



CHAMOMILE: FUNCTIONAL PROPERTIES AND IMPACTS ON POULTRY/SMALL RUMINANT HEALTH AND PRODUCTION – A REVIEW

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Abstract

Chamomile oil or extract, derived from the chamomile flower, is a natural remedy with various therapeutic properties. This review summarizes the current knowledge regarding the medicinal properties of chamomile oil or extract including its antimicrobial, antidiabetic, antitumor, and anti-inflammatory activities. Chamomile oil has exhibited antibacterial and antifungal properties against various microbes, involving *Escherichia coli*, *Candida albicans*, *Pseudomonas aeruginosa*, and *Staphylococcus aureus*. It has also been found to regulate blood sugar levels in animal and human studies, making it a potential candidate for diabetes treatment. Moreover, chamomile oil has antitumor properties, as it can induce apoptosis in cancer cells and inhibit their growth. In addition, chamomile oil has anti-inflammatory features, making it a possible option for treatment under inflammatory circumstances such as eczema, arthritis, and inflammatory bowel diseases. Chamomile oil has also been found to have valuable impacts on poultry farming due to its antimicrobial properties. It may be utilized as an organic substitute for antibiotics in chicken production. It is effective against common poultry pathogens, including *Salmonella* and *E. coli*, and can also improve poultry growth and feed conversion rate. In conclusion, chamomile oil or extract are promising natural remedy with various therapeutic properties and useful impacts on poultry and small ruminants.

Key words: chamomile oil, therapeutic properties, antibiotics alternative, growth rate

Additives for livestock feed are utilized on a global scale for a variety of purposes. According to El-Adawy et al. (2015), some aid in meeting the requirements for vital nutrients, while others help improve performance and feed intake and maximize feed use. The health of livestock with high growth rates is crucial when choosing feed additives. Consumers are increasingly questioning the usage of feed additives. As a result, the feed sector is very interested in worthwhile alternatives that consumers could accept. Alternatives include botanicals, enzymes, prebiotics, probiotics, and highly accessible minerals (Wenk, 2003). Herbs have also been consumed for ages as food and for therapeutic purposes. Several herbal products in the market might improve the immune system's performance. Many active phytochemicals have been found in various plants, such as flavonoids, lignans, terpenoids, sulphides, carotenoids, plant sterols, coumarins, polyphenolics, phthalides, curcumins, and saponins (Cross et al., 2007).

There is a vast range of activities for herbs, spices, and their oils (botanicals). They can also have anthelmintic, antibiotic, and coccidiostat properties, as well as the ability to promote feed consumption and endogenous secretion. It is common to use herbs to preserve animals and their products against oxidation (Wenk, 2003; Abd El-Hack et al., 2016, 2018, 2019, 2020; Abdel-Moneim et al., 2020). Traditional sources of medicinal herbs have been used to cure various illnesses in people and animals. In monogastric animals, several nutritional herbs and essential oils were also investigated for their antibacterial and growth-supporting properties (Cross et al., 2007; Abou-Kassem et al., 2021; Raza et al., 2021). Researchers using medicinal herbs in broiler diets increased growth performance, feed conversion efficiency, meat quality, and lowered feed costs (Saeed et al., 2017, 2018; Swelum et al., 2021).

Chamomile, one of the *Asteraceae* family members, is either a perennial or annual plant. Ubessi et al.

(2019) state that the plant increases hunger and reduces perspiration and uncomfortable swellings. Native to temperate Europe and Asia, chamomile is grown there and around the world for its great medicinal, cosmetic, and culinary value. It has been used in Egypt, Rome, and Greece for countless years. The specific uses of this plant were initially documented in Uyghur medicine in China. Traditional Chinese medicine practitioners think that chamomile-based medicines have a relaxing effect. The herb is used in conventional, homoeopathic, and Unani medicines (Singh et al., 2011; Dai et al., 2022). *Anthemis nobilis* (L.) and *Matricaria chamomilla* L. (or *Matricaria recutita*) are the primary chamomile species. It is an annual plant, and its blossoming season lasts from May to July in China. A perennial plant belonging to the genus *Chamaemelum* is called *Chamaemelum nobile* (L.). In China, the blossoming season lasts from April through May (Dai et al., 2022). *M. chamomilla* L. is a moderately popular plant that has been extensively studied and utilized. Nowadays, this plant can be found in the pharmacopeia of 26 nations worldwide.

This review article highlights the beneficial impacts of chamomile oil or extracts as a feed additive on poultry and small ruminant production and health.

Chemical structure of chamomile

The flower heads of chamomile are frequently utilized in medicine. Chamomile includes polysaccharides, volatile oils, terpenes, sterols, coumarins, terpenoids, and flavonoids. Chamomile contains a variety of different chemicals, and as a result, it has a broad spectrum of pharmaceutical actions (Figure 1), including anticancer, anti-infective, anti-inflammatory, antioxidant, hypoglycemic, hypotensive, hypolipidemic, antiallergic, antidepressant, and neuroprotective benefits (Singh et al., 2011; Ubessi et al., 2019; Desam and Al-Rajab, 2021; Dai et al., 2022).

Terpenoids were the primary elements in *M. chamomilla* essential oil (Mc EO). The main ones included bis-

abolol and its oxides A and B, chamazulene, bisabolone oxide A, and β -farnesene. Many variables, including the environment and geographical locations (Orav et al., 2010; Piri et al., 2019), plant cultivars (Ghasemi et al., 2017), and genetic factors have an impact on its structure (Mavandi et al., 2019) (Figure 2). Additional elements such as drying methods, extraction methods (Homami et al., 2016), salicylic acid levels (Ghasemi et al., 2017), and the application of cyanobacterial suspension as a bio-fertilizer (Zarezadeh et al., 2020) could also impact the chemistry of EO. However, phenolic substances such as coumarins, flavonoids, and phenolic acids predominated in *M. chamomilla* oil. Moreover, research has also been done on the makeup of amino acids (Qureshi et al., 2013). Treatment with ethephon, cadmium, and copper impacted their chemical makeup, including the amounts of coumarin, phenolic acid, and flavonoids (Petrulova et al., 2020), as well as copper (Kováčik et al., 2009).

Mode of actions

Farmers have furthermore exploited the plant as an additional source of animal feed. Alsaadi et al. (2020) said aqueous floral oil improved biochemical and hematological parameters and boosted rabbit animal development. In a different research, adding *M. chamomilla* to goats' diet increased their consumption of *Juniperus phoenicea* (Caleja et al., 2015). Oils from *M. chamomilla* were also studied as preservatives in cottage cheese, yogurt, and biscuits (Majeed et al., 2015; Caleja et al., 2016, 2017). However, *M. chamomilla* can be used as an agricultural tool due to its antifungal properties. *M. chamomilla* oil may be used in greenhouse settings to manage *Pythium ultimum* fungus in bean plants, according to Ghoniem et al. (2021). Moreover, the potential applications of *M. chamomilla* as a biological surfactant were researched. Shadizadeh and Kharrat (2015) discovered that hydroglycolic oils might be employed as surfactants for a chemically improved oil extraction method since they reduced the oil-water surface tension.

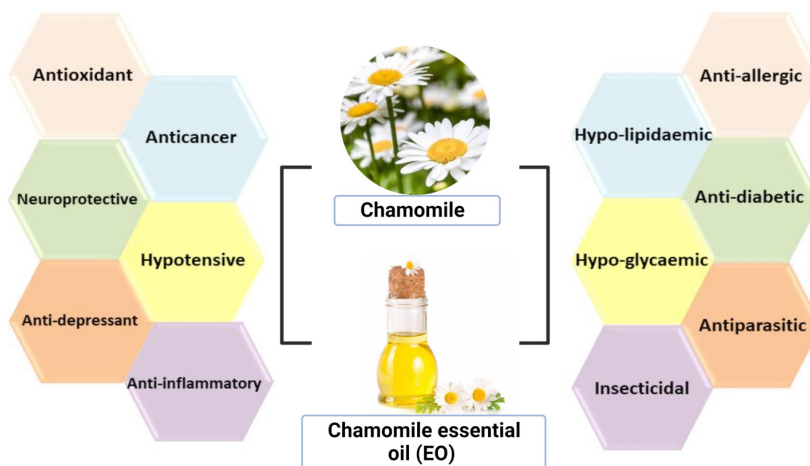


Figure 1. Pharmacological activities of *M. chamomilla* essential oil

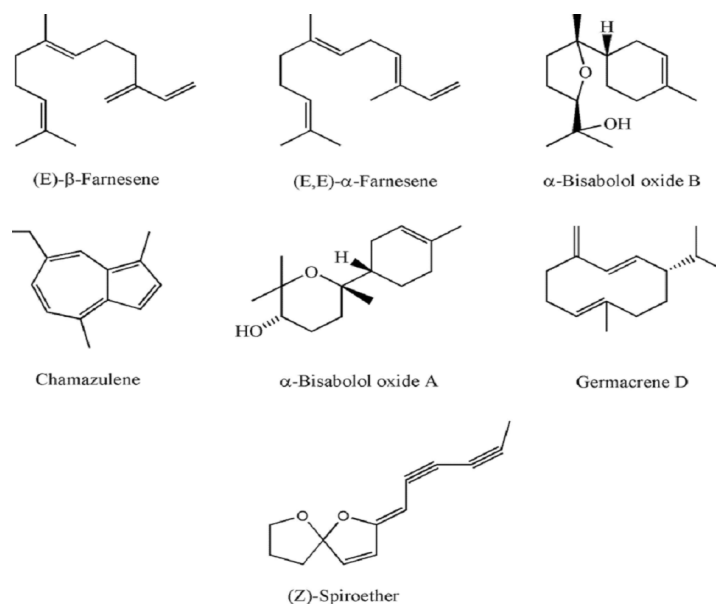


Figure 2. Chemical composition of chamomile oil

In a different investigation, *M. chamomilla* was employed by Ugi et al. (2019) as an environmentally sustainable inhibitor to prevent water corrosion in relatively mild steel. According to pharmacological studies, *M. chamomilla* possesses several biological functions. The antioxidant potential of EO was tested using several techniques. The enzymatic activity of its extraction has also been assessed for peroxidase, glutathione, catalase, superoxide dismutase, ascorbate peroxidase, and acetylcholine esterase. In addition, researchers looked at the antioxidant activity of extraction from waste produced during the processing of chamomile (Molnar et al., 2017), polyphenolic-polysaccharide conjugates (Kolodziejczyk-Czepas et al., 2015), and cell suspension culture (Hassanpour and Ghanbarzadeh, 2021).

Yet, *M. chamomilla* demonstrated antibacterial activities versus Gram-positive/-negative bacteria. Also, research looked at how *Mc* EO affected the development of *P. aeruginosa* biofilms and the synthesis of alginate (Owlia et al., 2007). Furthermore, Poudineh et al. (2021) confirmed that the plant exhibited potency against antibiotic-resistant microorganisms, such as multidrug-resistant *P. aeruginosa*, as highlighted in the studies of Sadat et al. (2020) and Ahani and Danesh (2021). In addition, *M. chamomilla* oils showed anti-adherence efficacy versus some bacterial species (Saiah et al., 2016). Nevertheless, the *Mc* EO and oils showed antifungal efficacy towards various fungi, particularly against *Aspergillus* sp. and *Candida* sp. (Abd Rashed et al., 2021).

The impacts of *M. chamomilla* on oxidative stress, bacteria, and fungi differed generally based on some variables, including the kind of plant utilized, the organ employed, the oiled solvent, and the procedure. Moreover, *M. chamomilla* displayed anti-parasitic, insecticid-

al (Höferl et al., 2020; Al-Mekhlafi et al., 2021), anti-diabetic (Villa-Rodriguez et al., 2018), and anti-cancer properties (Ali, 2013; Nikseresht et al., 2017; Asadi et al., 2020).

Antibacterial activity

Many investigations studied the *Mc* EO and its oils for antibacterial potency. The agar diffusion method, which employs wells or discs, is typically used to evaluate the antimicrobial activities of EOs. Stanojevic et al. (2016) confirmed the antimicrobial property of the *Mc* EO using this method. *Staphylococcus aureus* was the most susceptible bacteria, while *Pseudomonas aeruginosa* was the strain that was the hardest. Using the disc diffusion method, Owlia et al. (2007) observed no action toward *P. aeruginosa*.

Nonetheless, the EO lowered biofilm development and alginate synthesis, demonstrating its effectiveness in managing bacteria that produce biofilms. Nevertheless, findings from the dilution and diffusion procedures revealed that *B. subtilis* was the most vulnerable bacterium to the Moroccan *Mc* EO (El-Assri et al., 2021). Moreover, the EO had the greatest inhibiting zone towards *B. cereus* and the lowest MBC and MIC amounts versus *S. aureus* (Kazemi, 2015). The Gram-positive bacteria likewise displayed the lowest MIC values (Silva et al., 2012). These findings may be explained by modifications to the structure of cell walls since Gram-negative bacteria possess a complex, rigid barrier rich in lipopolysaccharide that prevents the entrance of antimicrobial agents (Chouhan et al., 2017).

Moreover, reports of *Mc* EO's antibacterial efficacy towards various *Streptococcus* species have been made (Owlia et al., 2007). Several Gram-positive bacteria were resistant to the commercial EO's antibacterial proper-

ties. The outcomes demonstrated that the EO revealed more efficiency than reference strains against *S. aureus* MRSA. *P. aeruginosa*, on the other hand, has shown that Gram-negative bacteria are possibly more susceptible to the EO than Gram-positive ones in both diffusion and micro-dilution experiments (Abdoul-Latif et al., 2011; Mahdavi et al., 2020). Moreover, *M. chamomilla* flower EO dramatically decreased *Enterococcus faecalis* growth (Shakya et al., 2019). More intriguingly, Satyal et al. (2015) found that *Mc* EO had the most potent antibacterial effects against *S. aureus* and *P. aeruginosa*. Moreover, Hartmann and Onofre (2010) observed the lowest MIC values towards *E. coli*, whereas *P. aeruginosa* showed no action. The highest results were found whenever the EO was applied 100% pure, resulting in the biggest inhibition zone against *S. aureus*. Besides, other variables, such as plant sources, could affect EO antibacterial effectiveness (Höferl et al., 2020). EO from Hungary (38.3% α -bisabolol) and South Africa (18.7% trans- β -farnesene) showed the greatest activity (MIC = 2000 g/mL) versus most bacterial strains. Roby et al. (2013) revealed that the EO exhibited the strongest antibacterial action towards all selected microorganisms when comparing the antimicrobial activities of the *Mc* EO and other extractions.

When EO levels increased, so did the antibacterial activity. Diethyl ether extraction was the least active of the studied oils, demonstrating how the extracted solvent affects antibacterial activity. Similar findings were made by Ismail et al. (2013), who discovered that ethanol and methanol extraction examined at various dilutions was simply effective against *S. aureus* at higher concentrations. The oil was also ineffective against all isolates at all the tested quantities. According to Abdalla and Ab-

delgadir (2016), petroleum ether extraction had the most incredible activities (diameter of 22:26 mm) against all the bacteria examined, compared to ethanol, methanol, and ethyl acetate extractions.

Nevertheless, Mariod et al. (2019) investigation of aqueous, chloroform, methanol, n-hexane, and ethyl acetate preparations from Egyptian and Sudanese *M. chamomilla* validated the relationship between the extracted solvent and plant origins and antibacterial properties. At doses of 50, 100, and 200 mg/mL, Sudanese methanolic extract had the maximum activity and had the best impact against *S. aureus* (W17). Another study found that ethanol extract had a lower inhibition activity versus *Helicobacter pylori* than ethyl acetate extract did (Malm et al., 2015).

MBC values also changed based on the ethanol used (MBC = 125 g/mL with 99.8% ethanol). Contrarily, cyclohexane extract has no action against any of the studied microorganisms, whereas ethanolic solution was solely effective versus *P. aeruginosa* (Carvalho et al., 2014). Alcoholic extracts of *M. chamomilla* were shown to have antibacterial properties (Cvetanović et al., 2015; Abdi et al., 2019; Khashan et al., 2020). Ethanol extract from flowers demonstrated action against 20 strains of the 24 *S. aureus* MRSA examined, compared to 7 for leaves extract (Sadat et al., 2020). However, the bactericidal activity of methanol extracts was also apparent (Abdoul-Latif et al., 2011; Hameed et al., 2018; Vora et al., 2018; Niknam et al., 2021). For all evaluated strains, the extract also displayed an anti-adherence action (Lavanya et al., 2016). Aqueous extracts also showed antimicrobial properties (Rahman and Chandra, 2015; Omran, 2018), which differed based on the plant tissue employed (Peerzada and Gupta, 2018).

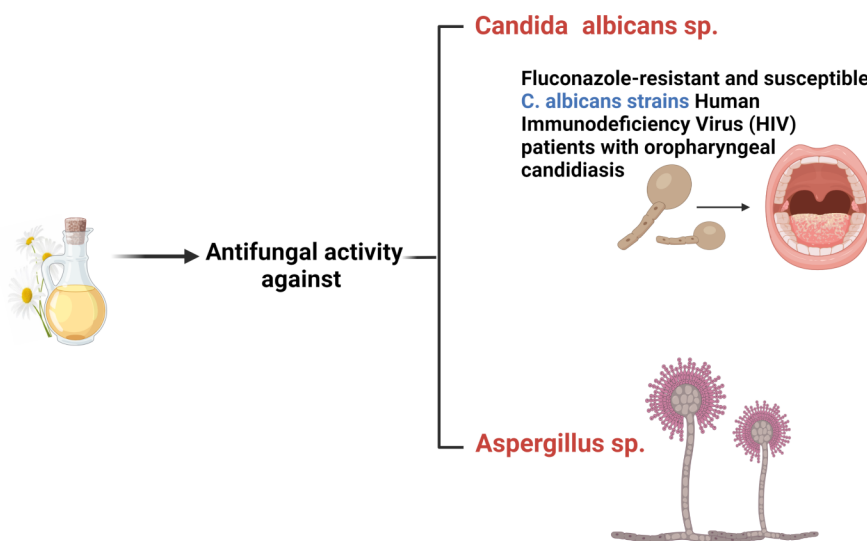


Figure 3. Antifungal activities of *M. chamomilla* essential oil

The antifungal activities

The literature has reported on the fungicidal activity of EOs, and extracts derived from several sections of *M. chamomilla*, indicating excellent effectiveness against a range of fungal strains. Many investigations looked at how *Mc* EO affected *Candida* spp. This illustrates the impact of EO chemical composition and plant origin on antifungal action. Moreover, the *Mc* EO inhibited both fluconazole-susceptible and -resistant *C. albicans* isolates obtained from HIV-positive individuals with oropharyngeal candidiasis, with a more substantial impact on susceptible strains (Sharifzadeh and Shokri, 2016) (Figure 3). In addition, although having a larger phenolic content, their sulfated derivatives showed a near antifungal efficacy. A new peptide (AMP1) with antifungal action against *Candida albicans* and *Aspergillus* species was identified from *M. chamomilla* in a different investigation by Seyedjavadi et al. (2019). As a result, it can be used as a source of intriguing antifungal compounds.

Anti-parasitic and insecticidal activities

The ability of *Mc* EO or extracts to prevent the emergence of various kinds of pests has been the subject of several investigations. The leishmanicidal efficacy of Tunisian *Mc* EO was assessed *in vitro* (Hajaji et al., 2018). The findings demonstrated that EOs had potent activity against promastigotes of *Leishmania amazonensis* and *L. infantum* (IC₅₀ = 10.8 and 10.4 g/mL after 96 h, respectively), while α -bisabolol was capable of activating promastigote impacts of programmed death of cells. Other research by Hajaji et al. (2017 b) looked at the effectiveness of α -bisabolol versus *Acanthamoeba castellanii*. According to the findings, α -bisabolol exhibits amoebic action with IC₅₀ = 20.83 g/mL and IC₉₀ = 46.60 g/mL, and it can enhance plasmatic membrane permeability and reduce ATP levels (Hajaji et al., 2017 b). On *A. castellanii*, the anti-*Acanthamoeba* efficacy of Tunisian *M. chamomilla* flower extract was assessed. *A. coumarin* combination is responsible for the methanolic extract's significant anti-*Acanthamoeba* action (IC₅₀ = 66.23 g/mL). The *Haemonchus contortus*, a gastrointestinal pathogen of small ruminants, was tested on the egg and adult phases by extracts from *M. chamomilla* flowers (Váradyová et al., 2018).

Higher egg-hatching inhibition was seen with methanolic and aqueous extracts (IC₅₀ values of 1.52 and 2.55 mg/mL, respectively). At the maximum concentrations used (8 mg. mL⁻¹), the methanolic extract caused 91.77% death after 8 hours, but the aqueous extraction caused only 75.05% death at similar doses (Hajaji et al., 2017 a). According to other research (Váradyová et al., 2018), methanol extract had the greatest anti-helminthic activity against *Haemonchus contortus*. In another investigation, 90% mortality indicated that *M. chamomilla*'s ethyl acetate extract displayed the best prospective larvicidal action versus *Culex pipiens*. Treatment of eggs at 240 g/mL concentration resulted in 86.49% hatching, but the life cycle was impossible since 100% of the larvae perished (Al-Mekhlafi et al., 2020).

Anti-diabetic activity

Researchers evaluated the anti-amylase and anti-maltase effects of *M. chamomilla* extraction and extracted apigenin, apigenin-7-O-glucosides, trans and cis-2-hydroxy-4-methoxy cinnamic acid glucosides (Villa-Rodriguez et al., 2015, 2018). The outcomes demonstrated a concentration-dependent suppression of both enzyme activities by the extract and chemicals. The greatest levels of apigenin and apigenin-7-O-glucoside-induced maltase and -amylase inhibition, respectively, were achieved.

Moreover, these two flavonoids could regulate sugar absorption and limit sucrose and glucose transfers. Furthermore, the hydro-methanolic extraction of *M. chamomilla* and a few isolated components reduced the action of aldose reductase in rat lenses (Hwang et al., 2018). Also, in high glucose circumstances, 3, 5-O-di-caffeoylquinic acid and luteolin-7-O-D-glucuronide prevented sorbitol buildup in the rat lens, whereas luteolin-7-O-D-glucuronide and luteolin prevented the production of advanced products of glycation. Moreover, the ethanolic extract of *M. chamomilla* displayed anti-glycation characteristics with a lipase inhibitory activity IC₅₀ of 264.2 g/mL (Franco et al., 2018).

Antitumor activity

The antitumor impacts of *M. chamomilla* extract and EO have also been examined in several cancer cell lines. Ali (2013) examined *Mc* EO's anticancer efficacy on the MCF-7 human breast cancer cell line. The findings demonstrated that EOs suppressed cell growth in a dose-based approach, with the maximum dosage 640 g/mL, showing an 89% inhibition after 24 hours of treatment. However, the anticancer properties of EO were evaluated, as opposed to two types of human promyelocytic leukemia (HL-60 and NB4) cell lines (Romeilah, 2009). The EOs inhibited both cell lines' proliferation. However, NB4 cells were more severely damaged (86.03% at 200 g/mL) than HL-60 cells (78.4% at 200 g/mL). Hydroalcoholic preparations from the aerial portions or roots of *M. chamomilla* also had an anti-proliferative impact on human cancer of breast cells (Kamali et al., 2014; Nikseresht et al., 2017). For aerial component extracts, the IC₅₀ was 785 g. mL⁻¹ against MDA-MB-468, 921 g. mL⁻¹ toward MCF-7, and 1560 g. mL⁻¹ toward MCF-7 was used for the root extraction. Fraihat et al. (2018) examined the effects of *M. chamomilla*'s methanolic extract on the solid human melanocyte tumor cell lines WM1361A and A375.S2. Results from this investigation indicated that the melanotic WM1361A cell line was solely inhibited in its ability to proliferate (IC₅₀ = 25.2 g/mL).

The anticancer action of *M. chamomilla* extracts, however, was found to be altered by the extraction technique, according to Cvetanović et al. (2015). Subcritical water extracts showed the strongest cytotoxic impacts on the murine fibroblast cell line, the human cervical cancer cell line Hep2c, and the human rhabdomyosarcoma cell lines (IC₅₀ = 30.54 g/mL). The *Ascites carcinoma* cells from Ehrlich were used to test the antitumor ability of

liquid extracts made from seeds of *M. chamomilla* produced at various pH settings and their associated sulfated byproducts (Wu et al., 2012). The *A. carcinoma* cell line's proliferation was somewhat decreased by all extracts at three distinct doses (300, 600, and 900 g. mL⁻¹). The anti-cancer activities of *M. chamomilla* seem to be connected to necrosis and apoptosis, in addition to a reduction in the capability of neoplastic cells to migrate and invade (Wu et al., 2012; Nikseresht et al., 2017) (Figure 4).

Anti-inflammatory activity

Animal models were used to study *M. chamomilla*'s anti-inflammatory properties. According to Wu et al. (2012), the EO, floral water, and water extraction of *M. chamomilla* may all greatly reduce the growth in mouse ears brought on by xylene, the swelling of rats' feet brought on by carrageenan and the rise of mice's celiac capillary artery permeability. Also, they significantly inhibited the rise in prostaglandin E2 and nitric oxide concentrations in carrageenan-induced rat pedal edema (Ortiz et al., 2017). Also, Nargesi et al. (2018) looked at how the hydroalcoholic extract from *M. chamomilla* affected the quantities of blood indicators for inflammation in rats. Tumor necrosis factor (TNF), interleukin 6 (IL-6), C-reactive protein (CRP), and fibrinogen blood levels did not significantly rise upon using hydroalcoholic extract at a dose of 110 mg/kg. In contrast, diclofenac or indomethacin, two non-steroidal anti-inflammatory drugs, and ethanolic extract, combined to exhibit intriguing synergistic anti-inflammatory properties on the effects of carrageenan on rat gastrointestinal damage and paws inflammation (Ortiz et al., 2017).

Effect of dietary chamomile oil

The ABTS assay was performed to study the antioxidant capacity of EOs produced using various extraction

methods (Melo-Guerrero et al., 2020). The extraction method impacted the results, with steam stripping having the highest antioxidant performance in the ABTS assay. This fact could be described by how different extraction techniques result in different chemical compositions for EOs. Using DPPH and FRAP tests, EOs and methanol extracts demonstrated intriguing antioxidant activity in another investigation on 13 grown *M. chamomilla* (Formisano et al., 2015). According to the surrounding conditions and chemical makeup, this activity changed. Indeed, EOs rich in oxygenated components and extracts with high phenolic contents demonstrated the greatest efficacy. The scientists found that extracts had increased DPPH activity compared to EOs, whereas FRAP test results showed equivalent activity for both. Also, the ability of two extracts to function as antioxidants (ethyl acetate extract and aqueous extract) from several plant components (root, stem, leaf, and flower) was investigated using the ABTS test (El Mihyaoui et al., 2021).

The findings revealed that hydrophilic antioxidant activity (HAA) greatly outperformed lipophilic antioxidant activity (LAA). The DPPH test discovered that methanol extracts had more activity than EO, whereas the β -carotene-linoleic acid assay revealed that EO had significantly increased antioxidant action (Abdoul-Latif et al., 2011). Further experiments demonstrated the methanolic extract's antioxidant efficacy (El-Agbar et al., 2018; Niknam et al., 2021). Moreover, the activity differed based on the plant organ or tissue employed, with isolated sections occasionally demonstrating stronger activity than entire herbs (Munir et al., 2014). Munir et al. (2014) stated that methanolic extracts have stronger antioxidant properties than ethanol extracts. According to Roby et al. (2013), methanol has the highest DPPH scavenging ability, followed by ethanol, diethyl ether, and hexane.

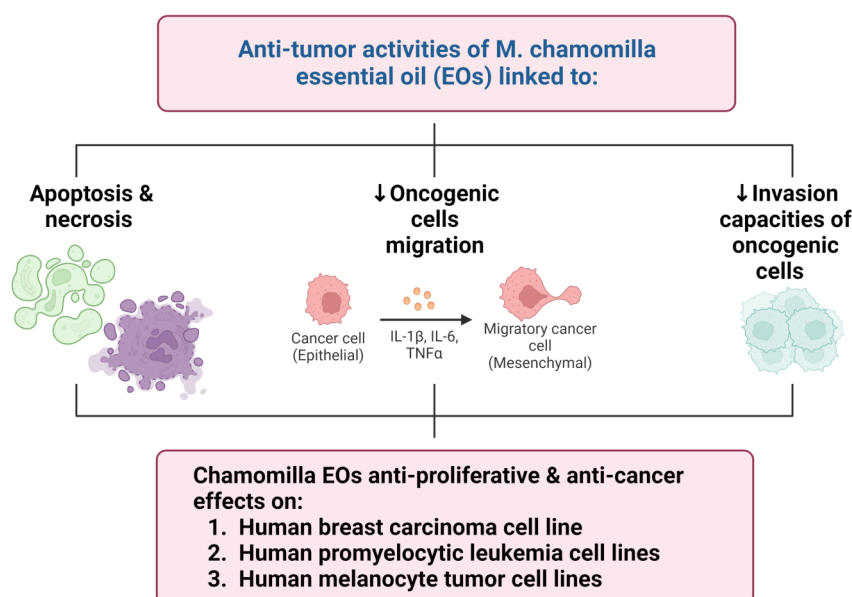


Figure 4. Antitumor activities of *M. chamomilla* essential oil

An ethanolic extract of *M. chamomilla* was demonstrated to neutralize DPPH radicals (Alibabaei et al., 2014; Afrigan et al., 2019). Compared to other extracts, a hydroethanolic extract from a processing waste fraction obtained using the maceration technique was shown to have the best antioxidant activity (Molnar et al., 2017). The highest DPPH scavenging capacity and ability to convert Fe^{3+} to Fe^{2+} were discovered whenever the antioxidant activity of extracts produced was examined using various extraction methods (microwave-assisted, Soxhlet, and ultrasound-assisted extraction) (Cvetanović et al., 2015). The antioxidant strength of the aquatic extract of *M. chamomilla* was also impacted by the temperature used while extracting subcritical water (Cvetanović et al., 2019). According to this study, producing extracts with antioxidant properties from processed garbage may be possible.

Whereas the maximum ABTS, hydroxyl radical scavenging and lipid peroxidation inhibitory effects were achieved by extraction at 150°C, extraction at 210°C produced extracts with the largest DPPH activity. Likewise, Sotiropoulou et al. (2020) examined the impact of extraction temperature (25, 80, and 100°C) on the DPPH capacity of aqueous extracts. The results revealed that the extract made at 80°C had the maximum activity, whereas the extract prepared at 25°C exhibited no activity. The largest phenol concentration was found at 80°C compared to other temperatures, which helps explain these results. True, extraction of more polyphenols may be facilitated by higher temperatures, but high temperatures (over 100°C) may result in the loss of unstable polyphenols. Also, the impact of various extraction factors on hydroalcoholic extract's antioxidant effect generated by dynamic maceration procedures was examined using a multivariate method. According to the findings, the variables that most impacted the extracts were the extracting temperature, plant-to-solvent ratio, and ethanol strength. The authors discovered that the extract showed excellent antioxidant activity and was abundant in apigenin, flavonoids, and apigenin-7-glycoside under ideal conditions (Pereira et al., 2018).

Hesperidinase and β -galactosidase enzyme treatment of *M. chamomilla* aqueous infusion resulted in a small rise in the amount of DPPH radical-scavenging action, though the treatment changed several phenolics (Franco et al., 2020). Also, *M. chamomilla* tea extract had excellent antioxidative capacity in lipid peroxidation studies using the liver tissue of chickens (Singh et al., 2018). Moreover, therapy with electron beam irradiation impacted the suppression of lipid peroxidation (Nemtanu et al., 2008). This method of plant microbial decontamination led to a dose-dependent decline in antioxidant properties.

The reduction in plant chemical components, such as flavonoids, tannins, and polyphenol carboxylic acids, was used to explain this outcome. Nevertheless, subjecting a suspension of *M. chamomilla* cells to a static magnetic field improved the cells' antioxidant capacity and

flavonoid metabolism (Hassanpour and Niknam, 2020). Moreover, cells cultured under clino-rotational conditions generated the activity of antioxidant enzymes that promoted cell growth and division (Hassanpour and Ghanbarzadeh, 2021). As a result, cell culture factors similarly influence antioxidant activity. The EOs and extracts of *M. chamomilla* have antioxidant action, allowing for the prevention or treatment of illnesses. Hydro-alcoholic extracts in male Wistar rats stopped the effects of a high-cholesterol diet on the development of superoxide dismutase globules and plasma malondialdehyde (Nargesi et al., 2018). In addition, administering 10 and 20% *M. chamomilla* powder to diabetic rats significantly reduced lipid peroxidation and raised serum levels of catalase, acetylcholine esterase, and glutathione (Hassanpour and Ghanbarzadeh, 2021).

Abaza et al. (2014) demonstrated that raising the chamomile flower (ChF) content in the swallowed meals significantly decreased the aerobic plate count and total coliform count. The same findings were seen when counting enteropathogenic organisms as intestinal portions became free from the third group at the highest ChF dose group, indicating that ChF had a significant and competing beneficial impact on enteropathogenic microorganisms. Counting and detecting *Salmonella* organisms cultured on dazzling green gave the results. Broth and culturing on *Salmonella Shigella* agar yielded negative findings, as all groups tested negative for *Salmonella*, including the control.

Growth performance

The greatest values of live body weight (LBW) were achieved by rabbits fed 0.5 ml g/kg of chamomile oil in contrast with other treatments, including the control, according to Nasr et al. (2022) who found that chamomile oil enhanced LBW at 9 and 13 weeks. During the rabbits' fattening stage, chamomile oil increased LBW at 9 and 13 weeks old. However, the maximum rates of LBW occurred at a concentration of 0.5 ml g/kg chamomile oil compared to other treatments and the control group. Adding 1.0% fennel or 0.75% chamomile to feed greatly enhanced growing rabbits' body weight gain and feed intake. Rabbits were given BD + 0.5 ml g/kg. Compared to the other groups, chamomile oil consumed the most feed during the entire duration (Skomorucha and Sosnówka-Czajka, 2013). Likewise, Simonová et al. (2007) discovered that chamomile oil is a viable substitute for stopping and managing bacterial and parasite illnesses and enhancing rabbits' overall health.

Research by Al-Mashhadani et al. (2013) has shown that the consumption of chamomile oil significantly affects the body weight of chickens. Compared to the control group, which had a 12.17% difference in final body weight, the birds consuming 400 mg of chamomile oil per kg showed the greatest gain. This was significantly higher than the other groups. The weekly feed consumption did not differ significantly between the control and the other groups. Furthermore, the feed conversion ratio

was substantially enhanced when ingesting 400 mg of chamomile oil per kg of food. These results show that chamomile oil is a beneficial supplement to feed, as it increases the body weight of chickens and improves feed conversion. The bioactive components that impact the gastrointestinal ecosphere primarily through growth inhibition of harmful microbes in the digestive tract steadily improved digestive enzymes, improved utilization of the digestive process of intestinal products, and improved liver enzymes and may be responsible for the beneficial development in average live body weight, weight gain, and ratio of feed conversions in the groups treated (Figure 5) (Cabuk et al., 2003; Hernandez et al., 2004; Patel et al., 2007; Windisch et al., 2008).

The chamomile oil in the meals was significantly reduced when it was added at 400 mg per kg. El-Adawy et al. (2015) showed that adding 1.0% basil, chamomile, fennel, or ginger to the food of developing rabbits significantly affected final body weight, daily and total weight increase, daily feed intake, and performance measures. Supplementation with basil, chamomile, or fennel improved performance, while ginger decreased final body weight by 17.34%. Fennel had the greatest effect, with a final body weight of 2125 g, total weight improvement of 1278 g, and daily weight increase of 26.07 g.

According to Prakash and Srinivasan (2011), the ethanolic extraction of ginger exhibited notable protection from the metabolic abnormalities caused by a high-fat diet by significantly lowering body weight gain and inhibiting hyperglycemia, hyperlipidemia and insulin resistance. Daily feed consumption increased considerably in

groups supplemented with diet P2 and P3 (supplied with chamomile or fennel) compared to those fed the control diet by 4.91% and 11.10%, respectively, and the daily weight gain was significantly developed in groups fed diet P2 by 9.36 and 17.91%. The daily feed intake was substantially higher in groups fed diet P3 by 9.36 and 17.91% (C). Moreover, the dietary supplements containing 1.0% fennel or 0.75% chamomile significantly increased the body weight improvement and food intake of developing rabbits. With the additive of fennel and chamomile to rabbit meals, feed conversion and performance index were considerably enhanced up to 13 weeks of age (Skomorucha and Sosnówka-Czajka, 2013). Ginger waste meal led to an increase in average daily feed intake for developing rabbits. Feed conversions and performance index increased in groups P2 and P3, but the highest feed conversion (4.74) and lowest performance index (33.74) were seen in the group fed 1% ginger (P4). Live body weight was less; however, feed intake was greater in this group, which may have caused the elevated food conversion rate and worse performance profile (Omaga et al., 2007).

Adding ginger to the diet significantly reduced the crude protein and fat digestion and the live body weight of the growing rabbits, likely due to the adverse effects of its polyphenolic compounds (Ali et al., 2008; Kota et al., 2008). Moreover, Ademola et al. (2009) noted that broiler hens' blood cholesterol, total lipids, and total protein levels drastically dropped when ginger was added, which may harm body weight increase. The basil supplementation (P1) had no noticeable impact on daily weight increase, daily feed intake, feed efficiency, or performance index (C).

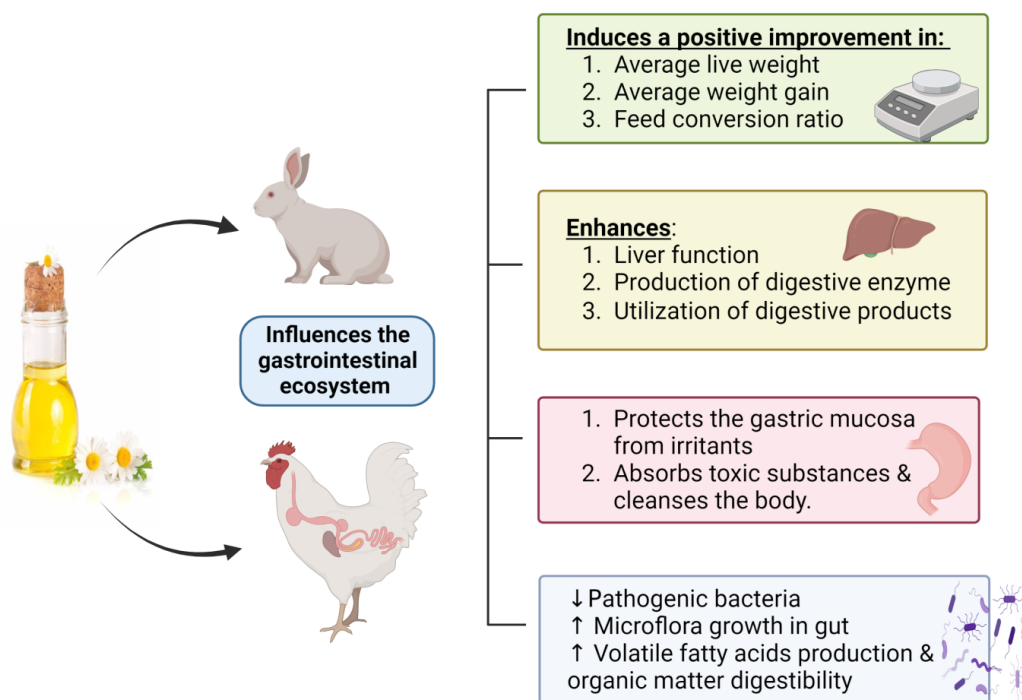


Figure 5. Effect of chamomile oil on growth performance

These findings contrast with those of El-kutry et al. (2009) and Abbas (2010), who noted a substantial increase in feed consumption, feed efficacy, and live body weight following adding 3 g of basil per kg of food in broiler diets. Adding medicinal and aromatic herbs to developing rabbit diets impacted the survivability percent of rabbits up to 13 weeks of age. The survivability of the rabbits given the control or P3 (fennel) diets was 100%, whereas that of the rabbits fed diets P2 (chamomile), P1 (basil), and P4 (ginger) was 87.5, 75, and 62.5%, respectively. The reduction in abdominal fat in these rabbits, which resulted in a substantial drop in daily body weight growth and ultimate live body weight, may be the cause of the increased death rates in the group fed diet having 1% ginger (P4).

According to Imbabi et al. (2021), fennel and caraway seeds may play a crucial part in lowering mortality rates by altering the pH of the rabbit digestive system to promote beneficial bacteria and prevent harmful ones. A small number of fennel seeds, 0.5%, resulted in a substantial reduction in the death rate of young rabbits (Romero et al., 2012). According to research by Mousa et al. (2021), adding chamomile and rosemary (CR) aqueous extract (5 ml/L) to developing rabbits' water consumption boosted average body weight increase and daily gain in comparison to the C1, R1 and R2 groups. Nevertheless, no discernible variations existed between the CR, C2, and control groups. Nevertheless, compared to the control and other treatment groups, the final body weight and weight increase of the rabbits that drank water containing 5 ml (R1) and 10 ml/L (R2) of rosemary extract remained lower. The drop in final BW and BWG brought on by adding rosemary extracts to the water supply may be responsible for these results.

Harach et al. (2009) documented that the inhibitory impact of rosemary extract (RE) on pancreatic lipase activity caused mice to gain less body weight than the control group. Decreasing weight gain with RE was more successful than with pure carnosic acid (92% vs. 7%) (Ninomiya et al., 2004). When compared to rabbits' water supply containing rosemary, El-Wardany et al. (2015) and Helal et al. (2017) showed an enhanced feed conversion ratio (FCR) of the rabbits' intake of water containing the CR mixture. The improvement in FCR was ascribed by Abaza et al. (2014) to an enhancement in the synthesis of volatile oils and the digestibility of organic matter.

Rosemary and garlic/rosemary EOs did not affect rabbit growth rates, according to Erdelyi et al. (2008), although they did produce digestive problems and decreased FCR. Compared to the rosemary treatment and the control one, the mortality rate for the C1 and C2 groups who received chamomile in their drinking water or the CR group that also received rosemary was reduced to 0%. With 5 ml and 10 ml/L rosemary extracts, the death rate jumped by 8.3 and 16.7%, respectively, whereas the control group's mortality ratio remained at 25%. Therefore, chamomile has been shown to benefit lowering mortality rates (Badaoui et al., 2016; Mousa et al., 2021).

The impact of chamomile on rabbit growth performance parameters was investigated by Abaza et al. (2014). In line with earlier research by Abaza et al. (2003), they discovered that rabbits fed the least chamomile (0.125%) experienced the greatest final body weight and daily body gain. These findings align with those of Abaza et al. (2003), who found that adding 0.25% chamomile to meals may help with FCR and growth.

Carcass traits

El-Adawy et al. (2015) revealed that the usage of nutritional supplements containing medicinal and aromatic herbs had a substantial impact on the majority of carcass features and the percentage of internal organs for pre-slaughter weight. Hot carcass weight rose considerably in animals fed P3 (1.0% fennel) and P2 (1.0% chamomile) diets compared to the control group by 15.77 and 9.93%, respectively (C). On the other hand, the P3 diet group, which contained 1.0% fennel, had the greatest dressing % (61.36%), while the P4 diet group, which included 1.0% ginger, had the lowest (56.24%).

Omar et al. (2020) found that adding oregano or sweet basil to dressing at a 0.5% concentration significantly boosted giblets and dressing. In general, nutritional supplements containing 1.0% basil, chamomile, or fennel had no discernible effect on the weight of the alimentary tract (full and empty), while 1% ginger considerably increased weight. These findings concur with Radwan and Khalill's (2002) findings, who discovered that the carcass data varied depending on the treatment when fed diets, including medicinal and fragrant herbs. According to research by Ibrahim et al. (2014), adding *M. chamomilla* L. to feed at concentrations of 0.25, 0.50, and 0.75% increased carcass weight (2.4–5.6%) and gizzard weight (14–32%) compared to the control group. Giblet weight was also raised by 5.8% at 0.75%. However, there was a loss in weight for the liver and heart (4.5–11.4% and 9.6–19.9%, respectively). Muscle atrophy and intramuscular lipid accumulation were the main morphological changes (Wang et al., 2013).

Blood parameters and histological observations

According to Abaza et al. (2014), increasing the quantity of ChF in the experimental rabbits' diets resulted in a considerable rise in total protein, albumin, globulin, triglycerides, and urea. The increase in protein biophysics may cause the rising total plasma protein and globulin levels. These outcomes are consistent with what was reported by Radwan and Khalill (2002). The highest concentrations of ChF (0.5 and 1.0%) markedly reduced total cholesterol while raising total plasma triglycerides and urea content. According to the results, the least significant level of plasma ALT activity was at 0.25% ChF. Additionally, those who consumed 1.0% ChF in their diets had the lowest significant level of plasma AST activity.

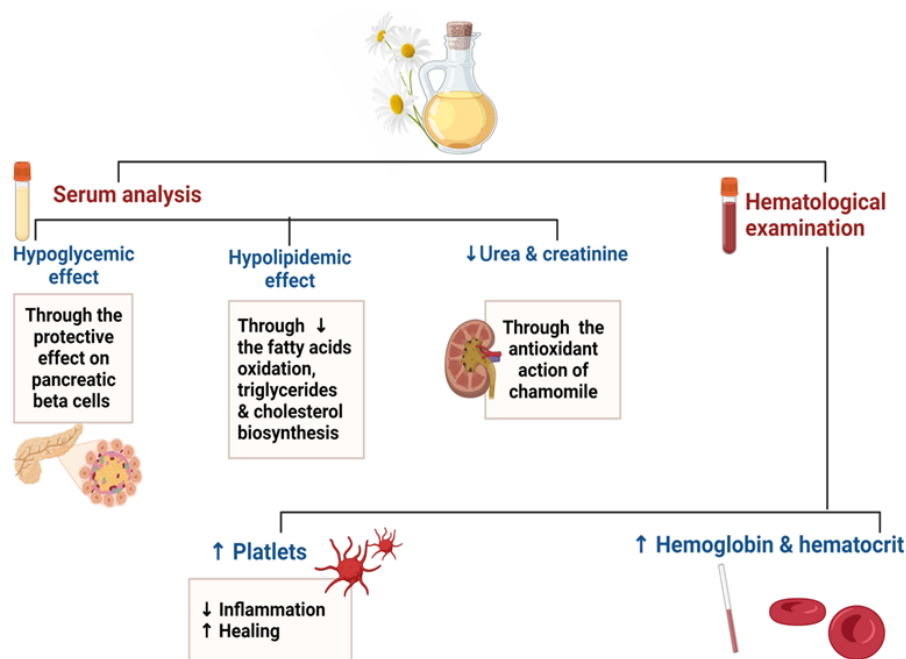


Figure 6. Effect of chamomile oil on blood parameters

According to research by El-Adawy et al. (2015), adding medicinal and aromatic herbs to diet substantially impacted plasma albumen, globulin, GOT, GPT, cholesterol, and total lipid concentrations. The diet augmented with 1.0% ginger had the greatest plasma globulin, while the diet supplemented with 1.0% fennel had the least GOT and greatest GPT. Rabbits fed meals, including fennel and ginger, reduced plasma total lipids and cholesterol considerably. Plasma creatinine total protein and urea between the control and other test groups did not differ significantly from one another. The inclusion of medicinal and aromatic herbs in animal diets was also found to have a substantial impact on blood parameters (EL-Nattat and EL-Kady, 2007; Ali et al., 2008).

According to Mousa et al. (2021), the total protein and albumin values obtained in the serum samples of rabbits given chamomile (C1–C2) and rosemary (R1) extractions or a combination of the two (CR) were lower than those in the control group.

Nevertheless, compared with other treatments, rabbits given 10 ml/L of rosemary extract (R2) exhibited greater albumin and total protein. There were no globulin changes found. All groups' total protein, albumin, and globulin levels were within the accepted range (Osman et al., 2021). Also, all treatment groups' blood glucose levels were considerably lower than those of the control group, with the C2 group having the lowest levels, followed by C1 and R1. Compared to other treatments, rabbits given 10 ml/L rosemary extract (R2) or a mixture of rosemary and chamomile (CR) had greater glucose concentrations. The pharmacological effect of chamomile on insulin secretion could cause reductions in blood serum

glucose concentration with chamomile extraction supplementation (Eddouks et al., 2005).

Similarly, Cemek et al. (2008) reported that chamomile extract processing had an antihyperglycemic effect. This action regulates blood glucose levels by protecting pancreatic beta cells, reducing oxidative stress caused by hyperglycemia (Figure 6). Also, rosemary contains anti-diabetic characteristics that help diabetic rats' oxidative metabolism and glucose consumption (Al-Jamal and Algadi, 2011). The blood glucose levels in rabbits given chamomile and rosemary were considerably lower than the control. Each treatment group had substantially lower blood total cholesterol and triglycerides than the control group. In comparison to rabbits given chamomile extract (5 ml/L), the total cholesterol content was higher in the serum of the rosemary extract (10 ml/L)-treated rabbits (C1) (Hamden et al., 2008; Bakr et al., 2017).

Moreover, R1 had greater triglyceride content than CR. Nevertheless, no changes between other treatment groups were statistically significant. The hypolipidemic impact of chamomile flowers extracts, which has a high concentration of flavonoids (63.3%), most of which are apigenin, and total phenolic compounds (23.2%), bioactive chemicals reported working as an oxidative agent scavenger, may be responsible for the alteration in lipid profiles in the groups who had chamomile (Avallone et al., 2000; Gupta and Misra, 2006). Likely, Rafrat et al. (2014) suggested using chamomile as a natural substance for decreasing blood cholesterol through two mechanisms due to the existence of flavonoids that enhanced indirect phosphorylation of the enzyme hydroxy-methylglutaryl-CoA (HMG CoA) reductase and reduced endogenous cholesterol synthesis. Moreover, Iweala and

Oludare (2011) validated that rosemary has a hypolipidemic impact because of the antioxidant action of its contents, which altered the rate of oxidized fatty acids in the liver and decreased the rate of triglycerides production in rats. Similar effects of rosemary and chamomile supplementation on lowering cholesterol and triglyceride levels have been described by Gupta and Misra (2006) and Nargesi et al. (2018). According to research by Mousa et al. (2021), adding chamomile to rabbits' water at 5 and 10 mg/L reduced their blood urea and creatinine quantities compared to the control group. Nevertheless, neither across treatments nor between other treatment groups nor the control group were there any discernible changes. According to Melillo (2007), the rabbits had urea and creatinine concentrations in the usual ranges (20–45 and 0.5–2.5 mg/dl, respectively).

Patients may benefit from using chamomile as a viable therapy method to lower their blood urea and creatinine levels (Kaseb et al., 2016). According to reports, it has an antioxidant effect that lowers these chemicals' blood levels in animals (Sampaio et al., 2016). Moreover, chamomile may have a negligible impact on rats' blood urea and creatinine levels (Shati and El-Kott, 2014). Moore et al. (2015) found that adding chamomile extract (10 ml/L) to the drinking water of rabbits decreased their RBC count, yet there were no physiological changes in RBC count across the control and treatment groups. Rosemary (R2) and a combination of rosemary and chamomile (CR) extract increased HGB and HCT concentrations, whereas chamomile (C2) alone increased platelet count. However, MCV was decreased with the higher dosage of the chamomile supplement. All changes were within normal physiological limits and did not impact rabbit viability or mortality.

Interestingly, the aqueous extracts of chamomile and rosemary have been reported to enhance platelet number,

most likely because of their active chemical contents (terpenoids, spiroethers, flavonoids, and coumarins), which decrease inflammation and facilitate wound healing (Sharifi-Rad et al., 2018; Daneshfard et al., 2020). This increased platelet count enables the healing of wounds and stops bleeding (Nurden et al., 2008). Ahmed and Razak (2022) divided New Zealand White rabbits into four groups. They administered 200 mg of chamomile flower oil, 400 mg of chamomile flower oil, 250 mg of vitamin E, and 0.3 mg of selenium per kg daily. The statistical analysis of the blood parameters revealed that the 400 mg chamomile flower oil dosed group had a substantially greater total red corpuscular count than the other groups in the second month. The total white corpuscular count, packed cell volume, and hemoglobin content were significantly superior in the first and second months. In contrast, the total platelet counts were superior in the first month.

Antioxidative status

Matricaria chamomilla essential oils (EOs) were put through various assays to determine their antioxidant activity, including DPPH, ABTS, FRAP, the capacity to bleach beta-carotene, the ability to chelate ferrous ions, and the ability to prevent lipid peroxidation. The enzymatic activity of the EOs, such as those of acetylcholine esterase, glutathione, and peroxidase, catalase, superoxide dismutase, and ascorbate peroxidase, has also been examined. After 90 minutes of treatment, the greatest scavenging activity was measured using the DPPH assay (Stanojevic et al., 2016). The findings revealed that *Mc* EO exhibited a similar ferrous ion chelating ability to the citric acid baseline but reduced efficiency of the DPPH and α -carotene bleaching assays compared to the benchmarks BHT and β -tocopherol (Mahdavi et al., 2020).

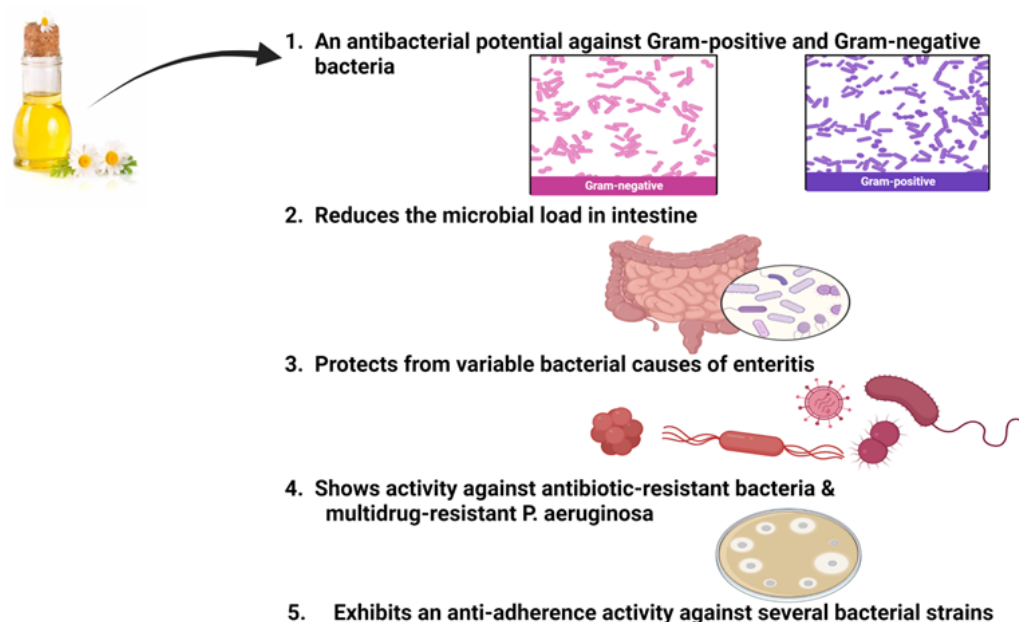


Figure 7. Effect of chamomile oil on gut microbiota

Gut microbiota

Klebsiella pneumoniae biofilms, an *Enterobacteriaceae* member, is widely known for being resistant to various antimicrobials due to its slimy capsule and thicker wall (de Oliveira and Franco, 2020). Tolouee et al. (2010) discovered that flavonoids, coumarins, and α -bisabolol, a key component of chamomile, had antibacterial and anti-inflammatory properties. Additionally, McKay and Blumberg (2006) demonstrated *in vitro* that ChF possesses considerable antioxidant and antibacterial action and strong antiplatelet activity. German ChF oils were marginally more efficient than oil from Roman ChF against 25 distinct Gram-positive and Gram-negative bacteria, together with twenty different strains of *Listeria monocytogenes* (Abaza et al., 2014). Thus, we could infer that the ChF significantly impacted microbial load decrease in the gut (Figure 7). ChF has been shown to have a powerful influence on *Enterobacteriaceae* colonization in the small intestine and can eliminate various enteritis-causing bacteria. The Mc EO has been shown to have antimicrobial activities against Gram-positive and Gram-negative bacteria, inhibiting *P. aeruginosa* biofilm formation and alginate creation (Owlia et al., 2007), as well as action against antibiotic-resistant microorganisms, such as *S. aureus* MRSA (Ahani and Danesh, 2021; Sadat et al., 2021) and multidrug-resistant *P. aeruginosa* (Poudineh et al., 2021). Also, *M. chamomilla* extract inhibited the adhesion of various bacterial strains (Lavanya et al., 2016). However, the Mc EO and extracts showed fungicidal efficacy against various 41 fungal species, particularly *Aspergillus* spp. and *Candida* spp., and *M. chamomilla*'s impact on oxidative stress, bacterial, and fungal pathogens differed based on plant origin, organ employed, extraction solvent, and procedure. *M. chamomilla* also has antiparasitic, insecticidal (Höferl et al., 2020; Al-Mekhlafi et al., 2021), anti-diabetic (Villa-Rodriguez et al., 2018), anticancer (Ali, 2013; Nikseresht et al., 2017) and anti-inflammatory properties (Asadi et al., 2020).

Meat quality

Voroshilin et al. (2019) revealed that rabbit meat has significant water-holding characteristics, with a water content ranging from 76 to 77%. Furthermore, the protein concentration was determined to be 20–22 wt% and the fat content to be 5–7%, which makes it an excellent option for nutritional items. Ibrahim et al. (2014) discovered that supplementing chamomile (*M. chamomilla* L.) as a feed supplement at 0.25, 0.50, and 0.75% decreased carcass lower abdomen fat, subcutaneous chest fat, neck fat, and leg fat when compared with the control group. These findings might be due to the capacity of chamomile's active components to reduce fat buildup. Fat deposition in the carcass may be related to a decrease in hepatic lipogenic enzymatic activity, which causes certain morphological abnormalities with the formation of vesicles electrodense lipid inclusions (Wu et al., 2011; Piri et

al., 2019). In other words, chamomile promotes energy expenditure while preventing the formation of absorbed fat. Similar findings revealed that several spices aid in energy expenditure to avoid the buildup of absorbed fat (Prakash and Srinivasan, 2011). In rats, chamomile extracts exhibited a strong antioxidant effect (Sebai et al., 2014).

Conclusions

In conclusion, chamomile oil is a natural remedy with various medicinal properties, including antimicrobial, antidiabetic, antitumor, and anti-inflammatory activities. Its potential use in poultry farming as a natural alternative to antibiotics is promising. Chamomile oil is effective against common poultry pathogens and improves growth rates. However, further research is needed to fully understand its safety and efficacy in humans and animals. Based on current research, chamomile oil could be a potential therapeutic option for specific health conditions and an alternative to antibiotics in poultry farming. Overall, the potential of chamomile oil as a natural and sustainable solution for health and agriculture is worth exploring further. Further research is needed to explore its potential therapeutic applications in humans and animals.

Conflicts of interest

All authors declare that they have no conflicts of interest that could inappropriately influence this manuscript.

Author contribution

All authors contributed equally to writing this review article. All authors read and approved the final version of this manuscript.

Data availability statement

No data are available.

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