A REVIEW ON HERBAL SYRUP DEVELOPMENT FROM KHAYA GRANDIFOLIOLA BARK FOR GASTRIC ULCER MAINTAINANCE

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ABSTRACT

Peptic ulcer disease is a prevalent gastrointestinal condition that affects millions of people worldwide and remains a significant public health concern. The increasing demand for safer and more affordable therapies has encouraged research into medicinal plants with potential anti-ulcer properties. *Khaya grandifoliola*, a member of the Meliaceae family, has been traditionally used in African medicine for the treatment of various ailments, including gastrointestinal disorders. The bark of this plant is rich in bioactive compounds such as flavonoids, tannins, alkaloids, saponins, and limonoids, which are associated with antioxidant, anti-inflammatory, antimicrobial, and gastroprotective activities. These phytochemical may contribute to ulcer prevention and healing by protecting the gastric mucosa, reducing oxidative damage, and enhancing the body's natural defense mechanisms. This review summarizes the available information on the phytochemical composition, pharmacological activities, extraction processes, and formulation considerations involved in the development of anti-ulcer syrup from *Khaya grandifoliola* bark. The review also discusses quality control requirements, stability factors, and safety aspects relevant to herbal syrup formulations. Existing evidence suggests that *Khaya grandifoliola* bark has considerable potential as a natural source of anti-ulcer agents and may be useful in the development of effective herbal products. However, further experimental and clinical studies are needed to confirm its therapeutic efficacy and support its pharmaceutical application.

Keywords: *Khaya grandifoliola*; anti-ulcer syrup; peptic ulcer disease; herbal medicine; phytochemical; gastroprotective activity; herbal formulation; medicinal plants.

1. INTRODUCTION

Peptic ulcer disease (PUD) is a common gastrointestinal disorder characterized by the development of lesions in the gastric or duodenal mucosa due to an imbalance between aggressive factors and the protective mechanisms of the gastrointestinal tract [1]. Despite significant advances in medical science and the availability of effective treatment options, PUD remains a major public health concern worldwide. The disease affects millions of individuals annually and contributes substantially to morbidity, reduced quality of life, and healthcare expenditure [2]. The occurrence of peptic ulcers is influenced by multiple factors, including infection with *Helicobacter pylori*, excessive gastric acid secretion, prolonged use of non steroidal anti-inflammatory drugs (NSAIDs), smoking, alcohol consumption, stress, and dietary habits [3,4].

The gastric mucosa is normally protected by several defense mechanisms, including mucus and bicarbonate secretion, adequate blood flow, rapid epithelial regeneration, and prostaglandin-mediated cytoprotection [5]. When these protective mechanisms are compromised or overwhelmed by aggressive factors such as gastric acid, pepsin, reactive oxygen species, and pathogenic microorganisms, ulceration may occur [6]. Among the various etiological factors, *Helicobacter pylori* infection and chronic NSAID use account for the majority of peptic ulcer cases worldwide [3,4]. If left untreated, peptic ulcers may lead to severe complications such as gastrointestinal bleeding, perforation, gastric outlet obstruction, and an increased risk of gastric malignancy [1].

Conventional treatment strategies for peptic ulcer disease primarily involve the use of proton pump inhibitors (PPIs), histamine H_2-receptor antagonists, antacids, antibiotics for *H. pylori* eradication, and mucosal protective agents [1,7]. These therapies have significantly improved ulcer healing rates and reduced disease recurrence. However, prolonged use of certain anti-ulcer medications has been associated with adverse effects, including nutrient malabsorption, gastrointestinal disturbances, microbial resistance, and drug interactions [8]. Furthermore, the cost and accessibility of modern pharmaceuticals remain challenges in many developing countries. These limitations have encouraged researchers to explore alternative therapeutic approaches, particularly those derived from medicinal plants.

Medicinal plants have served as an important source of healthcare products for centuries and continue to play a significant role in traditional and modern medicine [9]. According to the World Health Organization, a large proportion of the global population relies on herbal medicine for primary healthcare needs [10]. Plant-derived products contain a wide range of bioactive compounds that exhibit diverse pharmacological activities, including antioxidant, anti-inflammatory, antimicrobial, and gastroprotective effects [11]. Several medicinal plants have demonstrated promising anti-ulcer properties through mechanisms such as inhibition of gastric acid secretion, enhancement of mucus production, scavenging of free radicals, stimulation of prostaglandin synthesis, and acceleration of mucosal healing [12].

Among the medicinal plants receiving increasing scientific attention is *Khaya grandifoliola* C. DC., commonly known as African mahogany. The plant belongs to the family Meliaceae and is widely distributed across tropical regions of West and Central Africa [13]. Traditionally, various parts of *K. grandifoliola*, particularly the stem bark, have been used for the treatment of malaria, fever, gastrointestinal disorders, inflammation, and infectious diseases [14]. The extensive ethnomedicinal use of the plant has stimulated scientific investigations into its phytochemical composition and pharmacological properties.

Phytochemical studies have revealed that *Khaya grandifoliola* bark contains numerous biologically active constituents, including flavonoids, tannins, alkaloids, saponins, terpenoids, and limonoids [15,16]. These secondary metabolites are known to possess significant therapeutic activities that may contribute to the prevention and treatment of peptic ulcer disease. Flavonoids exhibit strong antioxidant properties and help protect the gastric mucosa against oxidative damage caused by reactive oxygen species [17]. Tannins promote the formation of protective layers on damaged mucosal surfaces and may enhance tissue repair [18]. Saponins and terpenoids have demonstrated anti-inflammatory and cytoprotective effects, while limonoids possess antimicrobial and antioxidant activities that may further support ulcer healing [15,19]. The combined action of these phytochemicals provides a scientific rationale for the traditional use of *K. grandifoliola* in gastrointestinal disorders.

The increasing interest in herbal medicine has encouraged the development of suitable pharmaceutical dosage forms capable of delivering plant-derived bioactive compounds effectively. Syrups are among the most widely accepted oral dosage forms due to their ease of administration, pleasant taste, rapid absorption, and suitability for both pediatric and adult patients [20]. Herbal syrups offer advantages such as improved patient

compliance, accurate dosing, and enhanced stability of medicinal plant extracts. The formulation of anti-ulcer syrup using *Khaya grandifoliola* bark extract requires careful consideration of extraction methods, excipient selection, preservation, stability, viscosity, and quality control parameters to ensure product safety and efficacy [21].

The production of anti-ulcer syrup from *Khaya grandifoliola* bark represents a promising approach for integrating traditional medicinal knowledge with modern pharmaceutical technology. Such formulations may provide affordable, accessible, and effective alternatives to conventional anti-ulcer therapies, particularly in regions where medicinal plants remain an important component of healthcare systems. Therefore, a comprehensive review of the phytochemical constituents, pharmacological activities, extraction techniques, formulation strategies, quality control requirements, and therapeutic potential of *Khaya grandifoliola* bark is essential. This review aims to evaluate the available scientific evidence supporting the development of anti-ulcer syrup from *Khaya grandifoliola* bark and to identify future research directions for its pharmaceutical application

2. OVERVIEW OF GASTRIC ULCERS

Gastric ulcers are lesions that develop in the lining of the stomach due to damage to the gastric mucosa. They constitute one of the major forms of peptic ulcer disease (PUD) and remain a significant cause of gastrointestinal morbidity worldwide [22]. Gastric ulcers occur when the balance between aggressive factors, such as gastric acid, pepsin, *Helicobacter pylori* infection, and non steroidal anti-inflammatory drugs (NSAIDs), is disrupted, leading to mucosal injury and ulcer formation [23,24].

The stomach possesses several defense mechanisms that protect it from self-digestion. These include mucus secretion, bicarbonate production, adequate mucosal blood flow, prostaglandin synthesis, and continuous epithelial cell renewal [25]. When these protective mechanisms are weakened or overwhelmed, the gastric mucosa becomes susceptible to erosion and ulceration [26].

Among the various causes of gastric ulcers, *Helicobacter pylori* infection is one of the most important etiological factors. The bacterium colonizes the gastric mucosa and induces chronic inflammation, thereby increasing the risk of ulcer development [27]. Likewise, prolonged use of NSAIDs inhibits prostaglandin synthesis, resulting in reduced mucosal protection and increased vulnerability to gastric injury [24]. Other contributing factors include smoking, excessive alcohol consumption, stress, genetic predisposition, and poor dietary habits [28].

Patients with gastric ulcers commonly present with symptoms such as epigastric pain, nausea, vomiting, abdominal bloating, early satiety, and loss of appetite [29]. In severe cases, complications such as gastrointestinal bleeding, perforation, and gastric outlet obstruction may occur, potentially leading to life-threatening conditions if not promptly treated [30].

The management of gastric ulcers focuses on eliminating causative factors, suppressing gastric acid secretion, eradicating *H. pylori* infection, and promoting mucosal healing [32]. Although conventional therapies are effective, growing concerns regarding adverse effects, recurrence, and treatment costs have encouraged the exploration of alternative therapeutic agents, particularly those derived from medicinal plants with gastroprotective properties [12,16].

3.BOTANICAL PROFILE OF KHAYA GRANDIFOLIOLA

***Khaya grandifoliola* C. DC., commonly known as African mahogany, is a valuable medicinal and timber tree belonging to the family Meliaceae. The species is native to tropical regions of West and Central Africa and is widely distributed in countries such as Nigeria, Cameroon, Ghana, Côte d'Ivoire, Uganda, and the Democratic Republic of Congo [33,34]. In traditional African medicine, various parts of the plant, particularly the stem bark, leaves, and roots, are used for the treatment of malaria, fever, gastrointestinal disorders, microbial infections, inflammation, and other ailments [35]. The increasing scientific interest in**

K. grandifoliola is attributed to its rich phytochemical composition and diverse pharmacological activities.

3.1Taxonomical Classification

The taxonomic classification of *Khaya grandifoliola* is presented below [33,36]:

- **Kingdom:** Plantae
- **Division:** Magnoliophyta
- **Class:** Magnoliopsida
- **Order:** Sapindales
- **Family:** Meliaceae
- **Genus:** *Khaya*
- **Species:** *Khaya grandifoliola* C. DC.

The genus *Khaya* consists of several species, including *Khaya senegalensis*, *Khaya ivorensis*, *Khaya anthotheca*, and *Khaya grandifoliola*, all of which are recognized for their medicinal and economic importance [37].

3.2. Morphological Classification

Khaya grandifoliola is a large evergreen or semi-deciduous tree that can attain a height of 30–40 meters under favorable environmental conditions [34]. The tree possesses a straight cylindrical bole with a broad, dense crown. The bark is dark brown to greyish-brown, rough, and fissured, becoming increasingly scaly with age [38].

The leaves are alternate, compound, and paripinnate, consisting of several pairs of glossy leaflets. The leaflets are characteristically large, a feature reflected in the species name *grandifoliola*, meaning “large leaflets” [39]. The flowers are small, fragrant, and greenish-white, occurring in branched inflorescences.

The fruits are woody capsules that split open upon maturity to release numerous winged seeds, which facilitate wind dispersal [34,40]

3.3. Geographical Distribution And Habitat

Khaya grandifoliola is indigenous to the tropical rainforests and moist semi-deciduous forests of West and Central Africa [33]. The species thrives in areas with high rainfall, fertile soils, and warm climatic conditions. It is commonly found in lowland forests at altitudes ranging from sea level to approximately 1,500 meters above sea level [41]. Due to its high-quality timber and medicinal value, the species is also cultivated in plantations and agroforestry systems across several African countries [34].

3.4. Ethnomedicinal Uses

The medicinal applications of *K. grandifoliola* have been documented in numerous African communities. Traditional healers utilize bark decoctions and extracts for the management of malaria, fever, stomach disorders, diarrhea, dysentery, and inflammatory conditions [35,42]. The stem bark is particularly valued for its therapeutic effects against gastrointestinal ailments and is often administered orally in the form of decoctions or infusions [43]. In addition, extracts of the plant have been employed in the treatment of microbial infections, pain, and parasitic diseases [44].

3.5. Economic And Pharmaceutical Importance

Beyond its medicinal applications, *K. grandifoliola* is an economically important timber species widely used in furniture production, construction, and carpentry due to its durable and attractive wood [34]. From a pharmaceutical perspective, the plant has attracted considerable research interest because of the presence of bioactive compounds such as flavonoids, alkaloids, tannins, saponins, terpenoids, and limonoids [45]. These phytochemicals have demonstrated antioxidant, anti-inflammatory, antimicrobial, antimalarial, and gastroprotective activities, supporting the traditional use of the plant and its potential role in anti-ulcer syrup development [46,47].

The botanical characteristics, widespread traditional use, and rich phytochemical profile of *Khaya grandifoliola* provide a strong foundation for its investigation as a source of natural therapeutic agents. Understanding its taxonomy, morphology, distribution, and ethnomedicinal applications is essential for the proper identification, collection, and utilization of plant materials in pharmaceutical formulations, including anti-ulcer syrups.

3. PHYTOCHEMICAL CONSTITUENTS OF KHAYA GRANDIFOLIOLA BARK

The therapeutic potential of *Khaya grandifoliola* bark is largely attributed to its rich and diverse phytochemical composition. Phytochemicals are naturally occurring bioactive compounds produced by plants that contribute to their medicinal properties. Several studies have reported that the stem bark of *K. grandifoliola* contains a variety of secondary metabolites, including alkaloids, flavonoids, tannins, saponins, terpenoids, glycosides, steroids, and limonoids, which are associated with numerous pharmacological activities [48,49]. These compounds play important roles in the plant's defense mechanisms and have demonstrated significant biological effects in both experimental and clinical studies.

4.1. Flavonoids

Flavonoids are among the most important phytochemicals identified in *K. grandifoliola* bark. They are polyphenolic compounds widely recognized for their antioxidant, anti-inflammatory, and gastroprotective activities [50]. Flavonoids protect the gastric mucosa by scavenging reactive oxygen species, reducing oxidative stress, inhibiting lipid per-oxidation, and enhancing mucus secretion [51]. These activities are particularly important in the prevention and healing of gastric ulcers, where oxidative damage contributes significantly to mucosal injury.

4.2. Tannins

Tannins are naturally occurring polyphenolic compounds present in the bark of *K. grandifoliola*. They possess astringent properties and are known to promote the formation of protective layers over damaged tissues [52]. In gastric ulcer management, tannins help reduce irritation of the mucosal lining and facilitate tissue regeneration. Their antioxidant and antimicrobial activities further contribute to their therapeutic effectiveness in gastrointestinal disorders [53].

4.3. Alkaloids

Alkaloids constitute another important group of bioactive compounds found in *K. grandifoliola* bark [48]. These nitrogen-containing compounds exhibit a wide range of pharmacological activities, including analgesic, antimicrobial, anti-inflammatory, and antioxidant effects [54]. The presence of alkaloids may contribute to the plant's traditional use in the treatment of pain, infections, and gastrointestinal ailments.

4.4. Saponins

Saponins are glycosidic compounds known for their surface-active properties and diverse biological activities. Studies have demonstrated that saponins possess anti-inflammatory, antimicrobial, immunomodulatory, and cytoprotective effects [55]. In the gastrointestinal tract, saponins may enhance mucosal defense mechanisms and promote ulcer healing by stimulating mucus production and reducing inflammatory responses [56].

4.5. Terpenoids

Terpenoids represent one of the largest classes of plant secondary metabolites and have been detected in *K. grandifoliola* bark extracts [49]. These compounds exhibit numerous pharmacological activities, including antioxidant, anti-inflammatory, antimicrobial, and gastroprotective properties [57]. Their ability to modulate inflammatory pathways and reduce oxidative stress may contribute to the anti-ulcer effects of the plant

4.6. Limonoids

Limonoids are highly oxygenated triterpenoid derivatives that are characteristic constituents of plants belonging to the Meliaceae family [58]. Several limonoids have been isolated from *Khaya* species and are considered major bioactive compounds responsible for many of their medicinal properties [59]. Limonoids possess antioxidant, antimicrobial, anti-inflammatory, antimalarial, and cytoprotective activities. These properties support their potential role in protecting the gastric mucosa and promoting ulcer healing.

4.7. Steroids And Glycosides

Phytochemical analyses have also revealed the presence of steroids and glycosides in *K. grandifoliola* bark [48,49]. Plant steroids are known for their anti-inflammatory and membrane-stabilizing properties, while glycosides contribute to various biological activities depending on their chemical structure. Together, these compounds may enhance the therapeutic efficacy of the bark extraction

SIGNIFICANCE OF PHYTOCHEMICALS IN ANTI ULCER ACTIVITY

The anti-ulcer potential of *Khaya grandifoliola* bark is believed to result from the synergistic interaction of its phytochemical constituents. Flavonoids and tannins provide antioxidant protection against free radical-induced gastric damage, while saponins and terpenoids strengthen mucosal defenses and reduce inflammation [51,56]. Limonoids and alkaloids further contribute through their antimicrobial and cytoprotective actions [58,59]. The combined effects of these compounds support the traditional use of *K. grandifoliola* in the management of gastrointestinal disorders and justify its investigation as a source of active ingredients for anti-ulcer syrup formulation.

4. ANTI GASTRIC ULCER ACTIVITY OF KHAYA GRANDIFOLIOLA BARK

The search for effective and affordable anti-ulcer agents from natural sources has increased considerably in recent years due to the limitations associated with conventional therapies. Medicinal plants have gained significant attention because they contain diverse bioactive compounds capable of protecting the gastric mucosa and promoting ulcer

healing. Among these plants, *Khaya grandifoliola* has emerged as a promising candidate owing to its rich phytochemical composition and wide range of pharmacological activities [60,61]. Although the plant has traditionally been used in African medicine for the management of gastrointestinal disorders, recent scientific investigations have provided evidence supporting its potential role in gastric ulcer prevention and treatment[62].

The anti-ulcer activity of *K. grandifoliola* bark is largely attributed to the presence of phytochemicals such as flavonoids, tannins, saponins, alkaloids, terpenoids, and limonoids [63]. These compounds act through multiple mechanisms to protect the gastric mucosa from injury. Gastric ulcers are often associated with excessive production of reactive oxygen species, which cause oxidative damage to the gastric epithelial cells and compromise mucosal integrity [64]. Flavonoids present in *K. grandifoliola* bark possess potent antioxidant properties that neutralize free radicals, reduce lipid per-oxidation, and enhance the antioxidant defense system of the body [65]. By minimizing oxidative stress, these compounds contribute significantly to the prevention and healing of gastric ulcers.

Inflammation is another important factor involved in the pathogenesis of gastric ulcers. Damage to the gastric mucosa stimulates the release of inflammatory mediators, leading to further tissue injury and delayed healing 66[]. Studies have shown that extracts of *K. grandifoliola* exhibit anti-inflammatory activity through the inhibition of pro-inflammatory mediators and modulation of inflammatory pathways [67]. The anti-inflammatory effects of the bark may help reduce mucosal irritation, limit tissue damage, and accelerate ulcer healing.

Tannins, which are abundant in the stem bark of *K. grandifoliola*, also contribute significantly to its gastroprotective activity [63]. These compounds possess astringent properties and are capable of forming protective complexes with proteins on the surface of damaged tissues. This protective layer shields the gastric mucosa from the corrosive effects of gastric acid and pepsin, thereby facilitating tissue regeneration and repair [68]. Furthermore, tannins exhibit antimicrobial activity, which may help control microbial infections that contribute to gastrointestinal disorders [69].

The gastroprotective effects of *K. grandifoliola* bark may also be related to its ability to enhance mucus production and strengthen the mucosal barrier. Gastric mucus serves as the first line of defense against acid-induced injury by preventing direct contact between gastric acid and epithelial cells [70]. Phytochemicals such as saponins and terpenoids have been reported to stimulate mucus secretion and improve mucosal resistance to ulcero genic agents [71]. Enhanced mucus production not only protects the gastric lining but also promotes the healing of existing ulcers.

Several experimental studies involving medicinal plants rich in similar phytochemical constituents have demonstrated significant reductions in ulcer index, gastric acidity, and mucosal lesions in animal models [72]. The phytochemical profile of *K. grandifoliola* suggests that it may exert comparable effects. Limonoids, which are characteristic compounds of the Meliaceae family, have been associated with antioxidant, anti-inflammatory, and cytoprotective activities that support gastric mucosal protection [73]. These compounds may contribute to the overall anti-ulcer efficacy of *K. grandifoliola* bark by reducing gastric damage and enhancing tissue repair mechanisms.

The synergistic interaction among the various phytochemical constituents of *K. grandifoliola* bark is likely responsible for its overall anti-ulcer activity. Antioxidant compounds reduce oxidative stress, anti-inflammatory agents suppress tissue inflammation, tannins form protective barriers, and saponins enhance mucus production [65,68,71]. Together, these mechanisms contribute to the maintenance of gastric mucosal integrity and the promotion of ulcer healing.

The growing body of scientific evidence supporting the pharmacological activities of *K. grandifoliola* highlights its potential as a source of natural anti-ulcer agents. The incorporation of standardized bark extracts into pharmaceutical formulations such as herbal syrups may provide an effective and affordable alternative for the management of gastric ulcers. However, further experimental studies, toxicity evaluations, and clinical trials are necessary to establish the

efficacy, safety, optimal dosage, and mechanisms of action of *K. grandifoliola* bark in anti-ulcer therapy [76].

5. HERBAL SYRUP DEVELOPMENT FROM KHAYA GRANDIFOLIOLA BARK

The growing interest in herbal medicine has led to increased research on the development of plant-based pharmaceutical formulations that are safe, effective, and acceptable to patients. Among the various dosage forms available for herbal products, syrups are widely preferred because they are easy to administer, provide accurate dosing, and improve patient compliance due to their pleasant taste and smooth texture [77]. Herbal syrups are particularly useful for pediatric and geriatric patients who may experience difficulty swallowing solid dosage forms. The development of an anti-ulcer syrup from *Khaya grandifoliola* bark represents an important approach for transforming traditional medicinal knowledge into a standardized pharmaceutical product capable of delivering therapeutic benefits in a convenient and acceptable form.

The stem bark of *Khaya grandifoliola* contains several bioactive phytochemicals, including flavonoids, tannins, alkaloids, saponins, terpenoids, and limonoids, which have been associated with antioxidant, anti-inflammatory, antimicrobial, and gastroprotective activities [78,79]. These phytochemicals provide the scientific basis for the use of the plant in anti-ulcer therapy. However, the successful development of a herbal syrup requires careful consideration of extraction procedures, formulation components, quality control measures, stability parameters, and regulatory requirements to ensure the production of a safe and effective product [80].

The development of a herbal anti-ulcer syrup from *K. grandifoliola* bark requires a systematic process involving plant collection, authentication, extraction, phytochemical screening, formulation design, quality control evaluation, stability testing, and safety assessment [79]. Each stage plays a critical role in ensuring the consistency, efficacy, and safety of the final product.

6.1. Collection,Identification And Processing Of Bark

The quality of any herbal formulation depends greatly on the quality of the raw plant material. Fresh stem bark of *K. grandifoliola* should be collected from healthy trees and authenticated by a qualified taxonomist. Proper botanical identification is necessary to prevent adulteration and ensure reproducibility of therapeutic effects [80]. After collection, the bark should be thoroughly cleaned to remove dirt, foreign matter, and microbial contaminants. The material is then dried under shade at controlled temperatures to minimize degradation of heat-sensitive phytochemicals [81].

The dried bark is subsequently pulverized into a coarse or fine powder to increase the surface area available for solvent penetration during extraction. Proper drying and milling procedures enhance extraction efficiency and contribute to the preservation of active constituents [82].

6.2. Extraction Of Bioactive Constituents

Extraction is a crucial step in the development of herbal syrups because it determines the quantity and quality of phytochemicals present in the final product. Various extraction methods may be employed, including maceration, infusion, decoction, percolation, Soxhlet extraction, and ultrasound-assisted extraction . The choice of extraction method depends on the nature of the phytochemicals and the desired therapeutic outcome.

Hydroethanolic and aqueous solvents are commonly used for extracting bioactive compounds from medicinal plants because of their ability to dissolve both polar and moderately nonpolar constituents For anti-ulcer syrup development, ethanol-water mixtures are often preferred due to their efficiency in extracting flavonoids, tannins, saponins, and alkaloids from *K. grandifoliola* bark .

Following extraction, the solvent is removed by evaporation under reduced pressure or controlled heating conditions to obtain a concentrated extract. The extract may then be subjected to phytochemical screening to confirm the presence of biologically active compounds responsible for anti-ulcer activity

6.3. Phytochemical Standardization

Standardization is essential for ensuring batch-to-batch consistency of herbal formulations. Variations in plant source, harvesting season, geographical location, and extraction conditions can significantly influence phytochemical content . Therefore, standardized procedures should be established for extract preparation and quality evaluation.

Phytochemical screening of *K. grandifoliola* bark extract typically involves qualitative and quantitative determination of flavonoids, tannins, alkaloids, saponins, terpenoids, and limonoids . Modern analytical techniques such as High-Performance Liquid Chromatography (HPLC), Gas Chromatography-Mass Spectrometry (GC-MS), and Fourier Transform Infrared Spectroscopy (FTIR) may be employed for chemical characterization and standardization of the extract .

6.4. Formulation Of Anti Ulcer Syrup

The formulation stage involves incorporating the standardized bark extract into a suitable syrup base. A typical herbal syrup contains the active plant extract along with excipients such as sucrose, sorbitol, glycerin, preservatives, flavoring agents, coloring agents, and purified water

Sucrose is commonly used as a sweetening agent and viscosity enhancer, while sorbitol may serve as an alternative sweetener in sugar-free formulations. Glycerin functions as a co-solvent and humectant, improving the texture and stability of the syrup . Preservatives such as sodium benzoate or methylparaben are added to inhibit microbial growth and extend shelf life .

Flavoring agents may be incorporated to mask the bitter taste often associated with herbal extracts and improve patient acceptance. The concentration of each excipient should be optimized to achieve desirable organoleptic properties without affecting the therapeutic activity of the extract .

6.5. Evaluation Of Herbal Syrup

After formulation, the syrup must undergo comprehensive quality evaluation to ensure compliance with pharmaceutical standards. Important evaluation parameters include appearance, color, odor, taste, pH, viscosity, density, and sedimentation characteristics .

The pH of the syrup should remain within an acceptable range to maintain stability and minimize irritation upon administration. Viscosity measurements help determine the flow properties of the syrup and influence patient acceptability. Uniformity of drug content is also essential to ensure consistent dosing throughout the product .

Microbial quality testing is particularly important because herbal products are susceptible to contamination by bacteria, fungi, and yeasts. Total microbial counts should comply with pharmacopoeial specifications to guarantee product safety .

6.6. Safety And Regulatory Considerations

The safety of herbal syrups must be established before clinical use. Toxicological studies, including acute and subchronic toxicity evaluations, are necessary to identify potential adverse effects and determine safe dosage ranges .. In addition, compliance with Good Manufacturing Practices (GMP) and regulatory guidelines is essential for ensuring product quality, efficacy, and safety .

Regulatory authorities increasingly require evidence of standardization, stability, safety, and therapeutic effectiveness before approving herbal medicinal products. Therefore, scientific validation of *K. grandifoliola* bark syrup through laboratory studies and clinical trials is crucial for its successful pharmaceutical development .

In conclusion, the development of anti-ulcer syrup from *Khaya grandifoliola* bark involves a multidisciplinary approach encompassing pharmacognosy, phytochemistry, pharmaceutics, quality assurance, and toxicology. The rich phytochemical composition of the bark and its reported gastroprotective activities support its potential as a valuable ingredient in herbal anti-ulcer formulations.

Proper extraction, standardization, formulation, and quality control procedures are essential to ensure the production of a safe, effective, and stable herbal syrup for ulcer management.

6. EVALUATION AND QUALITY CONTROL OF HERBAL SYRUP

The evaluation and quality control of herbal syrups are essential to ensure their safety, efficacy, stability, and consistency. Herbal formulations are often subject to variations in phytochemical composition due to differences in plant source, harvesting conditions, extraction procedures, and storage conditions. Therefore, comprehensive quality control measures must be implemented throughout the manufacturing process to guarantee the production of a standardized pharmaceutical product .. In the case of anti-ulcer syrup formulated from *Khaya grandifoliola* bark extract, evaluation parameters include organoleptic properties, physicochemical characteristics, microbial quality, phytochemical standardization, stability assessment, and safety evaluation .

7.1. Organoleptic Evaluation

Organoleptic evaluation involves the assessment of sensory characteristics such as appearance, color, odor, taste, and clarity of the syrup. These properties influence patient acceptance and provide preliminary information regarding product quality . The syrup should possess a uniform appearance without precipitation, phase separation, or excessive turbidity. Since *K. grandifoliola* bark extract may impart a bitter taste, suitable flavoring agents can be incorporated to improve palatability and enhance patient compliance

7.2. Determination Of Ph

The pH of a herbal syrup is an important quality parameter because it affects product stability, preservative efficacy, and patient comfort. A properly maintained pH helps prevent degradation of active constituents and minimizes microbial growth . The pH is typically measured using a calibrated digital pH meter under standardized conditions. Significant changes in pH during storage may indicate chemical instability or microbial contamination .

7.3. Viscosity Measurement

Viscosity refers to the resistance of a liquid to flow and is a critical parameter in syrup formulations. Appropriate viscosity ensures uniform dosing, ease of pouring, and desirable mouthfeel .The viscosity of herbal syrups is commonly determined using instruments such as Brookfield viscometers. Variations in viscosity may occur due to changes in temperature, sugar concentration, or degradation of formulation components .

7.4. Specific Gravity And Density

Specific gravity and density measurements are useful indicators of syrup quality and consistency. These parameters provide information regarding the concentration of dissolved solids and help maintain batch-to-batch uniformity **.** Determination of specific gravity is generally carried out using a pycnometer or hydrometer according to pharmacopoeial procedures.

7.5. Content Uniformity And Phytochemical Analysis

Content uniformity ensures that the active constituents are evenly distributed throughout the formulation and that each dose delivers the intended therapeutic effect **.** Phytochemical analysis is performed to identify and quantify major bioactive compounds such as flavonoids, tannins, alkaloids, saponins, and limonoids present in *K. grandifoliola* bark extract **.**

Advanced analytical techniques including High-Performance Liquid Chromatography (HPLC), High-Performance Thin-Layer Chromatography (HPTLC), Gas Chromatography-Mass Spectrometry (GC-MS), and Fourier Transform Infrared Spectroscopy (FTIR) are commonly employed for phytochemical standardization and quality assurance **.** These techniques help establish chemical fingerprints that can be used to verify product authenticity and detect adulteration.

7.6. Microbial Quality Assessment

Herbal products are particularly susceptible to microbial contamination because plant materials may contain bacteria, fungi, yeasts, and other microorganisms acquired during cultivation, harvesting, processing, or storage **.** Microbial quality assessment is therefore a critical component of quality control.

Tests typically include determination of total aerobic microbial count, total yeast and mold count, and the absence of specific pathogenic microorganisms such as *Escherichia coli*, *Salmonella* spp., *Staphylococcus aureus*, and *Pseudomonas aeruginosa* **.** Microbial limits should comply with the specifications established by pharmacopoeial and regulatory authorities.

7.7. Preservative Efficacy Testing

Preservatives are added to herbal syrups to inhibit microbial growth and extend product shelf life. Common preservatives used in syrup formulations include sodium benzoate, methylparaben, and propylparaben **.** Preservative efficacy testing evaluates the ability of these agents to prevent microbial proliferation during storage.

The test involves inoculating the formulation with selected microorganisms and monitoring microbial survival over a specified period. Successful preservative systems maintain microbial counts within acceptable limits throughout the product's shelf life **.**

7.8. Stability Studies

stability testing is conducted to determine the shelf life and storage conditions of the herbal syrup. These studies assess the physical, chemical, microbiological, and therapeutic stability of the formulation over time **.** Stability evaluation typically includes monitoring parameters such as color, odor, pH, viscosity, sedimentation, phytochemical content, and microbial load under different environmental conditions.

Accelerated stability studies are commonly performed at elevated temperature and humidity conditions, such as 40°C ± 2°C and 75% ± 5% relative humidity, in accordance with International Council for Harmonization (ICH) guidelines . Long-term stability studies are also conducted under recommended storage conditions to establish the expiration date of the product

7.9. Safety Evaluation.

Safety evaluation is an essential aspect of quality control for herbal formulations. Toxicological studies are performed to assess potential adverse effects and establish safe dosage ranges . Acute toxicity studies evaluate the effects of a single high dose, whereas subacute and chronic toxicity studies examine the consequences of repeated administration over extended periods.

In addition, testing for contaminants such as heavy metals, pesticide residues, mycotoxins, and residual solvents is necessary to ensure product safety and compliance with regulatory standards.

7.10. Regulatory Requirements And Good Manufacturing Practices

The manufacture of herbal syrups should comply with Good Manufacturing Practices (GMP) to ensure consistent quality and safety . GMP guidelines cover all aspects of production, including raw material selection, processing, packaging, storage, documentation, and quality assurance procedures.

Regulatory authorities such as the World Health Organization (WHO), European Medicines Agency (EMA), United States Pharmacopeia (USP), and national drug regulatory agencies require scientific evidence supporting the quality, safety, and efficacy of herbal medicinal products before market authorization . Proper documentation and adherence to regulatory guidelines facilitate product approval and enhance consumer confidence.

7. CONCLUSION

The increasing prevalence of peptic ulcer disease and the limitations associated with conventional anti-ulcer therapies have intensified the search for safer, cost-effective, and naturally derived therapeutic alternatives. Medicinal plants continue to play a significant role in drug discovery and healthcare, particularly in developing countries where traditional medicine remains an important component of primary healthcare. Among the numerous medicinal plants investigated for their gastroprotective properties, *Khaya grandifoliola* has emerged as a promising candidate due to its rich phytochemical composition and long history of traditional use in the management of gastrointestinal disorders.

This review highlights the potential of *Khaya grandifoliola* bark as a valuable source of bioactive compounds for the development of herbal anti-ulcer formulations. The bark contains several important phytochemical constituents, including flavonoids, tannins, alkaloids, saponins, terpenoids, and limonoids, which possess antioxidant, anti-inflammatory, antimicrobial, cytoprotective, and gastroprotective properties. These compounds act through multiple mechanisms to protect the gastric mucosa, reduce oxidative stress, enhance mucus production, inhibit inflammatory responses, and promote ulcer healing. The synergistic interaction among these phytochemicals may contribute significantly to the overall therapeutic efficacy of the plant.

In conclusion, *Khaya grandifoliola* bark possesses considerable potential as a natural source of anti-ulcer agents and represents a promising candidate for the development of herbal syrup formulations. Its rich phytochemical profile, traditional medicinal applications, and reported pharmacological activities support its use in gastric ulcer management. With continued scientific research, standardization, and clinical validation, *K. grandifoliola* bark-based anti-ulcer syrup may emerge as an effective, safe, affordable, and accessible therapeutic option for the prevention and

treatment of gastric ulcers. The integration of traditional herbal medicine with modern pharmaceutical technology offers significant opportunities for the development of innovative healthcare products capable of addressing the growing burden of gastrointestinal diseases worldwide.

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