studies

Long-term and accelerated stability studies should be conducted to evaluate the stability of isolated niacinamide and its formulated products under different environmental conditions. [8,10] Such studies may help determine suitable storage conditions, packaging requirements and product shelf life.

13.11 In-Vitro and Safety Evaluation

Before pharmaceutical or cosmetic application, future studies should evaluate the safety and biological compatibility of the purified fraction using appropriate in-vitro models. [8,9] Further biological investigations may be required to determine whether the flaxseed-derived material provides effects comparable to commercially available niacinamide.

13.12 Scale-Up and Industrial Feasibility

Once laboratory-scale extraction is optimized, scale-up studies can be performed to determine process reproducibility, yield, solvent consumption, purification efficiency and production cost. [4,7] Economic evaluation would be necessary to determine whether flaxseed can be practically developed as a commercially viable source of niacinamide.

13.13 Overall Future Perspective

The future scope of flaxseed-based niacinamide research lies in establishing a complete, reproducible and validated workflow from raw flaxseed to purified and analytically confirmed niacinamide. [2–5] Successful confirmation of the target compound could open opportunities for further pharmaceutical, nutraceutical and cosmetic research, although such applications should be supported by appropriate analytical, safety, stability and

formulation studies.

Conclusion

Flaxseed (Linum usitatissimum L.) is a nutritionally important and pharmacologically relevant plant material containing several valuable constituents such as α-linolenic acid, dietary fibre, proteins, lignans, minerals and other bioactive compounds. Its diverse phytochemical composition makes flaxseed an interesting candidate for further investigation as a potential source of bioactive compounds with pharmaceutical and cosmetic relevance.
Niacinamide, also known as nicotinamide or vitamin B3, is a water-soluble vitamin with important physiological, pharmaceutical and cosmetic applications. It is particularly relevant in topical formulations because of its reported roles in supporting the skin barrier, improving skin hydration, reducing the appearance of hyperpigmentation and supporting the management of oily or acne-prone skin.
The proposed investigation of flaxseed as a potential source of niacinamide involves systematic extraction, purification, identification and quantitative determination of the target compound. Techniques such as TLC, UV-Visible spectroscopy, FTIR and HPLC can be used as complementary approaches for preliminary screening, characterization and quantitative analysis.
However, the specific occurrence and concentration of niacinamide in flaxseed require experimental confirmation using appropriate reference standards and validated analytical procedures. Therefore, flaxseed should presently be described as a potential herbal source rather than an established natural source of niacinamide.
Optimization of extraction parameters such as solvent selection, solvent-to-sample ratio, extraction time, temperature, particle size and purification conditions may improve recovery and reproducibility Further validation of the analytical method for specificity, linearity, accuracy, precision, sensitivity and robustness would strengthen the reliability of the proposed approach.
If the presence of niacinamide is successfully confirmed and sufficient purity and recovery are achieved, the isolated fraction may be further investigated for pharmaceutical and cosmetic formulation development. Future studies should also focus on advanced structural confirmation, stability assessment, safety evaluation, formulation compatibility, scale-up and economic feasibility.
Overall, the flaxseed–niacinamide concept represents a promising research hypothesis, but its scientific validity depends on experimental demonstration of niacinamide in flaxseed and development of a reproducible extraction and validated analytical workflow. Such research could contribute to the exploration of plant-derived sources of valuable pharmaceutical and cosmetic ingredients while providing a basis for future sustainable and value-added applications.

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