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BIOLOGICAL PROPERTIES OF TURMERIC

Thaisa Muriel Mioranza[1]*; Jose Renato Stangarlin[2]; Odair Jose Kuhn[2]; Roberto Luis Portz[3]; Maria Isabel Balbi-Peña[4]; Kátia Regina Freitas Schwan-Estrada[1]; Lindomar Assi[2]; Heloisa Maria Formentini[2]; Clair Aparecida Viecelli[5]; Emanuelle Guandalin Dal'Maso[2]; Cristiane Claudia Meinerz[2]

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ABSTRACT - *Curcuma* spp. (turmeric) has been used since ancient days in popular medicine and gastronomy. Many of its bioactive compounds have just recently been identified and characterized as potential source of new medicines. In this review will relate aspects of cultivated turmeric (*Curcuma longa* L.), including taxonomy, chemical composition, production and processing, and biological activities such as the action against fungi, bacteria, nematodes, protozoa and viruses, including those of importance for human health, agriculture and food science.
Key words: antimicrobial activity, *Curcuma longa*, curcumin, curcuminoids, Zingiberaceae.

PROPRIEDADES BIOLÓGICAS DA CÚRCUMA

RESUMO - *Curcuma* spp. (cúrcuma ou açafrão) tem sido utilizada a muito tempo na medicina popular e na gastronomia. Muitos dos seus compostos biológicos tem sido identificadados e caracterizados como fonte potencial de novos medicamentos. Nesta revisão serão relatados aspectos do cultivo de açafrão (*Curcuma longa* L.), incluindo taxonomia, composição química, produção e processamento, e atividades biológicas como sua ação contra fungos, bactérias, nematoides, protozoários e vírus, incluindo aqueles de importância para agricultura.
Palavras-chave: atividade antimicrobiana, *Curcuma longa*, curcumina, curcuminoides, Zingiberaceae.

INTRODUCTION

The cultivated turmeric (*Curcuma longa* L., syn. *Curcuma domestica* Val.) belongs to class Liliospidae, order Zingiberales and family Zingiberaceae (SHRISHAIL et al., 2013), which is a rhizomatous herb originated more precisely from the hills of the Indian tropical forests (CECÍLIO FILHO et al., 2000). There are other species of the genus *Curcuma* with botanical and chemical characteristics related to *C. longa*, such as *C. aeruginosa* Roxb., *C. amanda* Roxb., *C. amarissima* Rosc., *C. angustifolia* Roxb., *C. aromatica* Salisb., *C. caesia* Roxb., *C. caulina* Grah., *C. codonantha* Skornickoa et al., *C. cordifolia* Roxb., *C. latifolia* Rosc., *C. longiflora* (Wall.) Rao and Verma, *C. leucorrhiza*, *C. zedoaria* Rosc. (syn, *C. xanthorrhiza* Roxb.), beyond the Indian endemic species *C. coriacea* Sabu and Mangaly, *C. decipiens* Dalz., *C. ecalcarata* Sivar and Indu, *C. ferrugenia* Roxb., *C. haritha* Mangaly and Sabu, *C. indora* Blatter, *C. kudagensis* Vel. et al., *C. karnatakansis* Vel. et al., *C. neilgherrensis* Wight, *C. pseudomontana* Grah., *C. raktakanta* Mangaly and Sabu, and *C. vamana* Mangaly and Sabu (SASIKUMAR, 2005). Thus, a very accurate evaluation to correctly identify all these species is necessary. The most recent reports show that there are about 133 species of turmeric worldwide (PRASAD; AGGARWAL, 2011).

Nowadays, turmeric is cultivated in countries of Asia and in some parts of South America, mainly in Peru and Bolivia, however India is still considered the biggest producer, exporter and consumer (SHRISHAIL et al., 2013). The turmeric cultivated in India is considered the best in the world due its high contents of curcumin (PRASAD; AGGARWAL, 2011). *C. longa*, the most economically valuable member of the genus, can be cultivated practically in all tropical and subtropical areas of the world. It is cultivated on a commercial scale and enters the market usually in the form of dried rhizomes that are then prepared according to their use.

These plants need temperature between 20 – 30 ºC and a considerable amount of annual rainfall to have an appropriate growth and development (PRASAD; AGGARWAL, 2011).

The rhizomes represent the economic interest of cultivated turmeric, being characterized and evaluated by the presence of the coloring curcumin, essential oils and oleoresin, besides other nutritive constituents (CECÍLIO FILHO et al., 2000). Turmeric powder is extensively used as a spice, coloring material, and pharmaceutical and

[1]Universidade Estadual de Maringá, UEM, CEP 87020-900, Maringá, Paraná, Brasil. E-mail: thaisamioranza@hotmail.com. *Autor para correspondência
[2]Universidade Estadual do Oeste do Paraná, UNIOESTE, Rua Pernambuco 1777, Caixa Postal 91, CEP 85960-000, Marechal Cândido Rondon, Paraná, Brasil
[3]Universidade Federal do Paraná, UFPR, Palotina, Paraná, Brasil
[4]Universidade Estadual de Londrina, UEL, Londrina, Paraná, Brasil
[5]Pontifícia Universidade Católica do Paraná, PUCPR, Toledo, Paraná, Brasil

cosmetic products (SUETH-SANTIAGO et al., 2015; PRASAD; AGGARWAL, 2011). The biologically active principles, the curcuminoids, can be used as anti-inflammatory, hypocholestraemic, choleratic, antimicrobial, insect repellent, antirheumatic, antifibrotic, antivenomous, antiviral, antidiabetic, antihepatotoxic, anticancerous and antihelminthic (CHATTOPADHYAY et al., 2004; XU et al., 2006; VORAVUTHIKUNCHAI, 2007; SINGH et al., 2011b). The curcumin is responsible for yellow coloration of rhizomes and biological activities (SUETH-SANTIAGO et al., 2015). Curcuma species also have ornamental value and can be used in aromatherapy and for cosmetic production. Some of these features and biological properties will be discussed later. In agriculture, the demand for new plants with metabolic molecules with insecticidal, fungicidal and herbicidal effects, with low or no residues and that reduce the impact to environment, have been increased lately (OOTANI et al., 2013).

DEVELOPMENT

Morphological characterization of *Curcuma longa*

The plant belongs to the herbaceous and perennial type, with 120 to 150 cm height in favorable environmental conditions. Turmeric is an erect plant with subterranean stem (rhizome) from where four or five leaves with long sticks are formed, alternate disposition, lancet in form, flat and light green color, presenting oblique furrows in the abaxial or ventral side and 25 to 50 cm length and 12 to 16 cm width, forming a kind of stem at the base (CECÍLIO FILHO et al., 2000).

Turmeric can reach a height of 1 meter with large and oblong leaves. The rhizomes mature in the ground, their coloration are yellowish brown with the inside orange, and when it is dried, it can be ground to a powder and used for various purposes (PRASAD; AGGARWAL, 2011).

The turmeric rizomes develop around of a central tuberous structure called primary rhizome, or known as head, from which are formed the secondary rhizomes, thinner than the primary, also called fingers because of its shape (MAIA et al., 1995). From lateral rhizomes many independent plants can sprout, which can also survive independently when isolated from the original plant. When the external whitish or grayish pellicle is removed from these rhizomes, a clear yellow to orange color is observed and a spicy, slightly bitter aroma and flavor.

The flowers are positioned in a long and central spike, enveloped by the leaf sheath, composed of an acute bract, imbricates, and greenish and whitish or brownish on the edges. Flower development has been explored by Udomdee et al. (2003). The calyx has a tubular form with three divisions, and the corolla also has the same form and is divided into three parts. Two stamens, reduced for bifid staminodes with a third, fertile one, form the androecium. The anther has two lobules and the ovary has three lobules. The fruit is a globular capsule, with three loculi, dehiscent and with many arillate seeds.

Curcuma longa varieties

The history of turmeric in India begins from immemorial times, prior to Indus valley civilization, and over there are a lot of varieties (VELAYUDHAN et al., 2012). Chandra et al. (1997, 1999) and Hazra et al. (2000), evaluating 25 and 22 different genotypes of turmeric, respectively, obtained from several regions of India, considered seven groups with different characteristics of production, showing this intense genetic variation. An evaluation based on chemical composition or biochemical processes in the plant can detect differences not observed in the phenotype. The species of these groups are very closely related with social, ethnic, rural, medicinal and cultural functions and folklore life of people in Asia (VELAYUDHAN et al., 2012).

Brazil is an important producer of turmeric, and some works has been developed about phylogenetic relationships, just like the work of Sigrist et al. (2011) that evaluated the genetic diversity of 39 accessions that are cultivated in this country from the states of Goiás, Mato Grosso do Sul, Minas Gerais, São Paulo and Pará, and the most genetic diversity was found within states, and São Paulo has the most divergent genotypes.

C. longa was grouped into 21 distinct morphotypes based on vegetative, floral, rhizome and quality features (VELAYUDHAN et al., 1999, cited by SASIKUMAR, 2005), which were divided into six taxonomic varieties: *C. longa* var. *typica*, *C. longa* var. *atypica*, *C. longa* var. *camphora*, *C. longa* var. *spiralifolia*, *C. longa* var. *musacifolia* and *C. longa* var. *platifolia*.

Besides these morphotypes and varieties, changes in the behavior can be observed in turmeric under different environments. As an extreme example, in its center of origin or similar climatical environment, the plant is perennial, however, in subtropical conditions, the plant is annual, and, with a decrease in temperature in winter, allocation of metabolites and nutrients from the aerial parts of rhizomes is accentuated, culminating in the complete death of the tissues of the aerial part (CECÍLIO FILHO; SOUZA, 1999).

Use in the food industry

There are three turmeric products that can be found on the market: turmeric powder, turmeric oleoresin and pure curcumin (SINGH et al., 2011a; SUETH-SANTIAGO et al., 2015).

Turmeric powder (with 60-80 mesh), obtained from whole dry or fresh rhizomes, has a peculiar color, aroma and taste, being used in mustard paste, for making vegetables and meat preparations and soups, as well as in typical Indians, Arabic and Chinese foods (SASIKUMAR, 2001). Closely related species are frequently substituted for true turmeric (C. longa) to obtain turmeric powder. This adulteration is associated with the mixing of related *Curcuma* species containing similar pigments as *C. aromatica* and *C. zedoaria*.

Turmeric oleoresin, obtained by extraction with some kinds of solvents from turmeric powder, and whose process efficiency is around 10-13%, possesses 37% to 55% of curcuminoids and up to 25% of volatile oil (LI et al., 2011). Turmeric oleoresin is orange-red in color and is used as food coloring, in mayonnaise, relish formulations and in butter and cheese in the form of powder or granules

for garnishing, in medicines and dietary supplement (PEROTTI, 1975; LI et al., 2011).

Pure curcumin, which contains about 10% curcumin, is not used directly in the food industry due its insolubility in water. So, curcumin is dissolved in food-grade solvent in a dose level that ranges between 5 and 200 ppm (HENRY, 1998). Nowadays news techniques (ecapsulation in microcapsules, nanosphere, nanoemulsions, liposomes and others) are developed to preserve the biological activities of essential oils and avoid their degradation when exposed to oxygen presence, temperature and light, and it increase the anti-microbial, antifungal, antiviral, and pesticidal activities in real food systems (MAJEED et al., 2015).

Turmeric rhizomes also contain approximately 4.4% of essential oil that can be obtained by steam distillation of turmeric powder during 6 h. The main component of essential oil is ar-turmerone (58%), but others compounds are also found, as turmerol, turmerona, limonene, borneol, zingiberene, and others (PÉRET-ALMEIDA et al., 2008).

However different species of genera *Curcuma* differ about main components: *C. longa* present mainly ar-turmerone (51.8%) and ar-turmerol (11.9%); *C. aromatica* presents mainly p-cymene (25.2%) and 1.8-cineole (24.8%); *C. amada* mainly myrcene (80.54%) and β-pinene (4.64%); *C. zedoaria* mainly 1.8 cineol (18.5%), cymene (18.42%) and α-phellandrene (14.9%) (SINGH et al., 2002).

The antioxidant activity of curcumin and turmeric, due to the suppression of reactive oxygen species (ROS) or scavenging the free radicals, is very important for the industries as a food additive to prevent the oxidation and resultant rancidity of oils and fats during storage and heating (KHANNA 1999; extensively reviewed in VORAVUTHIKUNCHAI, 2007).

Besides curcuminoids, turmeric has other nutritive constituents (quantity per 100 g): water 6 g; protein 8.5 g; fat 8.9 g; carbohydrate 69.9 g; ash 6.8 g; calcium 0.2 g; phosphorus 26 mg; sodium 0.03 mg; potassium 2 mg; iron 47.5 mg; thiamine 0.09 mg; riboflavin 0.19 mg; niacin 4.8 mg; ascorbic acid 50 mg; and food energy 390 kcal (PETER, 1999).

Phytochemistry

Only 20 species of *Curcuma* have been studied phytochemically, and *C. longa* is the most investigated specie. Until now, at least 235 compounds were identified, among which phenolic compounds, terpenoids, diarylheptanoids (known as curcuminoids), diarylpentanoids, monoterpenes, sesquiterpenes, diterpenes, triterpenoids, alkaloid, and sterols (LI et al., 2011).

The bio-protective properties of turmeric are associated with many compounds produced by plant secondary metabolism, such as curcuminoids, represented by curcumin (60%), desmethoxycurcumin, monodemethoxycurcumin, bisdemethoxycurcumin, dihydrocurcumin and cyclocurcumin (SHRISHAIL et al., 2013). Curcumin is responsible for yellow color and it is insoluble in water, but soluble in ethanol, alkalis, ketone, acetic acid and chloroform (SHRISHAIL et al., 2013).

The essential oils of rhizomes obtained by steam distillation are mainly constituted by sesquisterpenes, as ar-turmerone (61%), curlone (12.47%), ar-curcumene (6.11%), zingiberene (2.97%), α-sesquiphellandrene (2.81%) and a minor percentage of aromatic compounds as ethyl-4-isobutylbenzene (2.61%), α-bisabolene (1.48%), benzene (1.47%), benzaldehyde (1.44%), 1,2,3,5-tetramethyl-benzene (1.42%), 4-methyl-carbanilonitrile (1.09%), silane (0.84%) and phenol (3.45%) (LIJU et al., 2011), d-α-phellandrene (1%), d-sabinene (0.6), cineol (1%), borneol (0.5%) (MARTINS; RUSIG 1992), β-caryophyllene (0.2%), β-farnesene (0.2%), β-curcumene (2.5%), β-sesquiphellandrene (2.4%), β-bisabolol (0.3%), ar-turmerol (0.9%), α-atlantone and traces of α-phellandrene, p-cymene, limonene, 1.8-cineole, camphor, β-elemene, and germacrone (ZWAVING; BOS, 1992).

Different profiles of essential oil for the same species of *Curcuma* or for same plant parts have been reported and even the same authors have reported different values in a single species or the same plant parts in different papers (SHARMA et al., 1997; BEHURA 2000; BEHURA et al., 2002; CHANE-MING et al., 2002; BEHURA; SRIVASTAVA, 2004). The amount of cultivated turmeric components varies depending on the genotype, and environmental and geographic area of yield, agricultural practices, soil fertilizers used and maturity of rhizomes. This feature also depends on the *Curcuma* species. *C. longa* has the maximum number and size of curcuminoids compared to others species (LI et al., 2011). For instance, the mineral fertilization with N (nitrogen), P (phosphorus) and K (potassium) have influence in content of curcumin in turmeric, plants treated with P and K or in combination with N showed increase in curcumin (AKAMINE et al., 2007). Tanaka et al. (2009) studied different sources of turmeric rhizome powder purchased in pharmaceutical companies or markets from different regions of India and China and found curcumin contents varying 0.06 to 2.42%. The same was observed by Thaikert and Paisooksantivatana (2009) in 67 samples of *Curcuma longa* from different parts of Thailand. Rhizomes of turmeric with different stages of growth (2, 4, 6, 8 and 10 months after budding) have different amounts of curcumin, varying among 0.25% to 2.7%.

Although studies using methods to quantify and to identify several constituents in dried or fresh turmeric samples have been reported, there are few detailed analyses of the bioactive constituents of fresh turmeric. Such investigations are necessary to allow for metabolic profiling studies to be performed that could be used to ensure the authenticity of plant materials or to enable biochemical investigations that would seek to define the biosynthetic pathways leading to these compounds in the plant (JIANG et al., 2006).

Turmeric compounds belonging to two important groups of natural products, the diarylheptanoids and sesquiterpenoids, which are believed to be responsible for producing many of the important biological and medicinal activities of turmeric. The curcuminoids, including

curcumin, demethoxycurcumin and bisdemethoxycurcumin, are the major diarylheptanoids and have been shown to contribute for many of the biological properties of this species. In order to clarify if these three compounds are the only diarylheptanoids responsible for activity in the *Curcuma* species, Jiang et al. (2006) found 19 diarylheptanoids in crude methanolic extracts, that differed by substituent groups on the heptanoid skeleton and/or on the aromatic rings. These differences were ascertained by comparing the chromatographic and mass spectral data. Among these 19 diarylheptanoids, 12 have not been previously reported from turmeric and six of these are new compounds.

Production

Turmeric is propagated by vegetative way form from its rhizomes, whose quality as a rhizome-seed is directly linked to the productive potential of the culture, similar to that which occurs in potato, onion and garlic cultures. To choice the best propagation material, you should consider the genetic material, weight, age, accumulated reserve capacity, sanity and other factors (BERNI et al., 2014).

According to Cecílio Filho and Souza (1994) and Maia et al. (1995) the use of rhizome-seed with larger weight provides greater vigor to the plants, a considerable gain in the development period, having more time to accumulate reserves in the rhizomes. The same was observed by Berni et al. (2014) that the rizomes with large weight (± 15 g) resulted in higher production than small (± 5 g) and medium (± 10 g). Another difference observed by Cecílio Filho et al. (2000) regards the morphology and chronological order of rhizome formation, because central rhizomes are more vigorous than those that originate from it.

Planting should be performed in elevated flowerbeds to facilitate drainage as well as harvest. It is possible to obtain 24 t ha^{-1} using 80 cm row spacing and 30 cm among plants (CECÍLIO FILHO et al., 2004).

Turmeric is ready for harvesting 7 to 10 months after planting, when the lower leaves turn yellow. Harvesting is done by digging the rhizomes up. Leafy tops are then cut off, the roots and adhering earth is removed and the rhizomes are then washed. Some of these are retained for replanting as a future crop. India has the greatest productivity, reaching up to 22 t ha^{-1}. In Brazil, turmeric is cultivated more at Goiás, Mato Grosso and São Paulo States with an average productivity around 8 to 12 t ha^{-1} (PEREIRA; STRINGHETA, 1998; CECÍLIO FILHO et al., 2000). Cultivation of turmeric can provide a supplementary income to the farmers, and the higher net income can be observed when the farmers disposed off the product after drying. In India the production can reach to 4.9 t ha^{-1} to fresh turmeric (PAPANG; TRIPATHI, 2014).

Regarding fertilization, the quantity of nutrient necessary per hectare is the same quantity absorbed by the plant in the hectare. The quantity of nitrogen required by *C. longa* culture is variable, according to amount of rhizomes to be produced. Cecílio Filho (1996), producing 24.7 t ha^{-1}, in Minas Gerais State, Brazil, verified that the total transported by harvest of N, P, K, Ca, Mg, S was 111.8, 21.0, 95.1, 37.0, 29.8 and 3.1 kg ha^{-1} respectively. So that, according soil analysis the remaining nutrients should be supplied by fertilization. Akamine et al. (2007) showed that the highest yield of turmeric cultivated in Japan was obtained from the turmeric grown with NPK fertilization, because plants with this fertilization remain green longer and had higher shoot biomass.

Some priorities have to be looked before planting, such as infrastructure like road, capacity to storage, farm mechanization, transportation facility, market regulation and extension services, the last one with a great importance to help the farmers with dissemination of farm technologies and impart knowledge of entrepreneurship (PAPANG; TRIPATHI, 2014).

Biological activities

Curcuma species have been used in a variety of folk human medicine (CHATTOPADHYAY et al., 2004). Turmeric paste can be used topically on cuts, injuries, skin infection, poisonous insect and snake bites; common cold and bronchitis (oral); flatulence, indigestion and diarrhea (oral); hepatic disorders, anorexia and diabetic (external or internal); and sinusitis, catarrh and coryza (inhalation) (SHAH, 1997). Lee et al. (2003) verified a beneficial effect of turmeric powder, particularly curcumin, on the stomach as gastro protector. Curcumin from *C. longa* also has demonstrated a neuroprotective role for some types of induced brain damage, what could be a new source of medicaments to combat Alzheimer's disease (RAJAKRISHNAN et al., 1999; PARK; KIM, 2002).

Some authors have also reported on the use of turmeric preparations in traditional veterinary medicine, specifically for broken bones, scabies, hair fall, abscesses, wounds and parasitic diseases of domestic animals (MANDAL; CHAUHAN, 2000; SHARMA; JOSHI, 2004). For instance, *C. longa* can be used of paste form, made with a little among of water, to treat any type of skin infections, like ringworm in cattle population (MISHRA, 2011), or like ethanolic extract in the diet of chicken to protect them against negative effects of aflatoxin (RANGAZ; AHANGARAN, 2011). Furthermore, according with Shrishail et al. (2013), in veterinary turmeric is used to heal wounds or ulcers of animals.

Anti-inflammatory activities

The constituents of turmeric which has anti-inflammatory activities are curcumin, tetrahydro curcumin, α-curcumene, ar-turmerone and dehydro curdione (SHRISHAIL et al., 2013). Curcumin is a highly pleiotropic molecule and can interact with numerous molecular targets involved in inflammation, besides that the clinical trials based on cell culture and animal research shown that curcumin may have competence in treat inflammatory bowel disease, pancreatitis, arthritis and some types of cancer (JURENKA, 2009).

Araújo and Leon (2001) claimed that components, primarily curcumin and sodium curcuminate, extracted from turmeric can combat both chronic and acute inflammation. Buragohain and Dutta (1998), working with

gel which each 100 g contein 5 g of *Glycerrhiza glabra*, 2 g of *C. longa*, 10 g of *Cedrus deodara*, 5 g of *Paedaria foetida* and 10 g of sulfur for the control of bovine mastitis, observed an overall cure rate of 100% of inflammatory process at 14th day post-treatment. Kolte et al. (1999), working with rhizomes of *C. amada* (100 g), made mixtures with roots of *Withania somnifera* (100 g), *Asperagus racemosus* (100 g) and leaves of *Ocimum sanctum* (100 g) prepared as a paste and applied twice a day on udder for five days, obtained correcting of inflammatory process in cows without inconvenient presence of antibiotic in milk, although the effect was more slowly than antibiotic (Ampicillin + Cloxacillin). Funk et al. (2006) determined the efficacy of turmeric extracts in the prevention or treatment of arthritis, for this, female rats were treated with turmeric fraction or purified curcuminoids intraperitoneal injection four days prior or eight days after streptococcal cell wall induced arthritis adminstration, and found that the essential oil-depleted turmeric fraction (containing 41% of the three major curcuminoids) and purified curcuminoids (95% of the three major curcuminoids) were efficacious in preventing joint inflammation when treatment was started before, besides, purified curcuminoids was more potent in the prevention, suggesting that these three major curcuminoids are responsible for the anti-arthritic effect.

There are in the literature works studying the anti-inflammatory effects of curcumin in cancer models in animal studies, for instance, Shpitz et al. (2006) provided 0.6% of curcumin in oral diet of rats to study rat colonic aberrant crypt foci and found that curcumin reduced the growth of colorectal cancer, as well as, Kwon et al. (2009) also provided 0.6% of curcumin in oral diet of rats to analysis colonic apoptosis and observed that curcumin increased apoptosis in young rats and the cell proliferation.

The anti-inflammatory properties of curcumin can be attributed to its potent antioxidant capacity at neutral and acid pH, inhibition of cell signaling, diverse effects on cellular enzymes and its effects on angiogenesis and cell adhesion (SHARMA et al., 2005).

Antioxidant activities

Antioxidant activities is important because inhibit oxidation and protect cell and biologic process of free radicals that are unstable and cause random reaction damaging protein, nucleic acid and cell membrane accelerating premature aging (XU et al., 2006), and, in the food the oxidation process occur by the compost formation responsible for the rancid odor and flavor (VORAVUTHIKUNCHAI, 2007). Mices treated orally with turmeric oil (containing mainly ar-turmerone, curlone, ar-curcumene, phenol and zingiberene) at dosages of 100 and 500 mg kg^{-1} for 30 days had an increase of enzymes antioxidants in blood, such as catalase, superoxide dismutase, glutathione reductase and glutathione (LIJU et al., 2011).

Curcumin has been studied as an anti-oxidant because its ability to scavenge directly the ROS (O_2^-, OH, NO and $ONOO^-$ radicals). This action is linked to hydrogen donation that reacts with ROS and neutralizes possible cell damage (SUETH et al., 2015).

Toda et al. (1985) extracted methanolic fraction of turmeric and isolated three substances with antioxidant activities: curcumin, 4-hidroxycinnamoyl (feruloyl) methane, and bis (4-hidroxycinnamoyl) methane, at 0.1% concentration in linolenic acid. Lean and Mohamed (1999) demonstrated the effect of turmeric as an antioxidant, for this they mixing 0.5 g of ethanolic extract in 500 g of butter witch was incorporated in the cakes durin mixing. These authors measuring thiobarbituric acid (TBA) value and peroxide value, that cause rancid flavor, over a four-week period stored under ambient temperature and observed that TBA value in the 4th week in the butter cake with turmeric extract was 0.62 mg kg^{-1} whereas in control was 2.43 mg kg^{-1}, in this late case value up to 1.44 is unacceptable because present rancid flavor. Peroxide values were 10.2 m_{eq} peroxide kg fat^{-1} in cake with turmeric and 23.1 m_{eq} peroxide kg fat^{-1} in control treatment, therefore the turmeric extract avoids free radicals formation. Selvan et al. (1995) isolated a heat stable protein of 24 kDa extracted by water, that was effective to reduce lipid peroxidation and prevented Ca^+-ATPase inactivation showing its antioxidant role. Unnikrishnan and Rao (1995) demonstrated that the substances extracted from cultivated turmeric (demethoxy curcumin, bisdemethoxy curcumin and diacethyl curcumin) have the capacity to protect hemoglobin from oxidation even at concentrations as low as 0.08 mM. Curcumin and its derivatives, i.e. demethoxy curcumin and bis-demethoxy curcumin, were the primary inhibitors of lipid peroxidation in mouse liver microsomes, erythrocyte membranes and cerebral cells, acting on superoxide anions and hydroxyl radicals (reactive oxygen species) that are responsible for the oxidative burst. So that, there are several active compounds present in rhizomes of turmeric that can be used as antioxidant in the animal and human health or feeding.

Antimicrobial activities

Compounds from natural resources with antibacterial and antifungal properties are of great interest due to increased tolerance of microorganisms to existing traditional drugs (STANGARLIN et al., 2011). Curcumin, the pigment with bioactivity in turmeric rhizome, are reputed for their antimicrobial action. Research has been conducted to assess antibacterial and antifungal activity in various bacterial, fungal and nematode pathogens in plants (KUHN et al., 2006; BALBI-PEÑA et al., 2006; BABU et al., 2012.) and antibacterial, antifungal and antiviral in human and animals (AKRAM et al., 2010; MOGHADAMTOUSI et al., 2014).

Curcumin is a molecule readily accessible but the disadvantage is its low solubility in water, so Basniwal et al. (2011) prepared nanoparticles of curcumin and their results showed that the water solubility improved with the reduction of particle size, as well as the antimicrobial activity, against *Staphylococcus aureus*, *Bacillus subtilis*, *Escherichia coli*, *Pseudomonas aeruginosa*, *Penicillium notatum* and *Aspergillus niger*, and the mechanism for

antibacterial action is that these particles entered in bacterial cell and break the cell wall, leading to cell death.

Certain plants with antimicrobial properties have been exploited. These compounds act in many ways on various types of diseases and are being used to the crop as green pesticides (GURJAR et al., 2012). They are considered as potential alternatives to synthetic fungicides or lead compounds for new classes of synthetic fungicides such as podoblastin produced by *Podophyllum peltatum*. Several naturally occurring compounds such as tryptanthrin, indole 3-acetonitrile, and *p*-coumaric acid methyl ester have been isolated and identified from *Isatis tinctoria* L., against *Coniophora puteana* Schum. Fr. Karst. Additionally, the fungitoxicity of crude extracts and essential oils of medicinal plants such as *Achillea millefolium*, *Cymbopogon citratus*, *Eucalyptus* (*Corymbia*) *citriodora* and *Ageratum conizoides* has been verified (FIORI et al., 2000; see BENKEBLIA, 2007 for extensive review).

Turmeric oil obtained from hexane extraction of turmeric rhizomes and curcumin, were studied against 15 isolates of dermatophytes (six of *Trichophyton rubrum*, five of *Trichophyton mentagrophytes*, three of *Epidermophyton floccosum* and one of *Microsporum gypseum*), four isolates of pathogenic molds (*Trichophyton rubrum*, *T. mentagrophytes*, *E. floccosum* and *Sporothrix schenckii*) and six isolates of yeast (four of *Candida albicans*, one of *Candida tropicalis* and one of *Candida stellatoidea*). The minimum inhibitory concentration (MIC) of these compounds was determined in *in vitro* antifungal tests. All 15 isolates of dermatophytes could be inhibited by turmeric oil at dilutions of 1:40-1:320. None of the isolates of dermatophytes were inhibited by curcumin. The other four isolates of pathogenic fungi were inhibited by turmeric oil at dilutions of 1:40-1:80 but none were inhibited by curcumin. All six isolates of yeasts tested proved to be insensitive to both turmeric oil and curcumin. The inhibitory activity of turmeric oil was tested in *Trichophyton-induced* dermatophytosis in guinea pigs using turmeric oil (dilution 1:80) applied by dermal application on the 7th day following dermatophytosis induction with *T. rubrum*. An improvement in lesions was observed in 2-5 days and the lesions disappeared 6-7 days after the application of turmeric oil (APISARIYAKUL et al., 1995).

Gowda et al. (2004) evaluated a different herbal compounds and their efficacy to inhibit fungal growth and aflatoxin production in livestock feeds. With this objective, the anti-fungal properties of neem seed cake, neem oil, neem leaves, karanj seed cake, karanj oil, karanj leaves, mahua oil, castor seed cake, clove oil, turmeric, onion extract, garlic extract, asafoetida and thulasi leaf extract at different levels were tested on potato dextrose agar. Clove oil at 0.5% completely inhibited *Aspergillus parasiticus* growth. Neem seed cake, neem oil, clove oil, turmeric, onion extract and garlic extract were selected to test their efficacy to inhibit fungal growth and aflatoxin production in feeds because inhibited fungal growth by at least 20% in the preliminary screening. All the herbal compounds reduced fungal growth and aflatoxin production. Clove oil at 0.5-1% inhibited aflatoxin production, while others extracts reduce moderately, as 0.2-1% turmeric (reduction of 63%-84%), 0.1-1% onion (reduction of 64%-76%) and 0.2-1% garlic (reduction of 71%-84%).

Kim et al. (2003) verified the fungitoxicity of *C. longa* against the plant pathogens *Botrytis cinerea*, *Erysiphe graminis*, *Phytophthora infestans*, *Puccinia recondita*, *Pyricularia oryzae* and *Rhizoctonia solani*. Six different extracts (methanol, hexane, chloroform, ethyl acetate, butane and water fractions) were compared with synthetic fungicides (chlorothalonil + dichlofluanid) and four commercially available compounds derived from *C. longa* (borneol, 1.8-cineole, sabinene and turmeron). The hexane extract showed fungicidal activities against *E. graminis*, *P. infestans*, and *R. solani* at concentration of 1000 mg L^{-1}, whereas the ethyl acetate extract showed activity against *B. cinerea*, *P. infestans*, *P. recondita*, and *R. solani*. Curcumin isolated from the ethyl acetate fraction using chromatographic techniques showed fungicidal activity against *P. infestans*, *P. recondita*, and *R. solani* (100%, 100%, 63% control values, respectively) at 500 mg L^{-1} and (85%, 76%, and 45% of control) at 250 mg L^{-1}. Among the commercial compounds derived from *C. longa*, turmeron exhibited only weak activity against *E. graminis*, but no activity was observed from treatments with borneol, 1.8-cineole and sabinene.

Different curcumin bioconjugates along with piperoyl glycine, were synthesized and tested *in vitro* against different bacteria, specially causing secondary infections in human (*Escherichia coli*, *Staphylococcus aureus*, *Pseudomonas aeruginosa*, *Pseudomonas pyocyanin*, *Enterobacter cloacae*, *Klebsiella aeurogenus*, *Staphylococcus epidermidis*, *Staphylococcus aprophyticus*, *Micrococcus* sp., *Enterobacter aerogen* and *Enterococus* sp.) and fungi that cause nail infections (*Aspergillus fumigatus*, *Candida krusei* GO3, *Candida glabrata* and *Candida albicans*). 4.4'-di-*O*-(glycinoyl-di-*N*-piperoyl)-curcumin and 4.4'-di-*O*-acetyl-curcumin were more effective than cephalosporin, an antibacterial drug available in market, at the same concentration. The 4.4'-di-*O*-(glycinoyl-di-*N*-piperoyl)-curcumin and 4.4'-di-*O*-piperoyl curcumin had antifungal activity *in vitro* almost comparable with fluconazole, a popular antifungal drug. The results suggest that the enhanced activity of these bioconjugates with curcumin may be due to improved cellular uptake increasing its concentration inside the infected cells (MISHRA et al., 2005).

Ferreira et al. (2013) studied the antifungal activities of the essential oil of *C. longa*, extracted with hexane against the plant pathogenic fungus *Aspergillus flavus* Link and observed that essential oil, which the major compounds were ar-turmerone (33.2%), α-turmerone (23.5%) and β-turmerone (22.7%) reduce micelial growth in all concentrations tested (0.1, 0.25, 0.50, 1.00, 2.50 and 5.00%) with the best results in concentration of 0.5%. The authors also can be related that the spore germination and spore production were full inhibited in 0.5%, due the damage of hyphae and

conidiophores membranes showed by scanning electron microscopy.

Methanol extract of *C. longa* at 2 mg mL^{-1} also showed activity against *Magnaporthe grisea*, *Thanatephorus cucumeris*, Botrytis cinerea, *Phytophthora infestans* and *Puccinia recondite*, with 76%, 20%, 44%, 82% and 96% of control, respectively, when assayed *in vitro* (PARK et al., 2008).

Essential oils from *C. longa* obtained by hydrodistillation and by extraction with hexane were tested without dilution against the plant pathogenic fungi *Alternaria brassicicola*, *Aspergillus flavipes*, *Aspergillus niger*, *Cladosporium sphaerospermum* and *Fusarium oxysporum*, using an agar diffusion method with paper disks. Antifungal activity of both essential oils was observed only against *A. brassicicola* and *A. flavipes* and higher antimicrobial activity was provided by the hexanic extract compared to hydrodistillation (NAGHETINI, 2006). Pawar and Thaker (2006) found, however, that essential oil of *C. longa* showed no inhibition of hyphal growth and spore production in *A. niger* using standard disc diffusion assays.

Methanol extract of the rhizomes of turmeric effectively controlled the development of red pepper anthracnose caused by *Colletotrichum coccodes*. In addition three antifungal substances were identified from the methanolic extract of *C. longa* rhizomes, as curcumin, demethoxy curcumin, and bis-demethoxy curcumin using mass and ^{1}H-NMR spectral analyses. The curcuminoids in a range 0.4-100 μg mL^{-1} effectively inhibited the mycelial growth of three red pepper anthracnose pathogens, *C. coccodes*, *C. gloeosporioides*, and *C. acutatum*. The three curcuminoids inhibited mycelial growth of *C. coccodes* and *C. gloeosporioides* to a similar extent as the synthetic fungicide dithianon, but the synthetic agent was a little more effective against *C. acutatum*. The curcuminoids also effectively inhibited spore germination of *C. coccodes*, and bis-demethoxy curcumin was the most active. Among the three curcuminoids, only demethoxy curcumin was effective in a greenhouse test in suppressing red pepper anthracnose caused by *C. coccodes* (CHO et al., 2006).

The *in vitro* fungitoxicity of essentials oils of *Citrus sinenesis* (exocarp), *C. longa* (rhizome) and *Elettaria cardamom* (seed) against *Curvularia* spp. was studied by Chutia et al. (2006). *C. sinensis* was found to be most effective with complete mycelial growth inhibition at 1000 mg L^{-1} followed by *E. cardamom* and *C. longa* at 1500 mg L^{-1} and 2500 mg L^{-1}, respectively.

The effects of four alkaloids on the biosynthesis of ochratoxin A (OTA), ochratoxin B (OTB) and citrinin were examined on four OTA-producing aspergilli: *Aspergillus auricomus*, *A. sclerotiorum* and two isolates of *A. alliaceus*. Curcumin, a constituent of *C. longa*, completely inhibited mycelial growth of *A. alliaceus* isolate 791 at 0.1% (w/v) and decreased OTA production by 70% at 0.01% (w/v) (LEE et al., 2007a).

The use of Chinese medicinal plant extracts as natural antifungal agents to inhibit the growth of food-borne pathogens was investigated by Lee et al. (2007b). Hot water, 80% methanol or acetone extracts of *Curcuma longa* were screened against *Aspergillus niger*, *Botrytis cinerea*, *Fusarium moniliforme*, *Glomerella cingulata*, and *Phyllosticta caricae*. In this study, the inhibitory activity of acetone extracts of *C. longa* against all tested fungi varied significantly with minimum inhibitory concentrations (MIC) values ranged between 6.7 (*P. caricae*) and 40 mg mL^{-1} (*A. niger*, *F. moniliforme*, *G. cingulata*). The acetone extracts of *C. longa* maintained their activity against fungal strains when stored at 4 ºC, but not at 25 ºC.

The antifungal activity of ethanolic extract of turmeric (0.5 g of plant extract 500 g^{-1} of butter) was verified by Lean and Mohamed (1999), whose results showed delay in the appearance of the mould, and additionally, at 4th week reduced 83.3% the incidence, while the chemicals antioxidants butylated hydroxy toluene (BHT) reduced 50% and butylated hydroxy anisole (BHA) reduced only 16.7%.

Saju et al. (1998) consider the essential oil of turmeric as an excellent *in vitro* fungistatic agent against *Colletotrichum gloeosporioides*, *Sphaceloma cardamoni*, *Pestalotia palmarum*, *Rhizoctonia solani*, *Aspergillus* sp. and *Fusarium* sp. In human medicine, Chen et al. (2016), showed that the turmeric antifungal activity have been reported against different strains of *Candida*, *Cryptococcus*, *Aspergillus*, *Trichosporon* and *Paracoccidioides* (fungal infections associated with cancer) and there are different mechanisms of action of turmeric, such as the increase of ROS, which results in early apoptosis and leads to cell death; turmeric reduce ergosterol production, proteinase secretion and decreases the intracellular pH, which leads to the destruction of membrane fluidity and asymmetry; promove the hypersusceptibility calcineurin and regule MAP kinase pathway, which results in the disruption of cell wall integrity and inhibit the adhesion of fungi. All these mechanism increase the fungal death and reduce the fungal proliferation.

Singh and Rai (2000) tested several plant extracts to control *Fusarium udum*, that causes wilt in *Cajanus cajan*, and verified that turmeric extract showed *in vitro* fungitoxicity due the substance *p*-methoxy cinamate. Raja and Kurucheve (1998) also reduced *Macrophomina phaseolina* mycelial growth in vitro with turmeric extract.

Balbi-Peña et al. (2006a) conducted a study to evaluate the *in vitro* fungitoxic activity of turmeric extracts and curcumin against *Alternaria solani*. Four different concentrations (1%, 5%, 10% and 20%) of aqueous extracts of turmeric rhizomes (sterilized in autoclave) and four curcumin solutions (50, 100, 200 and 400 mg L^{-1}) were incorporated into potato dextrose agar medium in order to evaluate fungal mycelial growth and spore formation. To evaluate the temperature sensibility of the extracts, 10% and 15% turmeric extracts were also sterilized by filtration. The effects of autoclaved and non-autoclaved turmeric extracts and curcumin on *in vitro* spore germination were tested. The concentrations of 10% and 15% of non-autoclaved turmeric extracts inhibited the mycelial growth by 38.2% and 23.2% respectively, and the spore production by 71.7% and 87% respectively. When turmeric extracts were autoclaved, neither mycelial growth

nor spore germination was inhibited and the effect on the spore production was reduced, suggesting the presence of thermo-labile antimicrobial compounds. The non-autoclaved 5% extract inhibited up to 15% the spore germination. At the highest concentration, the curcumin solution inhibited the mycelial growth by 29.5%. Neither in vitro spore production nor spore germination was affected by curcumin.

Balbi-Peña et al. (2006b) also evaluated the potential of turmeric extracts and curcumin on the control of tomato early blight (*Alternaria solani*) under greenhouse conditions, using 1% and 10% turmeric extracts, 50 and 100 mg L^{-1} curcumin solutions, acibenzolar-S-methyl (ASM) (25 mg active ingredient (a.i.) L^{-1}), copper oxychloride (1,100 mg a.i. L^{-1}), azoxystrobin (80 mg a.i. L^{-1}) and control (water). The disease control showed by turmeric extracts and curcumin solutions was similar to cupric fungicide, but inferior to azoxystrobin. There was no statistical difference in commercial fruit production between treatments. Only 50 mg L^{-1} curcumin treatment had a higher percentage of larger fruits than the control.

Several turmeric species have demonstrated bactericidal activity. Tyagi et al. (2015) tested the antibacterial activity of curcumin I (purity ≥ 97%) against prominent pathogens in hospital settings, which are *Staphylococcus aureus* and *Enterococcus faecalis* (gram-positive) and *Escherichia coli* and *Pseudomonas aeruginosa* (gram-negative), at the concentrations 25 μM, 50 μM and 100 μM, and verified that turmeric had a strong antibacterial potential against all the tested bacteria mainly in concentration at 100 μM, due the membrane leakage in bacteria.

Turmeric can be used in food production and dental products for prevention of oral diseases, once that xanthorrhizol from *C. xanthorrhiza* demonstrated high bactericidal activity against pathogens caries and other related problems (HWANG et al., 2000). Sunilson et al. (2009), working with petroleum, chloroform, methanol and water extracts of *C. longa*, *Zingiber officinale* and *Alpinia galanga*, demonstrated a bactericidal effect against common food borne bacteria such as *Bacillus cereus*, *E. coli*, *Salmonella enteritidis*, *Clostridium perfringens*, *Campylobacter jejuni* and *Staphylococcus aureus*. The author related in the same work the antifungal activity of these extracts against *Saccharomyces cerevisiae*, *Hansenula anomala*, *Mucor macedo* and *Candida albicans* probably due to phenolic compounds present in the extracts.

The control of *Xanthomonas axonopodis* pv. *manihotis*, that causes cassava bacterial blight, was evaluated by Kuhn et al. (2006) using an aqueous extract of four turmeric genotypes originating from Jaboticabal (São Paulo State), Mara Rosa (Goiás State), Maringá and Mercedes (Paraná State), by treatment of infected cassava stems and their cultivation at field conditions. The results showed that at *in vitro* experiment, turmeric extract completely inhibited bacterial growth at 10% concentration for the genotype from Mercedes, while for Jaboticabal's turmeric there was a total control at 15% and for Mara Rosa at 20%. Turmeric genotype from Maringá did not fully inhibit bacterial growth at any of the extract concentrations used. Under field conditions, sproutings were extremely low, due to the degree of stem infection. Turmeric extract at 10% from Mercedes was harmful to cassava, reducing number of plants regarding the treatments control. Possibly there was a direct toxic action of the turmeric extract on plant physiology or induction of susceptibility in cassava to pathogen. There was no statistical difference in relation to the control treatment for plant parameters in the plant stand when 1% turmeric from Maringá was used. Chemical control was not completely efficient and there was no statistical difference among treatments for both severity and productivity. The results indicate that, although presenting antibacterial activity to *X. axonopodis* pv. *manihotis*, the turmeric extracts at the used concentrations could not present a curative effect in cassava stems infected with the pathogen.

Amaral et al. (2014), studying the biological active of compounds of the hexane fractions obtained from the crude methanol extract of the turmeric cortex and turmeric without cortex (hexRHIC and hex-RHIWC) and their respective liposomal formulations (LipoRHIC and LipoRHIWC) to prevent the growth of *Leishmania in vitro* and observed that the minimum inhibitory concentration to hexRHIC and hex-RHIWC was 125 and 250 μg mL^{-1} and LipoRHIC and to LipoRHIWC was 5.5 μg mL^{-1} and 125 μg mL^{-1}, respectively, and observed that the parasite treated with LipoRHIC at 5.5. μg mL^{-1} displayed a rounded body and had an abnormal membrane projection, mitochondrion swelling with several vacuoles inside the organelle and intracellular disorganization. Rasmussen et al. (2000) also showed that the ethanolic extract of turmeric inhibited the *in vitro* growth of *Plasmodium falciparum* and *Leishmania major*.

Turmeric also presents activity against plant nematodes and has potential anthelmintic in humans and animals (SHIH et al., 2007; AMIN et al., 2009; MIORANZA et al., 2016). In the work of Babu et al. (2012), the curcumin, mainly property of turmeric, presented a great nematicidal potential that inhibited 92.48% the activity of glutathione-S-transferase enzyme of *Meloidogyne incognita*, enzyme responsible for survival of nematode in the host plants and has antioxidant activity that cause detoxification of *M. incognita*.

The aqueous extract of turmeric at concentrations of 10% and 15% reduce the second stage juveniles (J2) mobility of *M. incognita* to zero in *in vitro* assay, 15% promoted more than 90% of mortality, and all concentrations (1%, 5%, 10% and 15%) reduce the hatching of nematode (MIORANZA et al., 2016).

Borges et al. (2013) studied the toxicity of aqueous extract of turmeric at concentration of 10% against juveniles of *Tubixaba tuxaua* and *M. incognita* and observed more than 100% of mortality of the pathogens.

Water extract of turmeric at 100 mg mL^{-1} promoted 100% of efficacy at *in vitro* assay against adult worms of *Strongyles bunostomum*, *Strongyloides trichuris* and *Capillaria*, parasites of cattle (AMIN et al., 2009).

Other biological activities of turmeric

Kermanshahi and Riasi (2006) conducted an i*n vivo* study to verify the effect of turmeric rhizome powder and soluble non-starch polysaccharide (NSP) degrading enzymes in some blood parameters of laying hens (hematocrit value, triglyceride, total cholesterol, HDL and LDL-cholesterol). Increasing dietary levels of turmeric rhizome powder (0.0, 0.05, 0.10, 0.15, and 0.20%) with or without a dietary enzyme (levels 0.0 and 0.05%) significantly decreased serum triglyceride, total cholesterol and LDL-cholesterol. Turmeric rhizome powder without enzyme significantly increased HDL-cholesterol. It was concluded that dietary supplementation of turmeric rhizome powder improves some of good indices of serum blood components in laying hens and might be used as an ingredient in laying hen diets for manipulating egg composition.

Bioassay-directed fractionation of ethyl acetate extract from *C. longa* rhizomes yielded three curcuminoids, which displayed topoisomerase I and II enzyme inhibition activity. Curcumin III 25 µg mL^{-1} was the most active curcuminoid, inhibiting topoisomerase. Curcumin I and curcumin II inhibited the topoisomerases at 50 µg mL^{-1}. Fractionation of the volatile oil from the rhizomes afforded ar-turmeron, which displayed mosquitocidal activity with an LD100 of 50 µg mL^{-1} on *Aedes aegyptii* larvae. Bioassay-directed fractionation of hexane extract from the turmeric leaves yielded labda-8(17),12-diene-15,16 dial with antifungal activity against *Candida albicans* at 1 µg mL^{-1} and inhibited the growth of *Candida kruseii* and *Candida parapsilosis* at 25 µg mL^{-1}. In addition, labda-8(17),12-diene-15,16 dial displayed 100% mosquitocidal activity on *A. aegyptii* larvae at 10 µg mL^{-1} (ROTH et al., 1998). Chander et al. (2000) tested for repelency of cetone extract of *C. longa* rhizomes at 1%, sprayed on both sides of the empty storage bag in which were packed rice dry and evaluated regarding presence of red flour beetle (*Tribolium castaneum* Herbst) after 2, 4 and 6 storage months. The authors observed repellency of 72.5% to the turmeric extract, equal to the neem oil (67.9%) and a close for repellency of the product cypermethrin (90.1%) used to this finality.

Kalaivani et al. (2012) tested the effect of extracts of *C. longa* on total larval instar and pupa of *Aedes aegypti* and the higher mortality rate against the fourth instar was reached at 200 mg L^{-1}. The authors suggest that these essential oils can be useful to reduce the breeding larvae of *A. aegypti* in containers, plastic bags and blocked roof gutters. Rabha et al. (2012) used essential oil of *C. longa* leaf to evaluate larvicidal activity against *Aedes albopictus* and *Culex quinquefasciatus in vitro*, and the lethal concentration of 24.7 (%v/v) showed the best larvicidal activity.

Tripathi et al. (2002) tested toxicity of leaf essential oil of *Curcuma longa* for contact or fumigation and its effect on progeny production in three stored-product beetles, *Rhyzopertha dominica* F. (lesser grain borer), *Sitophilus oryzae* L. (rice weevil), and *Tribolium castaneum* Herbst (red flour beetle) and observed that essential oil were toxic for this three insect species affecting larvae, adults, eggs and oviposition. Singh et al. (2002) tested the effect of volatile oil of C. zedoaria and *C. aromatica* against *Odontotermes obesus* (white termite), an pest of sugarcane, varying dose and exposure time and observed that 6 µL of *C. zedoaria* oil during 4 hours killed 100% of insects and 6 µL of *C. aromatica* oil during 2 hours killed 100% of insects, which was similar to chlorpyriphos (20%) and better that endosulfan (35%), showing promising as insecticidal.

The turmeric can also act as molluscicide. According Silva Filho et al. (2009) oleoresin (extracted with acetone) and essential oil (extracted by steam distillation) of turmeric were active against the adults nails of *Biomphalaria glabrata* at lethal concentration of 58.3 and 46.73 µg mL^{-1}, respectively, concluding that it can be an alternative to control these snails and the reduction of the disease caused by them, the Schistosomiasis.

REFERENCES

AKAMINE, H.; HOSSAIN, A.; ISHIMINE, Y.; YOGI, K.; HOKAMA, K.; IRAHA, Y.; ANIYA, Y. Effects of application of N, P and K alone or in combination on growth, yield and curcumin content of turmeric (*Curcuma longa* L.). **Plant Production Science**, Tokyo, v.10, n.1, p.151-154, 2007.

AKRAM, M.; UDDIN, S.; AHMED, A.; USMANGHANI, K.; HANNAN, A.; MOHIUDDIN, E.; ASIF, M. *Curcuma longa* and curcumin: a review article. **Romanian Journal of Biology - Plant Biology**, Bucharest, v.55, n.2, p.65-70, 2010.

AMARAL, A.C.F.; GOMES, L.A.; SILVA, J.R.A.; FERREIRA, J.L.P.; RAMOS, A.S.; ROSA, M.S.S.; VERMELHO, A.B.; RODRIGUES, I.A. Liposomal formulation of turmerone-rich hexane fractions from *Curcuma longa* enhances their antileishmania activity. **BioMed Research International**, v.2014, p.1-8, 2014.

AMIN, M.R.; MOSTOFA, M.; HOQUE, M.E.; SAYED, M.A. *In vitro* anthelmintic efficacy of some indigenous medicinal plants against gastrointestinal nematodes of cattle. **Journal of the Bangladesh Agricultural University**, Bangladesh, v.7, n.1, p.57-61, 2009.

APISARIYAKUL, A.; VANITTANAKOM, N.; BUDDHASUKH, D. Antifungal activity of turmeric oil extracted from *Curcuma longa* (Zingiberaceae). **Journal of Ethnopharmacology**, Pretoria, v.49, n.3, p.163-169, 1995.

ARAÚJO, C.A.C.; LEON, L.L. Biological activities of *Curcuma longa* L. **Memórias do Instituto Oswaldo Cruz**, Rio de Janeiro, v.96, n.5, p.723-728, 2001.

BABU, R.O.; MOORKOTH, D.; AZEEZ, S.; EAPEN, S.J. Virtual screening and *in vitro* assay of potential drug like inhibitors from spices against glutathione-S-transferase of *Meloidogyne incognita*. **Bioinformation**, v.8, n.7, p.319-325, 2012.

BALBI-PEÑA, M.I.; BECKER, A.; STANGARLIN, J.R.; FRANZENER, G.; LOPES, M.C.; SCHWAN-ESTRADA, K.R.F. Control of Alternaria solani in tomato by *Curcuma longa* extracts and curcumin - I. *In vitro* evaluation. **Fitopatologia Brasileira**, Lavras, v.31, n.3, p.310-314, 2006a.

BALBI-PEÑA, M.I.; BECKER, A.; STANGARLIN, J.R.; FRANZENER, G.; LOPES, M.C.; SCHWAN-ESTRADA, K.R.F. Control of *Alternaria solani* in tomato by *Curcuma longa* extracts and curcumin - II. *In vivo* evaluation. **Fitopatologia Brasileira**, Lavras, v.31, n.4, p.401-404, 2006b.

BEHURA, S. Gas chromatographic evaluation of *Curcuma* essential oils. **Proceedings of the Centennial Conference on Spices and Aromatic Plants**, Calicut, p.291-292, 2000.

BEHURA, S.; SAHU, S.; SRIVASTAVA, V.K. Major constituents in leaf essential oil of *Curcuma longa* L. and *Curcuma aromatica* Salisb. **Current Science**, Bangaluru, v.83, n.11, p.1312-1313, 2002.

BEHURA, S.; SRIVASTAVA, V.K. Essential oils of leaves of *Curcuma species*. **Journal of Essential Oil Research**, Messina, n.16, v.9, p.109-110, 2004.

BENKEBLIA, N. Natural biological compounds and food preservation. **Food**, v.1, p.111-245, 2007.

BERNI, R.F.; CHAVES, F.C.M.; PINHEIRO, J.B.; VAZ, A.P.A. Produção de açafrão em função de acessos e do peso de rizoma

semente. **Revista Brasileira de Plantas Medicinais**, Paulínia, v.16, n.3, p.765-770, 2014.

BHAWANA, BASNIWAL, R.K.; BUTTAR, H.S.; JAIN, V.K.; JAIN, N. Curcumin nanoparticles: preparation, characterization, and antimicrobial study. **Journal of Agricultural and Food Chemistry**, München, v.59, p.2056-2061, 2011.

BURAGOHAIN, J.; DUTTA, G.N. Evaluation of an externally applied herbal gel, AV/AMP/14, for the treatment of bovine subclinical mastitis. **Indian Veterinary Journal**, Chennai, v.75, n.8, p.734-755, 1998.

BORGES, F.G.; KUHN, O.J.; BATTISTUS, A.G.; ESTEVEZ, R.L.; COLTRO, S. Toxidade de tratamentos alternativos e químicos *in vitro* sobre *Tubixaba tuxaua* e *Meloidogyne incognita*. **Scientia Agraria Paranaensis**, Marechal Cândido Rondon, v.12, n.Suplemento, p.440-449, 2013.

CECÍLIO FILHO, A.B.; SOUZA, R.J.; BRAZ, L.T.; TAVARES, M. Cúrcuma: medicinal, condimentar e outros usos potenciais. **Ciência Rural**, Santa Maria, v.30, n.1, p.171-175, 2000.

CECÍLIO FILHO, A.B.; SOUZA, R.J. Influência do espaçamento e peso do rizoma-semente na cultura do açafroeiro-da-Índia. **Horticultura Brasileira**, Brasília, v.12, n.1, p.76, 1994.

CECÍLIO FILHO, A.B.; SOUZA, R.J. Caracterização dos estádios fenológicos da cúrcuma, em função da época e densidade de plantio. **Horticultura Brasileira**, Brasília, v.17, n.3, p.248-253, 1999.

CECÍLIO FILHO, A.B.; SOUZA, R.J.; FAQUIN, V.; CARVALHO, C.M. Época e densidade de plantio na produção de cúrcuma. **Ciência Rural**, Santa Maria, v.34, n.4, p.1021-1026, 2004.

CHANDER, H.; AHUJA, D.K.; NAGENDER, A.; BERRY, S.K. Repellency of different plant extracts and commercial formulations used as prophylactic sprays to protect bagged grain against *Tribolium castaneum* - a field study. **Journal of Food Science and Technology Mysore**, v.37, n.6, p.582-585, 2000.

CHANDRA, R.; DESAI, A.R.; GOVIND, S.; GUPTA, P.N. Metroglyph analysis in turmeric (*Curcuma longa* L.) germoplasm in India. **Scientia Horticulturae**, v.70, n.2-3, p.211-233, 1997.

CHANDRA, R.; GOVIND, S.; DESAI, A.R. Growth, yield and quality performance of turmeric (*C. longa* L.) genotypes in mid altitudes of Meghalaya. **Journal of Applied Horticulture**, v.1, n.2, p.142-144, 1999.

CHEN, J.; HE, Z.M.; WANG, F.L.; ZHANG, Z.S.; LIU, X.Z.; ZHAI, D.D.; CHEN, W.D. Curcumin and its promise as an anticancer drug: an analysis of its anticancer and antifungal effects in cancer and associated complications from invasive fungal infections. **European Journal of Pharmacology**, Utrecht, v.772, p.33-42, 2016.

CHANE-MING, J.; VERA, R.; CLAUDE CHALCHAT, J.; CABASSU, P. Chemical composition of essential oils from rhizomes, leaves and flowers of *Curcuma longa* L. from Reunion Islands. **Journal of Essential Oil Research**, Messina, v.14, n.4, p.249-251, 2002.

CHATTOPADHYAY, I.; BISWAS, K.; BANDYOPADHYAY, U.; BANERJEE, R.K. Turmeric and curcumin: biological actions and medicinal applications. **Current Science**, Bangaluru, v.87, n.1, p.44-53, 2004.

CHO, J.Y.; CHOI, G.J.; LEE, S.W.; JANG, K.S.; LIM, H.K.; LIM, C.H.; LEE, S.O.; CHO, K.Y.; KIM, J.C. Antifungal activity against *Colletotrichum* spp. of curcuminoids isolated from *Curcuma longa* L. rhizomes. **Journal of Microbiology and Biotechnology**, Kangnam-gu, v.16, n.2, p.280-285, 2006.

CHUTIA, M.; MAHANTA, J.J.; SAIKIA, R.C.; BARUAH, A.K.S.; SARMA, T.C. Influence of leaf blight disease on yield of oil and its constituents of *Java citronella* and *in vitro* control of the pathogen using essential oils. **World Journal of Agricultural Sciences**, Deira, v.2, n.3, p.319-321, 2006.

FERREIRA, F.D.; MOSSINI, S.A.G.; FERREIRA, F.M.D.; ARROTÉIA, C.C.; COSTA, C.L.; NAKAMURA, C.V.; MACHINSKI JUNIOR, M. The inhibitory effects of *Curcuma longa* L. essential oil and curcumin on *Aspergillus flavus* Link growth and morphology. **The Scientific World Journal**, Cairo, v.2013, p.1-6, 2013.

FIORI, A.C.G.; SCHWAN-ESTRADA, K.R.F.; STANGARLIN, J.R.; VIDA, J.B.; SCAPIM, C.A.; CRUZ, M.E.S.; PASCHOLATI, S.F. Antifungal activity of leaf extracts and essential oils of some medicinal plants against *Didymella bryoniae*. **Journal of Phytopathology**, Malden, v.148, n.7-8, p.483-487, 2000.

FUNK, J.L.; OYARZO, J.N.; FRYE, J.B.; CHEN, G.; LANTZ, R.C.; JOLAND, S.D.; SÓLYOM, A.M.; TIMMERMANN, B.N. Turmeric extracts containing curcuminoids prevent experimental rheumatoid arthritis. **Journal of Natural Products**, Columbus, v.69, n.3, p.351-355, 2006.

GOWDA, N.K.S.; MALATHI, V.; SUGANTHI, R.U. Effect of some chemical and herbal compounds on growth of *Aspergillus parasiticus* and aflatoxin production. **Animal Feed Science and Technology**, Madri, v.116, n.3-4, p.281-291, 2004.

GURJAR, M.S.; ALI, S.; AKTHAR, M.; SINGH, K.S. Efficacy of plant extracts in plant disease management. **Agricultural Sciences**, Milão, v.3, n.3, p.425-433, 2012.

HAZRA, P.; ROY, A.; BANDHOPADYAY, A. Growth characters as rhizome yield components of turmeric. **Crop Research**, Hisar, v.19, n.2, p.235-246, 2000.

HENRY, B. Use of *Capsicum* and turmeric as natural colours. **Indian Spices**, v.35, n.7-14, 1998.

HWANG, J.K.; SHIM, J.S.; PYUN, Y.R. Antibacterial activity of xanthorrhizol from *Curcuma xanthorrhiza* against oral pathogens. **Fitoterapia**, Novara, v.71, n.3, p.321-323, 2000.

JIANG, H.; TIMMERMANN, B.N.; GANG, D.R. Use of liquid chromatography–electrospray ionization tandem mass spectrometry to identify diarylheptanoids in turmeric (*Curcuma longa* L.) rhizome. **Journal of Chromatography**, v.1111, n.1, p.21-31, 2006.

JURENKA, J.S. Anti-inflammatory properties of curcumin, a major constituent of *Curcuma longa*: a review of preclinical and clinical research. **Alternative Medicine Review**, Napa, v.14, n.2, p.141-153, 2009.

KALAIVANI, K.; SENTHIL-NATHAN, S.; MURUGESAN, A.G. Biological activity of selected Lamiaceae and Zingiberaceae plant essential oils against the dengue vector *Aedes aegypti* L. (Diptera: Culicidae). **Parasitology Research**, Düsseldorf, v.110, n.3, p.1261-1268, 2012.

KHANNA, N.M. Turmeric – nature's precious gift. **Current Science**, Bangaluru, v.76, n.10, p.1351-1356, 1999.

KERMANSHAHI, H.; RIASI, A. Effect of turmeric rhizome powder (*Curcuma longa*) and soluble NSP degrading enzyme on some blood parameters of laying hens. **International Journal of Poultry Science**, Deira, v.5, n.5, p.494-498, 2006.

KIM, M.K.; CHOI, G.J.; LEE, H.S. Fungicidal property of *Curcuma longa* L. rhizome-derived curcumin against phytopathogenic fungi in a greenhouse. **Journal of Agricultural and Food Chemistry**, München, v.51, n.6, p.1578-1581, 2003.

KOLTE, A.Y.; SADEKAR, R.D.; MODE, S.G.; GAWAI, G.R. Comparative efficacy of indigenous medicinal plant preparation and tilox in subclinical mastitis in cows. **Indian Veterinary Journal**, Chennai, v.76, n.10, p.893-895, 1999.

KUHN, O.J.; PORTZ, R.L.; STANGARLIN, J.R.; DEL ÁGUILA, R.M.; SCHWAN-ESTRADA, K.R.F.; FRANZENER, G. Effect of aqueous extract from turmeric (*Curcuma longa*) on *Xanthomonas axonopodis* pv. *manihotis*. **Semina: Ciências Agrárias**, Londrina, v.27, n.1, p.13-20, 2006.

KWON, Y.; MAGNUSON, B. Age-related differential responses to curcumin-induced apoptosis during the initiation of colon cancer in rats. **Food and Chemical Toxicology**, Catalonia, v.47, n.2, p.377-385, 2009.

LEAN, L.P.; MOHAMED, S. Antioxidative and antimycotic effects of turmeric, lemon-grass, betel leaves, clove, black pepper leaves and *Garcinia atriviridis* on butter cakes. **Journal of the Science of Food and Agriculture**, Malden, v.79, n.13, p.1817-1822, 1999.

LEE, C.J.; LEE, J.H.; SEOK, J.H.; HUR, G.M.; PARK, Y.C.; SEOL, I.C.; KIM, Y.H. Effects of baicalcin, berberine, curcumin and hespiridin on mucin release from airway globet cells. **Planta Medica**, Muttenz, v.69, n.6, p.523-526, 2003.

LEE, S.E.; PARK, B.S.; BAYMAN, P.; BAKER, J.L.; CHOI, W.S.; CAMPBELL, B.C. Suppression of ochratoxin biosynthesis by naturally occurring alkaloids. **Food Additives and Contaminants**, York, v.24, n.4, p.391-397, 2007a.

LEE, S.H.; CHANG, K.S.; SU, M.S.; HUANG, Y.S.; JANG, H.D. Effects of some Chinese medicinal plant extracts on five different fungi. **Food Control**, Reading, v.18, n.2, p.1547-1554, 2007b.

LI, S.; YUAN, W.; DENG, G.; WANG, P.; YANG, P.; AGGARWAL, B.B. Chemical composition and product quality control of turmeric (*Curcuma longa* L.). **Pharmaceutical Crops**, Nacogdoches, v.2, n.1, p.28-54, 2011.

LIJU, B.V.; JEENA, K.; RAMADASAN, K. An evaluation of antioxidant, anti inflammatory, and antinociceptive activities of essential oil from *Curcuma longa* L. **Indian Journal of Pharmacology**, Ahmedabad, v.43, n.5, p.526-531, 2011.

LIN, J.K.; LIN-SHIAU, S.Y. Mechanisms of cancer chemoprevention by curcumin. **Proceedings of the National Science Council, Republic of China. Part B, Life Sciences**, v.25, n.2, p.59-66, 2001.

MAIA, N.B.; BOVI, A.O.; DUARTE, F.R. Influência de tipos de rizomas de multiplicação no crescimento de *Curcuma longa* L. (Cúrcuma). **Bragantia**, Campinas, v.54, n.1, p.33-37, 1995.

MAJEED, H.; BIAN, Y.Y.; ALI, B.; JAMIL, A.; MAJEED, U.; KHAN, Q.F.; IQBAL, K.J.; SHOEMAKER, C.F.; FANG, Z. Essential oil encapsulations: uses, procedures, and trends. **RSC Advances**, Bangalore, v.5, p.58449-58493, 2015.

MANDAL, M.K.; CHAUHAN, J.P.S. A survey of ethnoveterinary medicine practices in West Bengal. **Indian Journal of Veterinary Medicine**, Ghaziabad, v.20, n.2, p.90-91, 2000.

MARTINS, M.C.; RUSIG, O. Cúrcuma: um corante natural. **Boletim da Sociedade Brasileira de Ciência e Tecnologia de Alimentos**, Campinas, v.26, n.1, p.56-65, 1992.

MAZUMDER, A.; RAGHAVAN, K.; WEINSTEIN, J.; KOHN, K.W.; POMMIER, Y. Inhibition of human immunodeficiency virus type-1 integrase by curcumin. **Biochemical Pharmacology**, Kansas, v.49, n.8, p.1165-1170, 1995.

MIORANZA, T.M.; MÜLLER, M.A.; INAGAKI, A.M.; FUCHS, F.; COLTRO-RONCATO, S.; STANGARLIN, J.R.; KUHN, O.J. Potencial nematicida e nematostático do extrato de *Curcuma longa* sobre *Meloidogyne incognita*. **Revista de Ciências Agroambientais**, Alta Floresta, v.14, n.1, p.104-109, 2016.

MISHRA, S.; NARAIN, U.; MISHRA, R.; MISRA, K. Design, development and synthesis of mixed bioconjugates of piperic acid-glycine, curcumin-glycine/alanine and curcumin-glycine-piperic acid and their antibacterial and antifungal properties. **Bioorganic and Medicinal Chemistry**, Dortmund, v.13, n.5, p.1477-1486, 2005.

MISHRA, D. Ethnoveterinary practices and use of herbal medicines for treatment of skin diseases in cattle: a study in Polsara Block, Ganjam District, Orissa, India. **Veterinary World**, Wankaner, v.4, n.6, p.250-253, 2011.

MOGHADAMTOUSI, S.Z.; KADIR, H.A.; HASSANDARVISH, P.; TAJIK, H.; ABUBAKAR.; ZANDI, K. A review on antibacterial, antiviral, and antifungal activity of curcumin. **BioMed Research International**, Cairo, v.2014, n.2014, p.1-12, 2014.

NAGHETINI, C.D.C. **Caracterização físico-química e atividade antifúngica dos óleos essenciais da cúrcuma**. 2006. 61p. Dissertação (Mestrado em Ciência de Alimentos) - Universidade Federal de Minas Gerais, Belo Horizonte, 2006.

OONMETTA-AREEA, J.; SUZUKIB, T.; GASALUCKA, P.; EUMKEB, G. Antimicrobial properties and action of galangal (*Alpinia galanga* Linn.) on *Staphylococcus aureus*. **LWT - Food Science and Technology**, Athens, v.39, n.10, p.1214-1220, 2006.

OOTANI, M.A.; AGUIAR, R.W.; RAMOS, A.C.C.; BRITO, D.C.; SILVA, J.B.; CAJAZEIRA, J.P. Use of essential oils in agriculture. **Journal of Biotechnology and Biodiversity**, Gurupi, v.4, n.2, p.162-174, 2013.

PAPANG, J.S.; TRIPATHI, A.K. Costs and returns structure of turmeric (*Curcuma longa* linn.) and constraints faced by producers in Jaintia Hills district of Meghalaya, India. **Agricultural Research Communication Centre**, v.48, n.3, p.192-198, 2014.

PARK, S.Y.; KIM, D.S.H.L. Discovery of natural products from *Curcuma longa* that protect cells from beta-amyloidal insult, a drug discovery effort against Alzheimer's disease. **Journal of Natural Products**, Columbus, v.65, n.9, p.1227-1231, 2002.

PARK, I.K.; KIM, J.; LEE, Y.S.; SHIN, S.C. *In vivo* fungicidal activity of medicinal plant extracts against six phytopathogenic fungi. **International Journal of Pest Management**, Bariloche, v.54, n.1, p.63-68, 2008.

PAWAR, V.C.; THAKER, V.S. *In vitro* efficacy of 75 essential oils against *Aspergillus niger*. **Mycoses**, Malden, v.49, n.4, p.316-323, 2006.

PEREIRA, A.S.; STRINGHETA, P.C. Considerações sobre a cultura e processamento do açafrão. **Horticultura Brasileira**, Brasília, v.16, n.2, p.102-105, 1998.

PÉRET-ALMEIDA, L.; NAGHETINI, C.C.; NUNAN, E.A.; JUNQUEIRA, R.G.; GLÓRIA, M.B.A. Atividade antimicrobiana *in vitro* do rizoma em pó, dos pigmentos curcuminóides e dos óleos essenciais da *Curcuma longa*. **Ciência e Agrotecnologia**, Lavras, v.32, n.3, p.875-881, 2008.

PEROTTI, A.G. Curcumin - a little known but useful vegetable colour. **Indian Aliment for Products and Vegetables**, v.14, n.6, p.66-68, 1975.

PETER, K.V. Informatics on turmeric and ginger. **Indian Spices**, v.36, n.2-3, p.12-14, 1999.

PRASAD, S.; AGGARWAL, B.B. Turmeric, the golden spice: from traditional medicine to modern medicine. In: BENZIE, I.F.F.; WACHTEL-GALOR, S. (Ed). **Herbal medicine**: biomolecular and clinical aspects. Boca Raton (FL): CRC Press/Taylor & Francis, 2011. cap.13.

RAHBA, B.; GOPALAKRISHNAN, R.; BARUAH, I.; SINGH, L. Larvicidal activity of some essential oil hydrolates against dengue and filariasis vectors. **E3 Journal of Medical Research**, Milpitas, v.11, n.1, p.14-16, 2012.

RAJA, J.; KURUCHEVE, V. Influence of plant extracts and buffalo urine on the growth and sclerotial germination of *Macrophomina phaseolina*. **Indian Phytopathology**, New Delhi, v.51, n.1, p.102-103, 1998.

RAJAKRISHNAN, V.; VISHWANATHAN, P.; RAJASEKHARAN, K.N.; MENON, V.P. Neuroprotective role of curcumin from *Curcuma longa* on ethanol induced brain damage. **Phytotherapy Research**, Malden, v.13, n.7, p.571-574, 1999.

RANGSAZ, N.; AHANGARAN, M.G. Evaluation of turmeric extract on performance indices impressed by aflatoxicosis in broiler chickens. **Toxicology and Industrial Health**, v.27, n.10, p.956-960, 2011.

RASMUSSEN, H.B.; CHRISTENSEN, S.B.; KVIST, L.P.; KARASMI, A.A. A single and efficient separation of the curcumins, the antiprotozoal constituents of *Curcuma longa*. **Planta Medica**, Muttenz, v.66, n.4, p.396-398, 2000.

ROTH, G.N.; CHANDRA, A.; NAIR, M.G. Novel bioactivities of *Curcuma longa* constituents. **Journal of Natural Products**, Columbus, v.61, n.4, p.542-545, 1998.

RUBY, A.J.; KUTTAN, G.; BABU, K.D.; RAJASEKHARAN, K.N.; KUTTAN, R. Anti-tumour and antioxidant activity of natural curcuminoids. **Cancer Letters**, Heidelberg, v.94, n.1, p.79-83, 1995.

SAJU, K.A.; VENUGOPAL, M.N.; MATHEW, M.J. Antifungal and insect-repellent activities of essential oil of turmeric (*Curcuma longa* L.). **Current Science**, Bangaluru, v.75, n.7, p.660-662, 1998.

SASIKUMAR, B. Turmeric. In: Peter KV (Ed). **Handbook of Herbs and Spices**, v.1, n.2, p.297-308, 2001.

SASIKUMAR, B. Genetic resources of *Curcuma*: diversity, characterization and utilization. **Plant Genetic Resources**, Cambridge, v.3, n.2, p.230-251, 2005.

SELVAN, R.; SUBRAMANIAN, L.; GAYATHRI, R.; ANGAYARKANNI, N. The anti-oxidant activity of turmeric (*Curcuma longa*). **Journal of Ethnopharmacology**, Pretoria, v.47, n.2, p.59-67, 1995.

SHAH, N.C. Traditional uses of turmeric (*C. longa* L.) in India. **Journal of Medicinal and Aromatic Plant Science**, Stuttgart, v.19, p.948-954, 1997.

SHARMA, M.C.; JOSHI, C. Plants used in skin diseases of animals. **Natural Product Radiance**, New Delhi, v.3, n.4, p.293-299, 2004.

SHARMA, R.A.; GESCHER, A.J.; STEWARD, W.P. Curcumin: the story so far. **European Journal of Cancer**, New York, v.41, n.13, p.1955-1968, 2005.

SHARMA, R.K.; MISRA, B.P.; SARMA, T.C.; BORDOLOI, A.K.; PATHAK, M.G.; LECLERCQ, P.A. Essential oil of *Curcuma longa* from Bhutan. **Journal of Essential Oil Research**, Messina, v.9, n.5, p.589-592, 1997.

SHIH, P.C.; LEE, H.H.; LAI, S.C.; CHEN, K.M.; JIANG, S.T.; CHEN, Y.F.; SHIOW, S.J. Efficacy of curcumin therapy against *Angiostrongylus cantonensis* - induced eosinophilic meningitis. **Journal of Helminthology**, Egham, v.81, n.1, p.1-5, 2007.

SHPITZ, B.; GILADI, N.; SAGIV, E.; LEV-ARI, S.; LIBERMAN, E.; KAZANOV, D.; ARBER, N. Celecoxib and curcumin additively inhibit the growth of colorectal cancer in a rat model. **Digestion**, Basel, v.74, n.3-4, p.140-144, 2006.

SHRISHAIL, D.; HARISH, K.H.; RAVICHANRA, H.; TULSIANAND, G.; SHRUTHI, S.D. Turmeric: nature's precious medicine. **Asian Journal of Pharmaceutical and Clinic Research**, Sagar, v.6, n.3, n.10-16, 2013.

SIGRIST, M.S.; PINHEIRO, J.B.; AZEVEDO FILHO, J.A.; ZUCCHI, M.I. Genetic diversity of turmeric germplasm (*Curcuma longa*; Zingiberaceae) identified by microsatellite markers. **Genetics and Molecular Research**, Ribeirão Preto, v.10, n.1, p.419-428, 2011.

SINGH, G.; SINGH, O.P.; MAURYA, S. Chemical and biocidal investigations on essential oils of some indian curcuma species. **Progress in Crystal Growth and Characterization of Materials**, v.45, n.1-2, p.75-81, 2002.

SINGH, R.; RAI, B. Antifungal potential of some higher plants against *Fusarium udum* causing wilt disease of *Cajanus cajan*. **Microbios**, v.102, n.403, p.165-173, 2000.

SINGH, S.; KUANAR, A.; MOHANTY, S.; SUBUDHI, E.; NAYAK, S. Evaluation of phytomedicinal yield potential and molecular profiling od micropropagated and conventionally grown turmeric (*Curcuma longa* L.). **Plant Cell, Tissue Organ Culture**, Dijon, v.104, n.2, p.263-269, 2011a.

SINGH, R.; MEHTA, A.; MEHTA, P.; SHUKLA, K. Anthelmintic activity of rhizome extracts of *Curcuma longa* and *Zingiber officinale* (Zingiberaceae). **International Journal of Pharmacy and Pharmaceutical Sciences**, Sagar, v.3, n.2, p.236-237, 2011b.

STANGARLIN, J.R.; KUHN, O.J.; ASSI, L.; SCHWAN-ESTRADA, K.R.F. Control of plant diseases using extracts from medicinal plants and fungi. **Science Against Microbial Pathogens: Communicating Current Research And Technological Advances**, Badajóz, v.2, n.3, p.1033-1042, 2011.

SUETH-SANTIAGO, V.; MENDES-SILVA, G.P.; DECOTÉ-RICARDO, D.; LIMA, M.E.F. Curcumina, o pó dourado do açafrão-da-terra: introspecções sobre química e atividades biológicas. **Química Nova**, São Paulo, v.38, n.4, p.538-552, 2015.

TANAKA, K.; KUBA, Y.; SASAKI, T.; HIWATASHI, F.; KOMATSU, K. Quantitation of curcuminoids in curcuma rhizome by near-infrared spectroscopic analysis. **Journal of Agricultural and Food Chemistry**, München, v.56, n.19, p.8787-8792, 2008.

THAIKERT, R.; PAISOOKSANTIVATANA, Y. Variation of total curcuminoids content, antioxidant activity and genetic diversity in turmeric (*Curcuma longa* L.) collections. **Kasetsart Journal (Nat Sci)**, Bangkok, v.43, n.3, p.507-518, 2009.

TRIPATHI, A.K.; PRAJAPATI, V.; VERMA, N.; BAHL, J.R.; BANSAL, R.; KHANUJA, S.P.S.; KUMAR, S. Bioactivities of the leaf essential oil of *Curcuma longa* (Var. Ch-66) on three species of stored-product beetles (Coleoptera). **Journal of Economic Entomology**, Riverside, v.95, n.1, p.183-189, 2002.

TODA, S.; MYIASE, T.; ARICHI, H.; TANIZAWA, H.; TAKINO, Y. Natural antioxidants. III. Antioxidative components isolated from rhizome of *Curcuma longa* L. **Chemical and Pharmaceutical Bulletin**, Tokyo, v.33, n.4, p.1725-1728, 1985.

TYAGI, P.; SINGH, M.; KUMARI, H.; KUMARI, A.; MUKHOPADHYAY, K. Bactericidal activity of curcumin I is associated with damaging of bacterial membrane. **Plos One**, San Francisco, v.10, n.3, p.1-15, 2015.

UDOMDEE, W.; FUKAI, S.; PETPRADAP, L.; DA SILVA, J.A.T. *Curcuma*: studies on tissue culture, pollen germination and viability, histology and flow cytometry. **Propagation of Ornamental Plants**, Sofia, v.3, n.1, p.34-41, 2003.

UECHI, S.; MIYAGI, Y.; ISHIMINE, Y.; HONGO, F. Antibacterial activity of essential oils from *Curcuma* sp. (Zingiberaceae) cultivated in Okinawa against foodborne pathogenic bacteria. **Japanese Journal of Tropical Agriculture**, Tokyo, v.44, n.2, p.138-140, 2000.

UNNIKRISHNAN, M.K.; RAO, M.N. Inhibition of nitrite induced oxidation of hemoglobin by curcuminoids. **Pharmazie**, Frankfurt, v.50, n.7, p.490-492, 1995.

VELAYUDHAN, K.C.; MURALIDHARAN, V.K.; AMALRAJ, V.A.; GAUTAM, P.L.; MANDAL, S.; KUMAR, D. *Curcuma* genetic resources. Scientific Monograph n. 4. New Delhi: National Bureau of Plant Genetic Resources, Thrissur, Kerala, India, p.1-27, 1999.

VELAYUDHAN, K.C.; DIKSHIT, N.; NIZAR, M.A. Ethnobotany of turmeric (*Curcuma longa* L.). **Indian Journal of Traditional Knowledge**, New Delhi, v.11, n.4, p.607-614, 2012.

VORAVUTHIKUNCHAI, S.P. Family Zingiberaceae compounds as functional antimicrobials, antioxidants, and antiradicals. **Food**, v.1, n.2, p.227-240, 2007.

XU, Q.; DA SILVA, J.A.T.; KONG, L. Advance of biotechnology used in *Curcuma* plant research. In: DA SILVA, J.A.T. (Ed). **Floriculture, orna-mental and plant biotechnology**: advances and topical issues. London: Global Science Books, 2006. v.4, p.517-528.

ZWAVING, J.H.; BOS, R. Analysis of the essential oils of five *Curcuma* species. **Flavour and Fragrance Journal**, Malden, v.7, n.1, p.19-22, 1992.