

# Application of *Cymbopogon citratus* in Agro-Food Industry

Milica Aćimović<sup>1,\*</sup>, Biljana Kiprovska<sup>1</sup> and Sonja Gvozdenac<sup>1</sup>

<sup>1</sup> Institute of Field and Vegetable Crops, Maksima Gorkog 30, 21000 Novi Sad, Serbia

\* Correspondence: E-mail address: milica.acimovic@ifvcns.ns.ac.rs

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**Abstract:** Plants, particularly medicinal and aromatic species, and plant-derived compounds have been used for centuries in human and veterinary medicine, but nowadays they have increasingly important role in agro-food industry. They present a rich source of bioactive compounds with a wide range of applications that answer to/coup with certain emerging challenges. The most important are growing demands for food safety and concern about human health and environmental pollution that altogether impose the need for more intensive use of plants and their compounds in food industry and agricultural production. This is a reason why, in recent decades, more intensive research has been carried out related to new, bio-rational and specific trends in agro-food industry. *Cymbopogon citratus* Stapf., lemongrass, is one of medicinal plant species with large application potential in different areas. This review provides an insight into current research and potential applications of *C. citratus* in food and feed technology, plant protection (as repellent, biofungicide, bioinsecticide, bioherbicide, etc.) and in veterinary medicine purposes. The most comprehensive research on biological activity of lemongrass has been carried out in the field of medicine, entomology and plant protection. However, the information on allelopathic effects and agro-food application is scarce and insufficient, requiring additional research.

**Keywords:** food and feed; lemongrass; natural pesticide.

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## 1. Introduction

A vital part of food quality and safety share agriculture and food industry and, in the last decade, ecological food production shows a growth tendency to become a mainstream at the global scale. Medicinal plants have significant roles in agro-food industry, because they are rich in biologically active compounds which have a wide range of applications in many areas. In food production, they are added due to their flavoring properties, nutraceutical potential, as well as their role as natural preservatives. Additionally, medicinal plants in feed act as a natural growth promoters and probiotics. Due to their medicinal properties, these plants can be used in veterinary medicine, similarly as in human. Apart from this, medicinal plants have a great importance as an alternative pesticides in agricultural production, as well as in postharvest processing and during storage of food and feed products.

Recently, we published a review on medicinal and cosmetic purpose of *Cymbopogon citratus* (DC. ex Nees) Stapf. [1] and in this review, we tried to tackle agro-food application of this valuable plant.

*Cymbopogon citratus* (DC. ex Nees) Stapf. or lemongrass leaves and culms, and their essential oil, are widely used as a lemon flavor ingredient in herbal teas, prepared either by decoction or infusion, or in finished herbal products, such as capsules, tablets and creams. The essential oil of *C. citratus* mainly consists of the citral (80%), which is a mixture of two isomeric acyclic monoterpene aldehydes: geranial (*trans*-citral) and neral (*cis*-citral), and its content is higher in leaves than in culm [2]. Citral

is used in perfume industry, as well as for cleaning of wounds and treatment of skin diseases in forms of gels, or in hand hygiene as functional paper microencapsulated with essential oil [1]. Furthermore, *C. citratus* showed high contents of total phenolics (up to 100 mg/g), mostly flavonoids (luteolin and apigenin derivatives), as well as high free radical scavenging capacity [3].

Due to similar essential oil compounds to *Melissa officinalis* L. (native to Europe) and *Aloysia citriodora* Palau (native to Argentina and Chile), lemongrass (native to Srilanka and South India) is usually grown as a substitute due to higher content of essential oil.

According to Scopus, more than 1700 references were published in the period 1944-2020 on this species, with a growing trend in the last ten years (up to 100 references per year). Authors reported on this plant are mostly from Brazil and India, while other countries, especially from Europe is represented with a number of experiments.

The aim of this paper was to review possible applications of the *C. citratus* as food and feed, as well as its application in veterinary medicine and as a natural pesticide.

## 2. Application of lemongrass in food and feed industry

### *Application of lemongrass as a food product or food preservative*

Nutritionally, *C. citratus* is a good source of vitamins A and C, folic acid, magnesium, zinc, copper, iron, potassium, calcium and manganese [4]. The leaves of *C. citratus* have been used as a culinary flavoring that is cooked with foods, especially curries [5]. However, there is a limitation in utilizing *C. citratus* essential oil as a preservative in curry paste, because its strong flavor masks the original flavor of curry [6]. *C. citratus* essential oil is commonly used in teas, soups and curries. It is also suitable for poultry, fish and seafood [7].

Herbal cookies prepared from different percentage of *C. citratus* leaves powder (0, 1, 3 and 5%), had higher protein, lipid, crude fiber and ash contents and lower moisture and lipid contents. Cookies with 3% *C. citratus* powder showed the best quality when compared to other samples [8]. The suggested dose was about 0.7 mg/kg of body weight/day of lemongrass powder in cookies [9]. Furthermore, the addition of lemongrass essential oils (600 ppm) was highly recommended to increase the shelf life of industrial cakes by delaying the oxidation of oils [10].

Chaturvedi et al. [11] conducted an investigation to incorporate herbal extracts of *Coffea arabica* and *Cymbopogon citratus* rich in antioxidants in the development of delicious and nutritious aqualetes that could therapeutically help in improving the health of consumers. Addition of 5% aqueous extract of *C. citratus* can be used as a valuable ingredient for the production of herbal fruit aqualetes which can serve as a good nutritional, as well as bioactive components which exhibit a wide range of therapeutic potential in the management of innumerable health disorders related to oxidative stress, diabetes and cardio vascular diseases, etc. [12]. Also, it can be used as an ingredient in sports food products, for weight control [11].

Food preservative plays an important role in maintaining food quality and extending shelf life. Essential oils, as natural preservatives are preferred since they are less harmful to humans, when compared to chemical preservatives [6].

Because of strong antifungal activities of *C. citratus* essential oil against *Aspergillus ocraceus*, *A. orizae*, *A. fumigatus* and *A. parasiticus*, its application is proposed in growth control of the *Aspergillus* species in fermented fish [13]. Furthermore, *C. citratus* essential oil is quite efficient against *Scopulariopsis brevicaulis*, *Fusarium poae*, *F. verticillioides*, *Aspergillus niger*, *A. terreus*, *A. flavus* and *Penicillium citrinum* which are the most important food borne pathogens and harmful mycotoxins encountered in dairy products, especially cheese [14].

Spoilage flora of fresh orange juice is mainly composed of fungi belonging to the genera of *Cladosporium*, *Penicillium* and *Fusarium*, as well as *Enterobacter cloacae* and *E. aerogenes*. Antimicrobial tests revealed that both, fungi and bacteria, are susceptible to essential oil from *C. citratus* fresh leaves. According to this study, essential oil of *C. citratus* with high antimicrobial activity, could be used as an alternative in the preservation of fruit juices, replacing chemically synthesized antimicrobials [15]. Also, *C. citratus* essential oil reduced the pathogenic microbial load in the coriander revealing its

potential as a natural sanitizer, since it demonstrated superior or equivalent efficacy to commercial sanitizer [16].

The use of *C. citratus* essential oil in concentration higher than MIC value (0.5 µl/ml) in cream-filled cakes and pastries increases the time needed for the natural microflora to reach concentrations able to produce a perceivable spoilage and reduce the risk of diseases associated with the consumption of contaminated products [17].

Akakpo et al. [18] tested stabilization of soymilk with *C. citratus* essential oil at refrigerating conditions, with conservation of organoleptic properties up to three weeks against two weeks in absence of the oil. The sensory quality showed overall acceptability for soymilk with 0.15% of essential oil.

Awad et al. [19] tested beef burger formulae, which contained substitution of beef meat with dried lemongrass in different ratios: 1, 2 and 3%. They tested chemical composition, lipid oxidation (thiobarbituric acid values), microbiological and organoleptic properties at -20 °C storage for three months. Results indicated that higher percent (3%) of lemongrass had higher antioxidant (lower lipid peroxidation) and antimicrobial properties (lower total bacterial counts), however the formulae which contained 1% of lemongrass showed the best acceptability by organoleptic evaluation. Similar antioxidant properties were reported for lemongrass essential oil when applied in meat products [20, 21]. Lemongrass essential oil in concentration of 0.1 and 0.2% in 12 days application in refrigerated storage showed high antioxidant and antimicrobial capacity, however sensory acceptance was impaired again.

The suitability of two forms, distillate (3.5%) and powder (0.75%) of *C. citratus* as a new, natural flavoring in 'herbal ice cream' was studied. The use of herbal distillates led to slight decrease in nearly all milk constituents. While the powder yielded ice creams with significantly higher fat, protein, carbohydrates, total solids and pH compared to those containing distillate. The ash content and overrun of ice cream was not markedly affected by type or form of *C. citratus* flavorings. For 'Lemongrass ice cream' with valued citral component and superior total sensory score, 3.5% of *C. citratus* distillate is recommended [22].

Chitosan is a biopolymer promising for food packaging. Vázquez et al. [23] reported that chitosan with addition of *C. citratus* essential oil (0.1 and 0.25%) improved tensile strength, elongation and water vapor permeability and moisture sensitivity.

#### *Application of lemongrass as a feed product*

The increasing concern of antibiotic residues in poultry products, Antibiotic Growth Promoters, has stimulated many researchers to find alternatives. One of the alternatives is the herbal feed additive such as *C. citratus* essential oils, with known properties, such as: antibacterial, antiviral, antifungal, antihelminthic, antioxidant, anti-inflammatory, coccidiostats, immunomodulatory, hypolipidemic properties, and without residues, safe food product for food and feed.

Ogbonna et al. [24] conducted the study in which they used a total of 108 days-old broiler arbor acre chicks which were fed with leaf meal of *C. citratus* for 8 weeks in order to check the efficacy of this alternative to mycotoxin binder in aflatoxin contaminated feed of broiler chicken. Results show that *C. citratus* is effective as toxin binder in poultry feed without any negative implication on both internal and external characteristics of the bird. Considering the risk of drug resistance which the antibiotics tend to impose on broilers, *C. citratus* leaf meal can be considered as a viable alternative to antibiotics growth promoters [25].

Also, the use of 1.5% *C. citratus* leaf meal, as a feed additive, proved to have significantly better growth performance, feed intake and feed conversion ratio and decrease in cost of broiler production [26]. Besides these findings, there are studies which indicated that inclusion of *C. citratus* in a diet has no benefits on broiler performance [27,28].

After extraction of essential oil from *C. citratus*, leaves by steam distillation, large amounts of organic wastes are obtained. This by-product could easily be used as animal feed. The potential of sugarcane molasses and whey, as additives to ensile lemongrass leaves was tested by Ventura-Canseco et al. [29] and proved to have inducing effect on lactic acid production. Also, the characteristic smell of cow

milk was suppressed due to the transmission of components from herbs into the milk of cows during feeding [30]. Wanapat et al. [31] concluded that supplementation of lemongrass leaf powder at 100 g/day improved digestibility of nutrients, rumen microbial population, and microbial protein synthesis efficiency, thus improving rumen ecology in beef cattle.

Besides lemongrass leaves and essential oils, Ujilestari et al. [32] used self-nano emulsifying drug delivery system of *C. citratus* essential oil with nanoparticles size and proposed its use as feed additive for poultry.

### 3. Application of lemongrass in veterinary medicine

Parasitic nematodes are of the major economic importance in livestock. An alternative for the control of parasites is phytotherapy. Macedo et al. [33] evaluated the efficacy of *C. citratus* decoction (CcD), *C. citratus* essential oil (CcEo) and citral against *Haemonchus contortus* using *in vitro* egg hatch test (EHT) and larval development test (LDT) and an *in vivo* test using a *Meriones unguiculatus* (gerbil) model. The effective concentrations (EC50) required to inhibit 50% of egg hatching were 0.46, 0.14 and 0.13 mg/ml for CcD, CcEo and citral, respectively. The EC50 values in the LDT were 5.04, 1.92 and 1.37 mg/ml for CcD, CcEo and citral, respectively. *H. contortus* population in the group treated with *C. citratus* essential oil was reduced by 38.5% in comparison to the control group.

Another research [34], confirmed that leaf extract of *C. citratus* has potential medicinal value, as well as antiviral activity against Newcastle disease virus *in vivo*.

### 4. Application of lemongrass as biopesticide

#### *Application of lemongrass as biofungicide in organic and conventional agriculture*

Several studies report the biological activity of *C. citratus* oil on pathogenic fungi. Bankole and Joda [35] performed experiments aiming to determine the potential of powder and essential oil from dried ground leaves of *C. citratus* in controlling storage deterioration and aflatoxin contamination of melon seeds (*Colocynthis citrullus* L.). Shelled melon seeds were inoculated with four fungi species: *Aspergillus flavus*, *A. niger*, *A. tamarii* and *Penicillium citrinum*. The powdered dry leaves and essential oil from lemon grass were mixed with the inoculated seeds at levels ranging from 1-10% (w/w) and 0.1 to 1% v/w, respectively. The ground leaves significantly reduced the extent of deterioration in melon seeds inoculated with different fungi compared to the untreated inoculated seeds. The essential oil at 0.1 and 0.25% (v/w) and ground leaves at 10% (w/w) significantly reduced deterioration and aflatoxin production in shelled melon seeds inoculated with toxigenic *A. flavus*. At higher dosages (0.5 and 1.0% v/w), the essential oil completely prevented aflatoxin production. After 6 months in farmers' stores, unshelled melon seeds treated with 0.5% (v/w) of essential oil and 10% (w/w) of powdered leaves of *C. citratus* had significantly lower visible infection of seeds with *Aspergillus spp.* and significantly higher seed germination compared to the untreated seeds. The oil content, free fatty acid and peroxide values in seeds protected with essential oil after 6 months did not significantly differ from the values in seed before storage. The efficacy of the essential oil in preserving the quality of melon seeds in stores was similar to fungicide (iprodione) treatment.

Atanda and Olopade [36] tested potential of *C. citratus* leaf powder in prevention of *Aspergillus flavus* infestation in seed treatment of maize and concluded that 14% (w/w) leaf powder prevents of maize grains (25<sup>th</sup> day of incubation) and thus disables accumulation of aflatoxin B1 (AFB1) content of the grains.

Another study also confirmed *in vitro*, direct toxic activities of *C. citratus* essential oil on the mycelial growth and sporulation of *Alternaria solani*, however when applied onto tomato plants (250, 500, 750, 1000 and 1500 µl/l, 72 h before the fungi inoculation) inhibition of sporulation failed, only fungal growth was prevented and it was in correlation to essential oil concentration [37].

Furthermore, the antifungal activity of lemongrass essential oil was confirmed again and showed new antifungal activity toward five *Aspergillus* species (*A. flavus*, *A. parasiticus*, *A. ochraceus*, *A. niger*, *A. fumigatus*). The activity of the oil against the mycotoxigenic fungi had MIC values ranging from 15-118 mg/ml [38]. Apart from this, another study confirmed that *C. citratus* essential oil exhibited

noticeable inhibition on dry mycelium weight and synthesis of aflatoxin B1 by *A. flavus*, completely inhibiting AFB1 production at 4 µl/ml [39].

Baker and Grant [40] confirmed that *C. citratus* is used as a pesticide active ingredient, primarily as an anti-fungal agent in post-harvest management, while Olascuaga-Vargas and Pérez-Cordero [41] reported the use of *C. citratus* essential oil as an alternative agent in management and control of field tuber rot caused by *Fusarium equiseti* in growing yams (*Dioscorea spp.*).

Ethanollic and methanolic extracts (8%) of lemongrass showed *in vitro* inhibition of *Colletotrichum gloeosporioides*, however they lack the efficiency *in vivo*, as well as in postharvest treatment of guavas (*Psidium guajava*) used in that study [42].

#### Application of lemongrass as bioinsecticide

Plants and plant derived compounds have been used for decades as repellents and insecticides in medicinal and veterinary entomology, human hygiene, agricultural production and post-harvest management of insect pests.

The most intensive research on biological activity of lemongrass (*C. citratus*) has been carried out in the field of medical and veterinary entomology, against hematophagous insects-vectors of different human and animal pathogens. The repellent activity of *C. citratus* essential oil was evaluated by Kimutai et al. [43] against the sand fly *Phlebotomus duboscqi* (Diptera: Phlebotominae). This species is an important vector of zoonotic cutaneous leishmaniasis (ZCL) and presents a public health problem in Africa. In the study, essential oil was highly repellent to *P. duboscqi* adults. Also, the repellency increased and biting rates decreased with the increasing doses of *C. citratus* essential oil. The effective doses were 0.04 (ED50) and 0.79 mg/ml (ED90) of oil, respectively [43]. Very high mortality of *P. duboscqi* sand fly (82.22-100% of females and 88.89-100% of males) was recorded 72h after the exposure to different doses of *C. citratus* oil (0.125-0.75 mg/ml) by Kimutai et al. [44] and Nyamwamu [45]. These authors suggested that this oil is a candidate natural repellent and also potent insecticide that can be used against *P. duboscqi* due to high efficacy at low doses.

Mosquitoes (Diptera: Culicidae) are cosmopolitan nuisance pest with high medical significance due to the fact that they transmit several diseases including chikungunya, lymphatic filariasis, Japanese encephalitis, malaria and dengue fever. Since there is a growing concern about the effect of chemical based insecticides on the environment, human health and mosquito resistance, more intensive research is being carried out using plant-based preparations. Kazembe and Chauruka [46] tested the repellency potential of petroleum ether and aqueous extracts of *C. citratus* and several other plant species (*Ocimum gratissimum* and *Astrolochii hepii*) against *Aedes aegypti* mosquitoes. The petroleum ether was more effective as repellent than the aqueous extract against *A. aegypti* and expressed 100% repellence for 1.5h, while the mixtures of *C. citratus* and *O. gratissimum* petroleum ether extracts showed prolonged this activity to 2.5h. Mixture of *C. citratus* and *A. hepii* extracts lasted 3.5h. Essential oils from *C. citratus*, *C. nardus* and *Eucalyptus citriodora* were evaluated for their repellent effects against *Anopheles arabiensis* mosquitoes *in vitro* by Solomon et al. [47]. These three essential oils exhibited a concentration-dependent repellent action against *A. arabiensis*, which decreased in a time. *C. citratus* was the second most repellent oil (after *C. nardus*) that provided above 70% relative protection for 3h exposure, but it declined as time elapsed. The combination of equal amounts of *C. nardus* and *C. citratus* oils resulted in a better protection than their individual effects. Ebe et al. [48] assessed larvicidal effect of petroleum ether and aqueous extracts (0.4-4 mg/ml) of *C. citratus* leaves and roots, against the first instar stage of three mosquito species, *Anopheles gambiae*, *Culex quinquefasciatus* and *Aedes aegypti*. Leaf extracts proved to be more efficient than roots and petroleum ether extracts more efficient than the water ones, due to higher amount of active ingredients in leaves and their solubility in nonpolar solvents. The extracts expressed the strongest effect on *A. gambiae* causing the highest mortality (13.995), followed by *A. aegypti* (12.641) and *C. quinquefasciatus* (11.426). Otabor et al. [49] tested the larvicidal efficacy of the methanol extract of *C. citratus*, *Ocimum gratissimum* and *Vernonia amygdalina* against the third instar larvae of *Culex quinquefasciatus*. The results suggested that 72h after the exposure to *C. citratus* extract, the percentage of mortality was 66.67% at 1000 ppm, whereas at 750 ppm the mortality was 8.33%. These results are in accordance

with a report of Idibie et al. [50], showing that the efficacy of *C. citratus* essential oil reduces with time due to the diffusion of the vapor phase and elimination of their active compounds from the vicinity. *C. citratus*, along with several other etheric plants were tested as potential repellents of *Anopheles malaria* vector in Benin [51]. The results in this study revealed that *C. citratus* extracts were 100% effective for animal bait and human volunteers for at least 2h after the application, after which the repellence decreased. Thus, the authors concluded that methanol extracts of *C. citratus* leaves could be used for the development of topical cream that repels mosquitoes for effective control of malaria. Izah and Youkparigha [52] tested larvicidal activity of aqueous and ethanolic extracts of *C. citratus* on malaria vector, *Anopheles gambiae*. Ethanolic extracts expressed stronger toxicity compared to the aqueous extract, with toxicity rate (LC50) 104.47 ppm value and 161.06 ppm, respectively. As in previous studies, the mortality rates were dose dependent.

The activity of *C. citratus* essential oil against house fly, *Musca domestica* (Diptera: Muscidae) was assessed by Pinto et al. [53]. Essential oil of *C. citratus* was chemically characterized and tested on the post-embryonic development of *Musca domestica*. The chemical analysis by GC-MS identified 13 major constituents and the main components were isomers geranial and neral, which together form monoterpen citral. This corresponds to a total of 97.92% of the compounds identified. Both essential oils and monoterpene citral were applied topically to newly-hatched fly larvae (1  $\mu$ l/larva). The results show that both essential oil and citral, the main bioactive compound of this oil, caused morphological changes in adult specimens and that mortalities of newly-hatched larvae to adult periods were dose-dependent for both essential oil and citral, reaching 90%. Lethal concentration (LC50) was 4.25 for the oil and 3.24% for citral. Based on the results, the authors suggested that both the oil and citral can be used in further formulations for breeding control of *M. domestica*, to avoid re-infestations.

In agriculture pest management, essential oils, including *C. citratus*, have found the practical application on a small scale. However, based on the results of a number of performed experiments *C. citratus* has been reported to possess antifungal, nematocidal, acaricidal and insecticidal activities. Ohsawa and Ohsawa [54] evaluated the efficacy of *C. citratus* extract against *Plutella xylostella* (Lepidoptera: Yponomeutidae) larvae. The LD50 was 7.7 g/insect by topical application, suggesting satisfactory insecticidal activity. Active compounds that possess insecticidal activity to the *P. xylostella* have not yet been identified, but in this work, bioassay-guided fractionation led to the isolation of the active compound as an essential oil, 3,7-dimethyl-2,6,-octadienal or citral. Costa et al. [55] evaluated insecticide activity of *C. citratus* essential oil against *Myzus persicae* (Hemiptera: Aphididae) and *Frankliniella schultzei* (Thysanoptera: Thripidae), the most significant phitovirus vectors of great economic importance. *M. persicae* transmits Potato virus Y (PVY), Tomato yellow top virus (ToYTV) and Tomato bottom yellow leaf virus (TBYLV) to tomato crops and causes large economic losses to the production of tomato and cotton. *F. schultzei* transmits Tospovirus, Groundnut ring spot virus (GRSV) and Tomato spotted wilt virus (TSWV) to tomato plants. In this work, the toxicity of *C. citratus* oil was 0.28% (LC50) for *M. persicae* was and 1.49% for *F. schultzei* indicating that essential oil from lemongrass is a promising biorational alternative for managing *M. persicae*. Additionally, chemical characterization of the oil was performed and nine compounds were identified, with geranial (49.98%) and neral (37.78%) being the major components [55]. Pests such as the pink worm, *Pectinophora gossypiella*, cause severe losses in cotton fields in Côte d'Ivoire. For decades, the repeated use of chemical insecticides to control these pests has threatened the viability of the production system. Faced with the negative consequences related to the use of synthetic chemicals, the search for alternative methods is essential. Kobenan et al. [56] evaluated the chemical properties and the insecticidal activity of essential oils extracted from *C. citratus*, *C. nardus* and *Citrus sp.* on *P. gossypiella*. The results showed that the pest expressed variable levels of sensitivity to mentioned plant oils. *C. citratus* oil was the most toxic to *P. gossypiella*, and lethal concentrations, LC50 and LC90, were 1.67 and 4.07%, respectively. *C. citratus* extract was the richest in oxygenated monoterpenes (73.71%) followed by *C. nardus* extract (46.59%). Therefore Kobenan et al. [56] suggested that essential oil of *C. citratus* could be used rationally as an alternative option to chemical insecticides in current cotton pest control program in Côte d'Ivoire. Ngongang et al. [57] reported insecticidal activity of *C. citratus* essential oil against tomato borer (*Tuta absoluta*, Lepidoptera:

Gelechiidae), the invasive and devastating pest of tomatoes, through contact and fumigation routes. The oil exhibited high insecticidal efficacy, regardless on the application mode, with LD50 of 35.8 and 72.2  $\mu\text{l/l}$  air on contact and fumigation routes, respectively. The oil also prolonged pupal duration at all tested doses, regardless on the application routes. The recorded results showed the acute and long-term insecticidal effects of the *C. citratus* essential oil, although a greenhouse and open field trials are required prior to implementation of this oil in integrated pest management. Aside from insecticidal activity of *C. citratus* essential oil, in this study a Gas Chrommatography (GC)-Mass Spectrometry (MS) profile was determined. Neral (21.41%), geranial (21.36%) and  $\beta$ -myrcene (9.74%) were the major constituents of lemongrass oil, that exhibited higher insecticidal efficiency regardless on the application mode in both contact and fumigation routes. Magierowicz et al. [58] compared the effects of *C. citratus* essential oil (0.1%, w/v), water and acetone extracts (10%) of larvae and oviposition of females of the most dangerous pest of black chokeberry - *Acrobasis advenella* (Lepidoptera: Pyralidae), using free choice tests of feeding site. This pest damages flower buds that results in decreased yield, while pest feeding inside fruits causes deterioration in their quality. After the treatment of infructescences with *C. citratus* acetone extracts, females did not lay eggs. Among tested preparations, the highest percentage of *A. advenella* larvae and adults was recorded on plants soaked in *C. citratus* aqueous extract (10%) and essential oil (0.1%), which in this case had attractive role for this pest species. Biological activity of *C. citratus* essential oil and its constituents was also assessed by Brügger et al. [59] on *Podisus nigrispinus* (Heteroptera: Pentatomidae), a predator of Lepidopteran and Coleopteran pests, that is commonly involved in biological control programs. Nymphs exposed to the *C. citratus* essential oil and its constituents were repelled, while *P. nigrispinus* adults were tolerant to the *C. citratus* essential oil and its constituents, geranyl acetate and citral. The altered respiratory activity with geranyl acetate and the fact that they were repelled by citral suggests caution with regard to the use of the *C. citratus* essential oil and its constituents in IPM that involve this predator, in order to avoid reduced efficiency against pests.

Post-harvest losses in a food supply chain due to insect pests vary greatly among different crops-commodities, areas and economies. They may amount from 5 to 15% in developed, and between 30–40% in underdeveloped countries, sometimes reaching 50% [60]. Chemical measures in storage pest management have limited effects, especially given the recent ban of a number of efficient pesticidal compounds. Therefore, botanical insecticides present potential biorational alternative. So far, several studies have been carried out related to the potential use of *C. citratus* against storage pests. Toxicity and repellent activity of *C. citratus* essential oil was tested by Paranagama et al. [61] against bean weevil, *Callosobruchus maculatus* (Coleoptera: Bruchidae), the most devastating pest of stored cowpea. In contact toxicity bioassay, *C. citratus* essential oil, applied at rate 0.15 g/l, caused 100% mortality of *C. maculatus* and the number of laid eggs was zero, while LC50 was 0.026 g/l. In olfactometer and choice chamber bioassays, the percent of bruchid responses decreased with increasing doses oil. Only 7.0% bruchids settled in at rate of 160 mg/l in choice chamber. These results suggested that the essential oil *C. citratus* could be used as alternative to develop less toxic treatment system to protect stored cowpea grains against *C. maculatus*. Paranagama et al. [62] also tested *C. citratus* essential oil for repellent activity, fumigant toxicity and contact toxicity against rice weevil, *Sitophilus oryzae* (Coleoptera: Curculionidae), in comparison with other oils (*C. nardus*, *Cinnamomum zeylanacum* leaves and *Alpinia calcarata* rhizome). According to the results, *C. citratus* was the most toxic oil to *S. oryzae*, especially during the fumigant toxicity test (LC50: 0.035 g/l). Ekrakene and Ogunsede [63] evaluated the effects of three phytochemicals: saponins, flavonoids and alkaloids from two medicinal plants, *C. citratus* and *Murraya koeinigi*, as grain protectant against the bean weevil, *C. maculatus* (0.2 g, 0.4 g and 0.6 g/ml concentration per 100 grains of cowpea) based on adult mortality, adult emergence, grain damage effect and weevil perforation index (WPI). There was an increase in adult mortality with the increase in concentrations of phytochemicals, regardless on plant species. Also, higher efficacy was registered 3 days after the treatment. Saponins from both test plants were more effective as adulticides whereas flavonoids and alkaloids were more potent against the immature stages, thus more potent as seed protectants. The insecticidal potential of powdered leaves and ethanol extract of *C. citratus* against *C. maculatus* was studied by Uwamose and Okolugbo [64] using test tube contact toxicity method. The extract (0.5 ml/kg) caused 100% mortality of adult *C. maculatus* after 96h

exposure, while powder (3.5 g/kg) had significantly lower, although satisfactory, efficacy (90%). The result suggest that *C. citratus* products, both powder and ethanol extract have the potential for use as protectants of stored cowpea against this pest. Uwamose et al. [65] also tested toxicity of lemongrass products (leaf powder and methanolic leaf extract) against adult rice weevil, *S. oryzae*. The LC50 of the powder was 4.91 g/10 g of rice, while lethal time necessary to cause 50% of population mortality (LT50) was 160.51 h. The LC50 value of the methanol extract was 2.16 mg/20 ml of with an LT50 of 75.10 h. The methanol extract of *C. citratus* caused higher mortality compared to the powder. Toxicity of *C. citratus* (leaves powder and methanolic extract of leaves) against adult rust-red flour beetle, *Tribolium castaneum* (Coleoptera: Tenebrionidae) was also assessed by Manonmani et al. [66]. Total mortality of adults (100%) was recorded in the treatment with extracts after 24 h exposure. The LC50 of the extract was 0.75 mg/20 ml and lethal time (LT50) was 71.10h. The methanol extract of *C. citratus* caused higher mortality compared to the powder which was less toxic. The study showed that *C. citratus* products have the potential to be effectively used in the management of *T. castaneum* in storage of grains and pluses.

A number of authors have also evaluated repellent effects of lemongrass *C. citratus* [67-70], while various studies presented results on its insecticidal effects [71-75].

Sedentary endoparasitic nematodes, such as *Meloidogyne* species (root-knot nematodes RKN), induce morphological and physiological changes within the plant root system. The products of thermally-degraded *C. citratus* were evaluated for nematicidal activity, as an alternative of toxic synthetics. The products exhibited moderate nematicidal activity, yet promising at 90 mg/ml concentration, when compared to carbofuran, the synthetic nematicide [76].

#### *Allelopathic activity of lemongrass*

Allelochemicals are important and innovative tools for weed control, as they neither harm the environment nor increase weed management costs. The secondary metabolites can be extracted by water or soaking and later applied on soil or leaves. Krenchinski et al. [77], evaluated the leaf aqueous extracts of *C. citratus*, and confirmed its negative impact on germination of *Bidens pilosa* and *B. subalternans* seeds. The concentrations of extract interfered, inversely and proportionally, decreasing germination and germination speed. Besides this, cytotoxic and genotoxic effects of aqueous extracts from *C. citratus* leaves was confirmed on *Lactuca sativa* (lettuce) root tip meristem cells by cytogenetic studies. After 72h exposure, lemon grass aqueous extracts (mg/ml), reduced the mitotic index, the seed germination and the root development of lettuce. The extracts have also induced chromosome aberrations and cellular death in the roots cells of *L. sativa* [78]. Allelopathic effects of *C. citratus* essential oil on the seed germination and seedling growth of corn and barnyard grass (*Echinochloa crus-galli*) in field and in obturator, show that the allelopathy of *C. citratus* should not be ignored when planted it with other crops [79]. Poonpaiboonpipat et al. [80] confirmed that high concentration of *C. citratus* essential oil significantly inhibited germination and seedling growth of *Echinochloa crus-galli*, 28 days after sowing at spray treatment. Chlorophyll a, b and carotenoid content decreased with concentrations of essential oil, indicating that essential oil interferes with photosynthetic metabolism. *C. citratus* essential oil caused an electrolyte leakage indicating membrane disruption and loss of integrity, as well as an increase in thiobarbituric acid reactive substances (TBARS), suggesting lipid peroxidation. It is to conclude that essential oil is phytotoxic and could be utilized as a natural herbicide for future weed control. Additionally, allelopathic potential of *C. citratus* essential oils was tested on germination and seedling growth of different species of weeds: *Panicum virgatum*, *Chloris barbata*, *Euphorbia hirta* and *Stachytarpheta indica* [81]. *C. citratus* essential oil has shown high effectiveness in inhibiting seed germination and suppressing seedling growth in all targeted weeds, especially at concentration of 5 µl/ml.

## 5. Conclusion

Bearing in mind all summarized agro-food applications and potent bioactivities, *Cymbopogon citratus* can be successfully used in all food and feed sectors. In whichever form, as dry leaves powder, extract or essential oil, *C. citratus* proved to have potential as food preservative, feed product, curative



agent in human and veterinary medicine, as well as biopesticide, due to insecticidal and allelopathic activities.

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