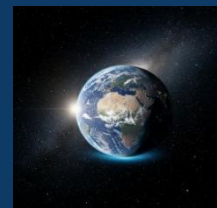




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Biological and Therapeutic Properties of Honey in Wound Healing

Julia Jastrzębska, ORCID <https://orcid.org/0000-0001-9921-0881>

E-mail: j.jastrzebska2105@gmail.com

Medical Centre in Łańcut LLC, Ignacego Paderewskiego 5, 37-100 Łańcut, Poland

Łukasz Kogut, ORCID <https://orcid.org/0009-0000-6151-4628>

E-mail: lukasz.kogut2@wp.pl

Department of Bioenergetics, Food Analysis and Microbiology, Institute of Food Technology and Nutrition, Faculty of Technology and Life Science, University of Rzeszów, Aleja Rejtana 16C, 35-959 Rzeszów, Poland

Katarzyna Gunia, ORCID <https://orcid.org/0009-0003-0111-5758>

E-mail: katarzyna.gunia2000@gmail.com

Collegium Medicum, University of Rzeszów, al. Tadeusza Rejtana 16C, 35-959 Rzeszów, Poland

Yana Nyankovska, ORCID <https://orcid.org/0000-0003-0518-4753>

E-mail: yana.nyankov@gmail.com

Clinical Regional Hospital No. 2 named after St. Queen Jadwiga in Rzeszów, Lwowska 60, 35-301 Rzeszów, Poland

Rafał Kołodziej, ORCID <https://orcid.org/0009-0009-5029-600X>

E-mail: rakolodziej@ur.edu.pl

Collegium Medicum, University of Rzeszów, al. Tadeusza Rejtana 16C, 35-959 Rzeszów, Poland

Anna Teneta, ORCID <https://orcid.org/0009-0000-3000-5011>

E-mail: at126307@stud.ur.edu.pl

Collegium Medicum, University of Rzeszów, al. Tadeusza Rejtana 16C, 35-959 Rzeszów, Poland

Ignacy Hatała, ORCID <https://orcid.org/0009-0008-2428-8906>

E-mail: ignacy.hatala6@gmail.com

Medical University of Łódź, Al. Kościuszki 4, 90-419 Łódź, Poland

Szymon Lulek, ORCID <https://orcid.org/0009-0000-3827-2907>

E-mail: szymonlulek.z@gmail.com

Clinical Regional Hospital No. 2 named after St. Queen Jadwiga in Rzeszów, Lwowska 60, 35-301 Rzeszów, Poland

Jan Żrebiec, ORCID <https://orcid.org/0009-0001-4330-7809>

E-mail: janzrebiec75@gmail.com

Faculty of Health Sciences and Psychology, Collegium Medicum, University of Rzeszów, 1A Warzywna Street, 35-310 Rzeszów, Poland

Jakub Konieczny, ORCID <https://orcid.org/0009-0005-3708-5858>

E-mail: jkonieczny10.11@gmail.com

Clinical Regional Hospital No. 2 named after St. Queen Jadwiga in Rzeszów, Lwowska 60, 35-301 Rzeszów, Poland

Corresponding Author

Łukasz Kogut, E-mail: lukasz.kogut2@wp.pl

Abstract

Background. Chronic and infected wounds remain a major clinical challenge due to impaired tissue regeneration, persistent inflammation, bacterial biofilms, and antimicrobial resistance.

Aim. This review aimed to assess the biological and therapeutic properties of honey in wound healing, with emphasis on its mechanisms of action, clinical applications, and emerging therapeutic approaches.

Material and methods. A narrative review of scientific literature on honey in wound management was conducted, focusing on its biological properties, mechanisms of action, clinical effectiveness, and modern formulations.

Results. Honey acts through high osmolarity, acidic pH, hydrogen peroxide, and bioactive compounds, including polyphenols, flavonoids, antimicrobial peptides, and methylglyoxal. Medical-grade honey exhibits antimicrobial, anti-inflammatory, antioxidant, and regenerative effects. It may inhibit multidrug-resistant bacteria, disrupt biofilms, promote autolytic debridement, angiogenesis, and tissue regeneration. Clinical benefits have been reported in diabetic foot ulcers, venous leg ulcers, pressure ulcers, burns, and postoperative wounds. Honey-based hydrogels, nanofibres, films, and biomaterial dressings may further improve therapeutic effectiveness.

Conclusions. Medical-grade honey is a valuable adjunct in wound management due to its ability to control infection and support tissue regeneration. Further clinical studies and product standardisation are required to optimise treatment protocols and confirm its effectiveness.

Key words: honey, medical-grade honey, wound healing, chronic wounds, antimicrobial activity, tissue regeneration, wound management

1. Introduction

Wound management represents one of the major challenges in contemporary regenerative medicine. The aim of therapy is not only to achieve wound closure and restore skin integrity, but also to re-establish normal skin function and obtain the best possible aesthetic outcome without excessive fibrosis or scarring [1]. Chronic wounds pose particular therapeutic challenges and constitute a significant health problem with medical, social, and economic implications [2]. It is estimated that they affect approximately 2.5% of the general population, with their prevalence increasing with age [2,3]. The treatment of chronic wounds is highly costly and places a substantial burden on healthcare systems [2,4]. At the same time, these conditions have a considerable impact on patients' quality of life, leading to chronic pain, reduced social activity, isolation, and an increased risk of depressive disorders [5,6]. Moreover, certain types of chronic wounds have been associated with mortality rates exceeding those observed in many malignant diseases [2,7].

Normal wound healing is a complex and dynamic biological process involving four overlapping phases: haemostasis, inflammation, proliferation, and tissue remodelling [8–10]. In chronic wounds, this process becomes disrupted, and the successive stages of healing fail to occur within the expected timeframe, which generally ranges from four weeks to three months [11]. In clinical practice, the most common types of chronic wounds include venous leg ulcers resulting from chronic venous insufficiency and venous hypertension, diabetic foot ulcers associated with neuropathy, vascular impairment and infection, pressure ulcers arising from prolonged pressure in immobilised patients, and infected postoperative wounds occurring as complications of surgical procedures [8,10].

Bacterial biofilms, which are present in the majority of chronic wounds, play an important role in the pathogenesis of these conditions [9]. Biofilms formed by microorganisms such as *Staphylococcus aureus* and *Pseudomonas aeruginosa* constitute an effective protective barrier that shields bacteria from both antibiotics and host defence mechanisms [2,9]. A further challenge is the increasing prevalence of antimicrobial resistance, which is recognised as one of the major threats to public health [2,12]. Persistent chronic inflammation, associated with excessive production of pro-inflammatory cytokines and matrix metalloproteinases, leads to degradation of the extracellular matrix and inhibition of fibroblast proliferation, thereby preventing the normal progression of the wound-healing process [4].

In the search for novel approaches to support wound management, increasing attention has been directed towards natural substances with antimicrobial and regenerative properties [2,13]. Among the most promising natural products is honey, which is one of the oldest therapeutic agents used by humans [13]. Its use in wound treatment was already known to the ancient civilisations of Egypt, Greece, Rome, China, and India [7]. The medicinal properties of honey have been described in both medical sources and religious texts [13]. Although its therapeutic importance declined following the introduction of antibiotics in the mid-twentieth century, there has recently been a marked resurgence of interest in the use of honey for wound management [7].

Contemporary research indicates that the therapeutic effects of honey cannot be attributed to a single constituent but instead result from the synergistic action of multiple biological mechanisms [8,14].

Particular attention has been given to the antimicrobial properties of honey, which are associated with hydrogen peroxide production, the presence of non-peroxide antimicrobial compounds, high osmolarity, and an acidic pH [9,15,16]. These mechanisms effectively inhibit microbial growth while simultaneously creating favourable conditions for the regeneration of damaged tissues [8,9,16]. In contrast to conventional antibiotics, the development of bacterial resistance to honey has not yet been demonstrated, which considerably enhances its therapeutic potential [2,11,17]. Honey has also demonstrated activity against multidrug-resistant strains, which represent a major clinical challenge in contemporary medicine [9,16,18].

The growing interest in honey-based therapy is also associated with advances in modern wound-dressing technologies [2,16,19]. Honey is currently incorporated into hydrogels, alginates, and other biomaterials designed for wound management [8,12,15,16,19]. Such approaches enable the controlled release of active compounds directly at the wound site, potentially enhancing therapeutic efficacy and reducing the risk of infection [16,19]. At the same time, the importance of using standardised medical-grade honey is emphasised, as such products undergo rigorous quality control and sterilisation procedures to ensure their safety for clinical use [2,10,11,17,20].

Given the growing interest in the application of honey in wound management and the increasing body of experimental and clinical evidence, a comprehensive review of current knowledge regarding its biological and therapeutic properties is warranted [21]. Of particular importance is an analysis of the mechanisms underlying the effects of honey, its efficacy in the treatment of different types of wounds, and the potential applications of this natural product in modern medical technologies [17,20].

2. Chemical and Biological Characteristics of Honey

Honey is a natural product produced primarily by *Apis mellifera* bees [22,23]. Nectar honeys are derived from floral nectar, whereas honeydew honeys originate from secretions of living plant parts and excretions of plant-sap-feeding insects [13,14]. Chemically, honey is a viscous, supersaturated sugar solution [13,15,24]. Its properties are not constant and depend on numerous factors, including botanical and geographical origin, harvesting period, climatic conditions, and storage practices [6,8,18]. Variability in chemical composition directly translates into differences in the biological activity of individual honey varieties [13,14].

2.1. Chemical Composition of Honey

Sugars constitute the predominant component of honey; however, its distinctive biological and therapeutic properties are primarily attributed to the presence of numerous minor constituents, which account for approximately 3% of the total product mass [14,15]. Carbohydrates represent approximately 65–87% of the total mass of honey and more than 95% of its dry matter [6,23]. The predominant sugars are fructose and glucose [15,23,25]. The fructose-to-glucose ratio usually ranges from 0.9 to 1.7 and is of considerable importance for the physicochemical properties of honey [23,25]. In addition to monosaccharides, honey also contains disaccharides

and oligosaccharides, including sucrose, maltose, isomaltose, and turanose, although their quantitative contribution is considerably lower [15,23,26].

Water is the second major component of honey, typically accounting for approximately 15–20% of its composition [3,23,27]. Water content influences product stability, viscosity, and susceptibility to fermentation [13,15]. Heather honey constitutes an exception, as its water content may reach up to 23% [23,28]. Minor constituents include proteins, enzymes, amino acids, particularly proline, organic acids, B-group vitamins and vitamin C, minerals, polyphenols, and volatile aromatic compounds [14,15]. The presence of these compounds contributes to the antibacterial, anti-inflammatory, antioxidant, and wound-healing-promoting properties of honey [14,15].

2.2. Biologically Active Compounds Present in Honey

Polyphenols and flavonoids constitute one of the most important groups of biologically active compounds in honey [23,26]. They are responsible for a substantial proportion of its antioxidant, anti-inflammatory, and antimicrobial properties [14,23]. Polyphenolic compounds identified in honey include caffeic acid, ferulic acid, gallic acid, and *p*-coumaric acid [14,15,23]. The most frequently reported flavonoids include quercetin, kaempferol, chrysin, pinocembrin, and luteolin [14,15,23]. The concentration of these compounds is strongly dependent on the nectar source; therefore, they are frequently used as markers of honey authenticity and botanical origin [13,14]. Their mechanisms of action primarily involve free-radical scavenging and inhibition of pro-inflammatory enzymes such as cyclooxygenase-2 (COX-2) [17,26]. As a result, these compounds protect tissues against oxidative stress and attenuate inflammatory processes [14,26].

Enzymes represent another important group of honey constituents [14,15]. Particular importance is attributed to glucose oxidase, which, following honey dilution, catalyses the oxidation of glucose to gluconic acid [1,13]. Hydrogen peroxide is generated as a by-product of this reaction and is regarded as one of the principal factors responsible for the antibacterial activity of most honeys [9,13,15,27]. Honey also contains catalase, which regulates hydrogen peroxide concentrations, as well as invertase, which participates in sucrose hydrolysis [13,15,29]. Diastase and amylase are additional enzymes involved in carbohydrate metabolism [14,15,21,25].

Organic acids also play an important biological role and account for approximately 0.1–1.5% of honey composition [14,23]. The most important is gluconic acid, which is formed through the activity of glucose oxidase [13,15,23]. Organic acids are responsible for maintaining the acidic pH of honey, which generally ranges from 3.2 to 6.1 [13,23,29]. Such conditions effectively inhibit the growth of numerous pathogenic microorganisms [9,13,15]. In the context of wound healing, an additional benefit of the low pH may be its ability to counteract the more alkaline environment characteristic of many chronic wounds [9,13,21,30].

Peptides and proteins are also particularly noteworthy among the biologically active constituents of honey [13,15]. The best-characterised compound within this group is defensin-1, also referred to as bee defensin-1 [2,13,15]. This peptide exhibits potent antibacterial activity, particularly against Gram-positive bacteria, and is capable of inhibiting bacterial biofilm formation [9,10,13]. Glycoproteins present in honey, such as major royal jelly protein 1 (MRJP1), participate in natural defence mechanisms and may contribute to the antimicrobial activity of the product [8,13].

2.3. Types of Honey Used in Medicine

Various types of honey are currently used in medicine, and these may differ in their chemical profiles and predominant mechanisms of action [8,9,15]. The best-known and most extensively studied honey currently used for therapeutic purposes is Manuka honey, originating from New Zealand and Australia [5,8,10]. It is produced from the nectar of *Leptospermum scoparium* and is distinguished by its high non-peroxide antibacterial activity [8,10,13]. This activity is primarily attributed to methylglyoxal (MGO), which is formed from dihydroxyacetone naturally present in Manuka nectar [2,8,10,13]. Owing to the high concentration of this compound, Manuka honey exhibits potent antimicrobial properties [2,7,9].

Another group of honeys that has attracted considerable interest for therapeutic applications comprises honeydew honeys, including Black Forest honey [9,30]. These honeys generally exhibit higher peroxide-dependent activity and contain greater concentrations of minerals and polyphenols than conventional nectar honeys [13,18,30]. The increased abundance of these constituents may contribute to their antioxidant and antimicrobial potential [13,14,30].

Other honey varieties characterised by high biological activity include the Malaysian Tualang, Gelam, and Kelulut honeys, which exhibit particularly pronounced anti-inflammatory effects [9,29,32]. Chestnut honey also demonstrates considerable therapeutic potential and is distinguished by its relatively high acidity [33]. In turn, buckwheat and acacia honeys may, in some experimental settings, promote faster wound closure than Manuka honey [10,20,29].

2.4. Medical-Grade Honey and Its Standardisation

Medical-grade honey (MGH) is a specialised honey product intended for therapeutic use [2,8,20]. To ensure patient safety and reproducibility of therapeutic outcomes, it is subjected to rigorous quality control and standardisation procedures [2,8,20]. Fundamental requirements include high product purity and appropriately controlled sourcing [11,20]. Medical-grade honey should be free from residues of pesticides, herbicides, antibiotics, and heavy metals that could compromise its safety in clinical applications [10,20].

An important stage in the preparation of medical-grade honey is sterilisation using gamma irradiation [2,8,20]. This process is generally performed at doses ranging from 10 to 50 kGy and enables the effective elimination of bacterial spores, including those of *Clostridium botulinum* [8,10,13]. Importantly, this method does not cause substantial destruction of enzymes or other biologically active constituents that are sensitive to high temperatures [8,20].

Assessment of the biological activity of the product is another important component of standardisation [20]. Medical-grade honey should demonstrate a defined level of antibacterial or antioxidant activity [20]. In the case of Manuka honey, specific quality indices are used, including the Unique Manuka Factor (UMF) and methylglyoxal content [2,13]. These parameters enable the therapeutic potential of the product to be assessed [2,13].

The physicochemical properties of medical-grade honey are also subject to quality control [1,20]. Parameters assessed include moisture content, which generally should not exceed 18%, reducing sugar content, electrical conductivity, and the concentration of hydroxymethylfurfural (HMF), which serves as an indicator of overheating or inappropriate storage conditions [8,20]. In addition, medical-grade honey products must comply with the relevant regulatory requirements for clinical use, for example through CE marking or appropriate authorisation by the US Food and Drug Administration (FDA) [2,20].

Because conventional food-grade honeys are not standardised, may exhibit unpredictable biological activity, and may contain contaminants, their use for wound treatment is not recommended [13,20]. In clinical practice, only preparations that meet the requirements established for medical-grade honey should be used [10,20].

3. Mechanisms of Action of Honey in Wound Healing

The mechanisms through which honey promotes wound healing are multifactorial and involve both the physicochemical properties of the product itself and its effects on host cells, microorganisms, and molecular processes occurring within damaged tissues [2,7,32]. Honey simultaneously exhibits antimicrobial, anti-inflammatory, immunomodulatory, and regenerative activities, enabling it to influence multiple stages of the wound-healing process [2,7,28]. Its therapeutic efficacy results from the synergistic interaction of numerous mechanisms that restrict infection and create favourable conditions for the restoration of damaged tissue structures [2,7,34].

3.1. Antibacterial Activity

Honey exhibits broad-spectrum antibacterial activity [2,5,9]. It is effective against numerous pathogenic microorganisms, including multidrug-resistant strains such as methicillin-resistant *Staphylococcus aureus* (MRSA) and *Pseudomonas aeruginosa* [2,5,9]. This activity is not attributable to a single bioactive compound but instead results from the simultaneous action of several complementary mechanisms [2,9,14].

An important role is played by the high osmolarity of honey, which results from its very high sugar content combined with a relatively low water content [9,15,24,30]. Such conditions generate high osmotic pressure, leading to the efflux of water from bacterial cells [2,9,18]. This subsequently results in cellular dehydration, shrinkage, and ultimately microbial death [2,9,21,30]. Another factor restricting bacterial growth is the low pH of honey, which typically ranges from 3.2 to 4.5 [2,7,9,30]. This acidic environment inhibits the proliferation of most pathogens that preferentially grow at near-neutral pH and may additionally contribute to protein denaturation within microbial cells [2,9,21,24].

Hydrogen peroxide (H_2O_2) constitutes another important component of the antimicrobial activity of honey and is generated through the action of glucose oxidase following dilution of honey with wound exudate [9,15,21,27]. Hydrogen peroxide exerts strong bactericidal effects by damaging microbial DNA, proteins, and cell membranes [2,9,24,30]. In the case of Manuka honey, particular importance is attributed to non-peroxide activity associated with the presence of methylglyoxal (MGO) [2,7,9,10]. This compound is capable of modifying bacterial proteins through glycation, disrupting DNA replication, and interfering with normal cell division [8,9,21,30].

Bee defensin-1 and polyphenolic compounds also contribute to the antibacterial properties of honey [2,9,10,15]. Bee defensin-1 is a peptide capable of forming pores in bacterial cell membranes, resulting in membrane disruption and cell death [2,9,10]. It may also inhibit bacterial biofilm formation [9,10,15]. Polyphenols and flavonoids present in honey restrict microbial proliferation by interfering with pathogen energy

metabolism and inhibiting DNA gyrase activity [9,15,26,30]. The combined effects of these mechanisms result in activity against both planktonic bacteria and microorganisms organised within biofilm structures [2,9,15,30].

3.2. Modulation of Inflammation and Immunomodulatory Activity

Honey may influence wound healing at different stages through its ability to modulate the host immune response [2,7,9,17]. Its biphasic activity involves both stimulation of an appropriate inflammatory response and attenuation of excessive or prolonged inflammation [9,17,21].

During the initial phase of healing, honey stimulates monocytes and macrophages to produce pro-inflammatory cytokines such as tumour necrosis factor- α (TNF- α), interleukin-1 β (IL-1 β), and interleukin-6 (IL-6) [2,9,17,21]. Activation of immune cells may help reinitiate endogenous repair mechanisms [9,17,21,22]. Restoration of an appropriate healing response is particularly relevant in chronic wounds, in which normal progression through the healing phases is impaired or arrested [9,17,21].

Angiogenesis is particularly important during tissue regeneration [2,9,35,36]. This process may be promoted, among other mechanisms, through hydrogen peroxide release and stimulation of macrophage activity [29,30]. These effects can increase the expression of vascular endothelial growth factor (VEGF), which plays a central role in the formation of new blood vessels [1,30,34]. Improved vascularisation facilitates the delivery of oxygen and nutrients to regenerating tissues [17].

Studies also indicate that hydrogen peroxide released from honey may induce calcium ion influx into keratinocytes [6,25]. This important molecular signal contributes to wound closure and may accelerate re-epithelialisation of the damaged tissue [2,6].

3.5. Reduction of Wound Malodour

An additional benefit of honey application is its ability to reduce the unpleasant odour associated with many infected and chronic wounds [4,24,37]. This phenomenon is commonly referred to as wound deodorisation [24].

Unpleasant wound odour is primarily associated with volatile sulphur-containing compounds and ammonia. These metabolites are generated during the microbial degradation of amino acids and proteins present within damaged tissues [30].

Honey supplies microorganisms with readily available glucose, which may shift their energy metabolism away from proteolytic pathways towards carbohydrate utilisation [9,30]. This metabolic shift results in the production of relatively odourless lactic acid rather than malodorous compounds derived from protein degradation. Consequently, honey may not only support the management of infected wounds but also improve patient comfort by reducing one of the most distressing symptoms associated with chronic skin lesions [4,9,37].

4. Clinical Applications of Medical-Grade Honey in Wound Management

Contemporary clinical studies and meta-analyses indicate that honey is an effective and safe adjunct in wound healing [9,21,24,30]. Particularly favourable effects have been observed with regard to infection control, disruption of bacterial biofilms, acceleration of tissue regeneration, and improvement in patient comfort [2,7,9,24]. Owing to its multifaceted mechanisms of action, medical-grade honey (MGH) is increasingly being used in the management of wounds of diverse aetiologies [8,17,20,21].

4.1. Diabetic Foot Ulcers

One of the most important areas of clinical application of honey is the treatment of diabetic foot ulcers [2,7,9]. This condition represents a major therapeutic challenge because of the high risk of infection, the frequent presence of bacterial biofilms, and the possibility of complications leading to limb amputation [7,9]. In patients with diabetes, the wound-healing process is often impaired; therefore, effective approaches capable of supporting tissue regeneration are of particular importance [7,9].

Meta-analyses including sixteen randomised clinical trials have shown that the use of honey-containing dressings significantly increases the likelihood of complete wound healing and reduces treatment duration compared with standard care [30]. A particularly important advantage is the ability of honey to disrupt bacterial biofilms formed, among others, by *Staphylococcus aureus* [2,9,38]. This may help limit the progression of infection and reduce the need for systemic antibiotic therapy [8,9].

Clinical studies have also demonstrated that honey-based therapy can accelerate the removal of necrotic tissue, reduce oedema, and improve the appearance of the wound bed [7,9]. Consequently, reductions in hospitalisation rates and in the risk of amputation, one of the most serious consequences of diabetic foot disease, have been reported [7,9].

4.2. Venous Leg Ulcers

Venous leg ulcers are among the most common chronic wounds and are caused by disorders of venous circulation [6,28]. Owing to their prolonged course and frequent bacterial colonisation, their management can be

highly challenging [2,28]. In this context, medical-grade honey has demonstrated considerable effectiveness in both infection control and the promotion of tissue regeneration [6,28].

Comparative studies have shown that ulcers treated with Manuka honey achieved complete healing after an average of approximately seven weeks of therapy [1,6]. In comparison, treatment with silver-containing alginate dressings required up to fourteen weeks [6]. These findings suggest that honey may substantially shorten the duration of treatment [6].

Another important benefit is the rapid resolution of clinical signs of infection [28]. It has been reported that treatment with medical-grade honey can eliminate clinical symptoms of infection after an average of approximately 2.2 weeks [28]. In addition, patients treated with honey dressings report less pain during dressing changes [6,9]. This may be attributed to the fact that honey dressings do not strongly adhere to the wound surface, thereby reducing trauma to newly formed tissue during dressing replacement [6,9,13,38].

4.3. Burns

Honey demonstrates particularly high clinical effectiveness in the treatment of burns, especially superficial and partial-thickness burns, including first- and second-degree injuries [8,21,24,39]. This represents one of the best-documented clinical applications of honey [8,21,24].

Systematic reviews and clinical analyses have shown that honey significantly reduces epithelialisation time compared with conventional treatment using silver sulfadiazine or polyurethane dressings [5,21,22,24,29]. This translates into faster restoration of epidermal integrity and earlier completion of the healing process [5,22,24].

Honey also exhibits anti-inflammatory activity, thereby reducing wound exudate and the intensity of the inflammatory response within damaged skin [19,24,38]. These effects may contribute to a lower risk of scar formation and a more rapid restoration of normal skin function [8,19,38]. An additional benefit is pain reduction, which improves patient comfort during treatment [19,24,38].

4.4. Postoperative Wounds and Acute Traumatic Wounds

Medical-grade honey is also used in the management of postoperative wounds and acute traumatic injuries [2,8,40]. It may be applied both for the prevention of surgical-site infections and for the treatment of complications that have already developed following surgical procedures [2,17,24].

The use of honey following procedures such as mastoid surgery, ophthalmic surgery, and Caesarean section has been associated with improved wound-healing outcomes [2,8,17,40]. Reported benefits include improved scar appearance, reduced pain, and a lower risk of wound dehiscence [2,17,24].

Honey may also be particularly relevant in elderly patients [8,11,40]. In older individuals, the skin is often thin, atrophic, and more susceptible to injury [2,11,40]. In cases of skin tears and abrasions, the use of honey may accelerate tissue regeneration and reduce the risk of an acute wound progressing to a chronic state [11,26,40].

4.5. Pressure Ulcers

Another important application of honey is the treatment of pressure ulcers, which occur primarily in patients subjected to prolonged immobilisation [2,4,24]. These wounds are particularly difficult to manage because of tissue necrosis, impaired local perfusion, and a high risk of infection [2,4,9].

The high osmolarity of honey promotes autolytic debridement of necrotic tissue [2,9,24,32]. This process plays a key role in preparing the wound bed for subsequent stages of treatment [2,12,32]. Removal of necrotic tissue helps restrict bacterial proliferation and improves the conditions required for tissue regeneration [2,9,24,32].

Very favourable therapeutic outcomes have also been reported in severe stage III and IV pressure ulcers [32]. In some studies, negative bacteriological cultures were obtained after only one week of treatment with medical-grade honey, indicating substantial antimicrobial effectiveness [32].

4.6. Other and Emerging Clinical Applications

Current research indicates that the therapeutic potential of honey extends beyond the treatment of cutaneous wounds [17,20]. Other potential applications in different areas of medicine are increasingly being investigated [17,20].

In dentistry, honey has been used to support healing of extraction sockets following tooth removal and in the management of oral mucositis in patients undergoing anticancer therapy [17,20,41]. Owing to its anti-inflammatory and antimicrobial properties, honey may accelerate the regeneration of damaged tissues and reduce pain [17,41].

Studies in abdominal surgery have also suggested the potential use of honey in the prevention of postoperative adhesions [17]. Although these findings are derived mainly from animal models, they indicate the possibility of extending the therapeutic applications of honey [17].

Neonatology represents another emerging area of interest [2,17]. Medical-grade honey has been reported to be safely used in preterm infants for the treatment of extravasation injuries [2,5,17]. This approach may support the healing process without causing significant adverse effects [2].

4.7. Clinical Benefits Associated with the Use of Honey

Regardless of wound type, the use of medical-grade honey is associated with a range of potential clinical benefits [2,8,20]. Honey can effectively reduce wound malodour, support autolytic debridement of necrotic tissue, stimulate granulation tissue formation, and promote angiogenesis [2,9,24,32]. At the same time, it has a favourable safety profile and is not associated with the development of bacterial resistance [2,5,20].

In clinical practice, the most commonly used formulations include sterilised honey preparations in the form of gels, ointments, and honey-impregnated dressings [2,8,20,32]. Widely used commercial products include Medihoney, L-Mesitran, and Activon [3,8,20]. Their use represents a valuable adjunct to contemporary wound management and is becoming increasingly established in routine clinical practice [2,8,20,32].

5. Modern Honey-Based Preparations and Future Perspectives

Contemporary regenerative medicine increasingly utilises honey not only as a natural therapeutic agent but also as a component of advanced wound-management systems [13,21,32]. Despite the numerous advantages of pure honey, its practical application may be limited by characteristics such as high viscosity, a tendency to leak from the site of application, and the natural variability of its biological composition [13,15,32,42]. For this reason, modern honey-based formulations are being developed to ensure prolonged contact of active substances with the wound bed, controlled release of therapeutic constituents, and improved ease of use for both patients and healthcare professionals [13,15,32]. The integration of honey with modern biomaterials enables more effective utilisation of its antimicrobial, anti-inflammatory, and regenerative properties [2,13,32].

5.1. Advanced Wound-Dressing Formulations

One of the most rapidly developing approaches involves honey-containing hydrogels and cryogels [2,13,25,32]. These three-dimensional polymer networks have a high water content and therefore resemble the natural extracellular matrix of tissues [29,32]. Combining honey with materials such as poly(vinyl alcohol) (PVA), alginates, chitosan, or gelatine enables the production of dressings capable of maintaining an optimally moist wound-healing environment [25,29,32,43]. These structures absorb excess wound exudate while simultaneously preventing desiccation of the wound bed [29,32]. An additional advantage is their cooling effect, which may contribute to the reduction of pain [32]. Cryogels represent a distinctive subgroup in which the macroporous structure provides improved mechanical stability and more controlled release of the bioactive constituents present in honey [2,25].

Another innovative approach involves nanofibres produced by electrospinning [2,13,25]. This technology enables the production of extremely thin fibres with diameters measured on the nanometre scale [13]. Their very high specific surface area facilitates efficient honey release and its uniform distribution across the wound surface [13,44]. Nanofibres, most commonly produced from polymers such as polycaprolactone (PCL) or polylactic acid (PLA), mimic the architecture of the natural extracellular matrix and thereby promote cell adhesion and stimulate fibroblast proliferation, which is essential for tissue reconstruction [13,25,44].

Honey-containing films and membranes are also used in modern wound care [12,13,32]. These are thin, transparent polymeric layers that act as protective barriers against external factors [12,13]. At the same time, they allow visual monitoring of the healing process without requiring dressing removal, thereby reducing the risk of damaging newly formed tissue [12,32].

Foams and sponges produced by freeze-drying constitute another important group of advanced formulations [13,25]. Their high porosity makes them particularly suitable for the management of heavily exuding wounds [13,25,32]. The presence of honey supports autolytic wound debridement and stimulates granulation tissue formation, thereby accelerating tissue regeneration [2,13,25,32].

5.2. Honey in Tissue Engineering and Advanced Technologies

The development of tissue engineering provides new opportunities for the use of honey in regenerative medicine [13,25,32]. One of the most promising approaches is the incorporation of honey into bioinks used for three-dimensional bioprinting [13,25,32,41]. Alginate- or pectin-based bioinks supplemented with honey exhibit improved rheological properties and greater printing precision [13,32,41]. At the same time, honey confers antibacterial properties on printed tissue scaffolds [13,32,41]. It has been demonstrated that lower honey concentrations, of approximately 27%, do not exert toxic effects and may additionally stimulate the activity of cells involved in tissue regeneration [32].

Another novel strategy involves dissolvable microneedles designed to deliver honey across the stratum corneum [2]. These systems enable effective transport of active constituents into deeper tissue layers and may be particularly useful in the treatment of deep infections caused by bacteria such as MRSA [2]. The use of

microneedles can simultaneously preserve the structural integrity of the formulation and improve therapeutic efficiency [2].

The application of honey in nanotechnology and within the concept of so-called green chemistry is also gaining increasing attention [25,41,45]. Honey may act as a natural reducing and stabilising agent during the synthesis of silver, gold, and zinc oxide nanoparticles [25,43,45]. The resulting nanocomposites exhibit stronger antimicrobial activity than the individual components used separately [25,43,45]. In addition, synergistic interactions may reduce potential toxicity towards host cells [25,41,43].

5.3. Supplemented and Bioengineered Preparations

Modern honey-based formulations are increasingly supplemented with additional compounds intended to enhance their therapeutic efficacy [20,21]. Examples include products containing additional antioxidants such as vitamins C and E [5,20,21,28]. Such combinations may enhance the anti-inflammatory and antibacterial effects of honey while simultaneously increasing its protective potential towards damaged tissues [5,20,21].

Bioengineered preparations designed to provide controlled release of hydrogen peroxide are also under development [13,20,21]. Products such as SurgihoneyRO are capable of maintaining antimicrobial activity for periods of up to eight days [13,21]. Sustained H₂O₂ production is particularly important in combating persistent bacterial biofilms, which represent one of the major factors underlying the chronicity of many wounds [13,21].

Another promising approach involves formulations combining honey with essential oils, including tea tree or cinnamon oils [2,20,44]. When formulated as nanoemulsions, such systems demonstrate enhanced activity against Gram-negative bacteria such as *Pseudomonas aeruginosa* [44]. This may broaden the spectrum of antimicrobial activity and increase the effectiveness of treatment for infected wounds [2,44].

Honey is also increasingly incorporated into combination therapies in which it acts synergistically with other modern treatment modalities [2,13,21]. One example is the combination of honey with vacuum-assisted closure (VAC) therapy [2]. The simultaneous application of both approaches can accelerate the removal of wound exudate and bacterial biofilm while creating favourable conditions for the regeneration of damaged tissues [2]. A particularly important research direction concerns synergistic interactions between honey and antibiotics [2,13,21]. Manuka honey has been reported to restore the susceptibility of certain antibiotic-resistant bacterial strains, including MRSA, to agents such as oxacillin [13,21]. This opens new therapeutic possibilities in addressing the growing problem of antimicrobial resistance [2,13,21].

Bioactive tissue scaffolds incorporating honey together with other biological materials, such as amniotic membrane or bovine collagen, are also being investigated for wound treatment [46]. Such multicomponent dressings are intended to stimulate multiple stages of the wound-healing process simultaneously, from infection control to tissue remodelling [46].

5.4. Future Perspectives and Challenges

The development of honey-based therapies offers numerous new opportunities, although it is also associated with substantial challenges [2,8,21]. One of the most innovative concepts is the genetic modification of bees to produce honey with increased concentrations of selected antimicrobial peptides or growth factors [8]. Such an approach could substantially increase the therapeutic potential of future honey-based preparations [8].

The concept of personalised apitherapy is also attracting increasing interest [7,17]. This approach involves selecting a specific type of honey according to the type and aetiology of the wound as well as the current stage of healing [7,17]. In the future, specific honey varieties may potentially be selected according to the predominant therapeutic requirement, such as infection control or stimulation of cellular migration [2,7,17].

However, the standardisation of honey-based products and prevention of honey adulteration remain major challenges [2,20]. Large, multicentre clinical trials are also required to establish more definitively the role of honey within contemporary standards of wound care [2,7,31]. Economic considerations are equally important [2,7,25,31]. Honey is a relatively inexpensive product and may represent a cost-effective alternative to more expensive synthetic dressings [7,25,31]. It therefore has the potential to play a particularly important role in low- and middle-income countries, where access to advanced medical technologies remains limited [2,7,25,31]. In the future, this may contribute to the broader implementation of honey-based therapies in the global management of chronic and infected wounds [2,7,8,31].

Conclusions

Medical-grade honey represents a promising adjunct to contemporary wound management due to its multifaceted antimicrobial, anti-inflammatory, antioxidant, immunomodulatory, and regenerative properties. Its therapeutic activity results from the synergistic interaction of several physicochemical and biological mechanisms, including high osmolarity, acidic pH, hydrogen peroxide production, and the activity of bioactive constituents such as polyphenols, flavonoids, antimicrobial peptides, and, particularly in Manuka honey, methylglyoxal. Through these complementary mechanisms, honey can inhibit microbial growth, including

multidrug-resistant strains, interfere with bacterial biofilms, modulate excessive inflammation, and create conditions favourable for tissue repair [2,7,9,13,15].

Available clinical evidence indicates that medical-grade honey may support several stages of wound healing by promoting autolytic debridement, granulation tissue formation, angiogenesis, re-epithelialisation, and regeneration of damaged tissues. The most extensively documented applications include diabetic foot ulcers, venous leg ulcers, pressure ulcers, burns, and selected postoperative wounds. In these conditions, honey-based treatment may contribute to improved infection control, shorter healing times, reduced pain and wound malodour, and greater patient comfort. Its activity against multidrug-resistant microorganisms and the absence of confirmed development of bacterial resistance to the complex antimicrobial mechanisms of honey further strengthen its potential role in the management of chronic and infected wounds [2,6,24,28,31,32].

The incorporation of honey into advanced biomaterials, including hydrogels, cryogels, nanofibres, films, membranes, foams, and tissue-engineering scaffolds, creates new opportunities for its application in regenerative medicine. These systems may improve local retention, provide controlled release of bioactive compounds, maintain an appropriate wound environment, and enhance the therapeutic potential of honey. Nevertheless, differences in honey composition and biological activity remain important limitations, highlighting the need for rigorous standardisation of medical-grade products. Further large-scale, multicentre clinical trials are required to define optimal formulations and treatment protocols and to establish more precisely the role of honey-based therapies within contemporary wound-care standards [2,7,13,20,25,32].

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Author Contributions:

Conceptualization: Julia Jastrzębska, Łukasz Kogut

Methodology: Julia Jastrzębska, Łukasz Kogut, Katarzyna Gunia

Resources: Katarzyna Gunia, Yana Nyankovska, Rafał Kołodziej, Ania Teneta, Ignacy Hatala, Szymon Lulek, Jan Żrebiec, Jakub Konieczny

Writing – original draft preparation: Julia Jastrzębska, Katarzyna Gunia, Łukasz Kogut, Yana Nyankovska, Rafał Kołodziej, Ania Teneta, Ignacy Hatala, Szymon Lulek, Jan Żrebiec, Jakub Konieczny

Writing – review and editing: Julia Jastrzębska, Łukasz Kogut, Katarzyna Gunia

Supervision: Julia Jastrzębska, Łukasz Kogut

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References

1. Aati H, Hassan HM, Darwish MA, Khanfar MA, Bahr HS, Ali AT, et al. Chemical profiling and wound healing activity of *Tamarix aphylla* honey. *Chem Biodivers*. 2025;22(12):e202501049. <https://doi.org/10.1002/cbdv.202501049>

2. Alhabbsi A, et al. Clinical significance of medical-grade honey in advanced wound care: A systematic review. *Int Wound J.* 2026;23(5):e70939. <https://doi.org/10.1111/iwj.70939>
3. Dahiya D, Nigam PS. Honey as a Natural Nutraceutical: Its Combinational Therapeutic Strategies Applicable to Chronic Wound Management. *AIMS Microbiol.* 2024;10(2):288-310. <https://doi.org/10.3934/microbiol.2024.2.288>
4. Paunică-Panea G, Teodorescu S, Preda A, Gligor LE, Silaghi A, Constantin VD. Chronic wound management; surgical therapy and complementary nursing with Manuka honey. *J Mind Med Sci.* 2023;10(1):139-147. <https://doi.org/10.22543/2392-7674.1361>
5. Boekema BKH, Chrysostomou D, Ciprandi G, Elgersma A, Vlig M, Pokorná A, et al. Comparing the antibacterial and healing properties of medical-grade honey and silver-based wound care products in burns. *Burns.* 2024;50(3):597-610. <https://doi.org/10.1016/j.burns.2023.10.009>
6. Kucharzewski M, Spycka K, Rojczyk E, Brela J. Topical Application of Manuka Honey for the Treatment of Non-Healing Venous Leg Ulcers. *Pharmaceuticals.* 2025;18(2):149. <https://doi.org/10.3390/ph18020149>
7. Rojczyk E, Spycka K, Sieroń A, Bazaliński D, Kucharzewski M. Manuka honey as a natural remedy for diabetic foot ulcers: efficacy compared with silver-based dressing. *Front Pharmacol.* 2026;17:1790277. <https://doi.org/10.3389/fphar.2026.1790277>
8. Barazesh P, Mehrabian A, Hajihassani H, Motalebi F, Hosseini Neiresi SM, Hajihassani R, et al. Medical-Grade Honey in Wound Healing: Anti-bacterial Properties and Innovative Applications. *J Apic Res.* 2025;64(2):125-135. <https://doi.org/10.1080/00218839.2025.1234567>
9. Bezerra A, Fonseca H, Rodrigues F, Delerue-Matos C, Gouvinhas I, Garcia J. Honey Therapy in Diabetic Foot Ulcers: A Promising Strategy for Effective Wound Healing. *Appl Sci.* 2023;13(23):12820. <https://doi.org/10.3390/app132312820>
10. Clare J, Lindley MR, Ratcliffe E. The Potential of Fish Oil Components and Manuka Honey in Tackling Chronic Wound Treatment. *Microorganisms.* 2024;12(8):1593. <https://doi.org/10.3390/microorganisms12081593>
11. Chrysostomou D, Pokorná A, Cremers NAJ, Peters LJF. Medical-Grade Honey Is a Versatile Wound Care Product for the Elderly. *J Aging Res Lifestyle.* 2024;13:51-59. <http://dx.doi.org/10.14283/jarlife.2024.7>
12. Boateng J, Khan S. Composite HPMC-Gelatin Films Loaded with Cameroonian and Manuka Honeys Show Antibacterial and Functional Wound Dressing Properties. *Gels.* 2025;11(7):557. <https://doi.org/10.3390/gels11070557>
13. Yupanqui Mies J, Vyas C, Aslan E, Humphreys G, Diver C, Bartolo P. Honey: An Advanced Antimicrobial and Wound Healing Biomaterial for Tissue Engineering Applications. *Pharmaceutics.* 2022;14(8):1663. <https://doi.org/10.3390/pharmaceutics14081663>
14. Tlak Gajger I, Dar SA, Ahmed MMM, Aly MM, Vlaineć J, et al. Antioxidant Capacity and Therapeutic Applications of Honey: Health Benefits, Antimicrobial Activity and Food Processing Roles. *Antioxidants.* 2025;14(8):959. <https://doi.org/10.3390/antiox14080959>
15. Hossain ML, Lim LY, Hammer K, Hettiarachchi D, Locher C. A Review of Commonly Used Methodologies for Assessing the Antibacterial Activity of Honey and Honey Products. *Antibiotics.* 2022;11(7):975. <https://doi.org/10.3390/antibiotics11070975>
16. Mies JY, Vyas C, Aslan E, Humphreys G, Diver C, Bartolo P. Honey: An Advanced Antimicrobial and Wound Healing Biomaterial for Tissue Engineering Applications. *Pharmaceutics.* 2022;14(8):1663. <https://doi.org/10.3390/pharmaceutics14081663>
17. Pleeging CCF, Wagener FADTG, de Rooster H, Cremers NAJ. Revolutionizing Non-Conventional Wound Healing Using Honey by Simultaneously Targeting Multiple Molecular Mechanisms. *Drug Resist Updat.* 2022;62:100834. <https://doi.org/10.1016/j.drug.2022.100834>
18. Bouacha M, Besnaci S, Boudiar I. Comparative Study of the Antibacterial Activity of Algerian Honeys and Manuka Honey Toward Pathogenic Bacteria from Burn Wound Infections. *Microbiol J.* 2023;85(2):26-36. <https://doi.org/10.15407/microbiolj85.02.026>
19. Zainuddin ANZ, Mustakim NN, Rosemanzailani FA, Fadilah NIM, Maarof M, Fauzi MB, et al. A Comprehensive Review of Honey-Containing Hydrogel for Wound Healing Applications. *Gels.* 2025;11(3):194. <https://doi.org/10.3390/gels11030194>
20. Peters LJF, Majtan J, Mossialos D, Szweda P, Mateescu C, Ozturk F, et al. Medical-grade honey: its definition and refined standards. *J Wound Care.* 2025;34(6):412-423. <https://doi.org/10.12968/jowc.2024.0206>
21. Tricou LP, Guirguis N, Djebbar S, Freedman BR, Matoori S, et al. Bee Better: The Role of Honey in Modern Wound Care. *Adv Therap.* 2025;8:2400502. <https://doi.org/10.1002/adtp.202400502>

22. Privrodski B, Jovanović M, Delić N, Ratajac R, Privrodski V, Stanojković A, et al. Harnessing Manuka Honey: A Natural Remedy for Accelerated Burn Wound Healing in a Porcine Model. *Pharmaceuticals*. 2025;18(3):296. <https://doi.org/10.3390/ph18030296>
23. Wilczyńska A, Żak N. Polyphenols as the Main Compounds Influencing the Antioxidant Effect of Honey—A Review. *Int J Mol Sci*. 2024;25(19):10606. <https://doi.org/10.3390/ijms251910606>
24. Schils M, Duveau C, Van Doornick G, Cherry I, Tazi H, Misani M, et al. Application of Honey Dressing in the Management of Postoperative Wounds, Ulcers, and Burns: A Systematic Review. *Cureus*. 2026;18(4):e106501. <https://doi.org/10.7759/cureus.106501>
25. Bonsignore G, Patrone M, Martinotti S, Ranzato E. “Green” Biomaterials: The Promising Role of Honey. *J Funct Biomater*. 2021;12(4):72. <https://doi.org/10.3390/jfb12040072>
26. Spoială A, Ilie CI, Ficaï D, Ficaï A, Andronescu E, et al. Synergic Effect of Honey with Other Natural Agents in Developing Efficient Wound Dressings. *Antioxidants*. 2022;12(1):34. <https://doi.org/10.3390/antiox12010034>
27. Hewett SR, Crabtree SD, Dodson EE, Rieth CA, Tarkka RM, Naylor K, et al. Both Manuka and Non-Manuka Honey Types Inhibit Antibiotic Resistant Wound-Infecting Bacteria. *Antibiotics*. 2022;11(8):1132. <https://doi.org/10.3390/antibiotics11081132>
28. Papanikolaou GE, Gousios G, Cremers NAJ, Peters LJF, et al. Treating Infected Non-Healing Venous Leg Ulcers With Medical-Grade Honey: A Prospective Case Series. *Antibiotics*. 2024;13(7):614. <https://doi.org/10.3390/antibiotics13070614>
29. Yasin SNN, Said Z, Halib N, Rahman ZA, Mokhzani NI, et al. Polymer-Based Hydrogel Loaded with Honey in Drug Delivery System for Wound Healing Applications. *Polymers*. 2023;15(14):3085. <https://doi.org/10.3390/polym15143085>
30. Matharu RK, Ahmed J, Seo J, Karu K, Golshan MA, Edirisinghe M, et al. Antibacterial Properties of Honey Nanocomposite Fibrous Meshes. *Polymers*. 2022;14(23):5155. <https://doi.org/10.3390/polym14235155>
31. Yao L, Dai J, Mei S. Honey dressing for diabetic foot ulcers: a systematic review and meta-analysis of randomized controlled trials. *Front Endocrinol*. 2026;17:1759703. <https://doi.org/10.3389/fendo.2026.1759703>
32. Zainuddin ANZ, Mustakim NN, Rosemanzailani FA, Fadilah NIM, Maarof M, Fauzi MB, et al. A Comprehensive Review of Honey-Containing Hydrogel for Wound Healing Applications. *Gels*. 2025;11(3):194. <https://doi.org/10.3390/gels11030194>
33. Ünlü AE, Altunkılıç F, Asgari Y, Demirtaş S, Gökçer Ş, Kıran F, et al. Property-Wound Healing Relationship of Manuka-, Anzer- and Chestnut-Honey: Characterization, Antibacterial Properties and Cell Culture Applications. *Turk J Agric Food Sci Technol*. 2024;12(10):1826-1834. <https://doi.org/10.24925/turjaf.v12i10.1826-1834.6869>
34. Hartono P, Wibowo MD, Susilo DH, et al. Effectiveness of Manuka honey in increasing osteoblasts and chondrocytes and reducing osteoclasts in rabbit mandibular symphysis fractures. *Bali Med J*. 2024;14(1):38-40. <https://doi.org/10.15562/bmj.v14i1.5414>
35. Lotfinia F, Norouzi MR, Ghasemi-Mobarakeh L, Naeimrad M, et al. Anthocyanin/Honey-Incorporated Alginate Hydrogel as a Bio-Based pH-Responsive/Antibacterial/Antioxidant Wound Dressing. *J Funct Biomater*. 2023;14(2):72. <https://doi.org/10.3390/jfb14020072>
36. Taherpour A, et al. Formulation and characterization of organic-inorganic nanocomposite hydrogels for wound healing applications. *BMC Complement Med Ther*. 2025;25:446. <https://doi.org/10.1186/s12906-025-0446>
37. Sukarni S, Kunimitsu M, Kazuhiro O, Liana DF, Mahyarudin M, Aminuddin M, et al. Wound microbiota and its impact on chronic wound healing treated with medical-grade honey. *J Tissue Viability*. 2026;35:100981. <https://doi.org/10.1016/j.jtv.2025.100981>
38. Kgwadi M, Mongalo S, et al. Honey-based treatment strategies for infected wounds and burns: a systematic review of clinical and preclinical research. *Wound Med*. 2026;35:100188. <https://doi.org/10.1016/j.wndm.2026.100188>
39. Fadilah NIM, Phang SJ, Kamaruzaman N, Salleh A, Zawani M, Sanyal A, et al. Antioxidant Biomaterials in Cutaneous Wound Healing and Tissue Regeneration: A Critical Review. *Antioxidants*. 2023;12(4):787. <https://doi.org/10.3390/antiox12040787>
40. Papanikolaou GE, Kegels P, Gousios G, Kegels F, Peters L, Cremers N. Use of Supplemented Medical-Grade Honey to Treat Traumatic Skin Injuries in Geriatric Patients in a Home-Care Setting. *Cureus*. 2025;17(3):e80189. <https://doi.org/10.7759/cureus.80189>
41. Alqutaibi AY, Al-Molla BH, Al-Ghaban N, Taher A, Somsanith N, Jang YS, et al. Honey- and Propolis-Based Agents in Dental Implants: A Systematic Review. *Eur J Dent*. 2026;20(1):123-131. <https://doi.org/10.1055/s-0046-1234567>

42. Rodriguez I, Alvarez A, Massey C, Miller L, Rannou R, Croce M, et al. A Preliminary Direct Comparison of the Inflammatory Reduction and Growth Factor Production Capabilities of Three Commercially Available Wound Products: Collagen Sheet, Manuka Honey Sheet, and a Novel Bioengineered Collagen Derivative + Manuka Honey + Hydroxyapatite Sheet. *Int J Mol Sci.* 2022;23(18):11057. <https://doi.org/10.3390/ijms231811057>
43. Shahabadi N, Saba Zendehehsham S, Khademi F. Honey-Based Sodium Alginate–Polyvinyl Alcohol Hydrogel Containing Green-Synthesized Chitosan–Zinc Oxide Nanoparticles for Wound Healing. *Bioinorg Chem Appl.* 2025;2025:6024411. <https://doi.org/10.1155/2025/6024411>
44. Gallo C, Girón-Hernández J, Gentile P, Cassa MA, Honey DA, Fox EM, et al. Electrospun polycaprolactone membranes loaded with manuka honey for skin tissue regeneration. *Sci Rep.* 2024;14:12345. <https://doi.org/10.1038/s41598-024-71466-4>
45. Ghramh HA, Alrumman SA, Ahmad I, Kalam A, Elbehairi SEI, Alfaify AM, et al. Chemical Characterization of Honey and Its Effect (Alone as well as with Synthesized Silver Nanoparticles) on Microbial Pathogens' and Human Cancer Cell Lines' Growth. *Nutrients.* 2023;15(3):684. <https://doi.org/10.3390/nu15030684>
46. Faramarzi MR, Farid GA, Babamiri B, Lotfy H, Goli R, Faraji N, et al. Management of an infected wound complicated by osteomyelitis secondary to neuropathy caused by previous leprosy; successful treatment with gauze ribbon and complementary therapies. *Clin Infect Pract.* 2025;23:100370. <https://doi.org/10.1016/j.clinpr.2025.100370>