Original article

Study on enhanced absorption of phenolic compounds of Lactobacillus-fermented turmeric (Curcuma longa Linn.) beverages in rats

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Summary Lactobacillus plantarum, used as starter culture to produce turmeric beverages, was isolated and screened from the turmeric rhizomes. Fermented turmeric beverages were evaluated for its antioxidant activity using 2,2-diphenyl-1-picrylhydrazyl (DPPH) radical-scavenging activity and ferric-reducing antioxidant power (FRAP) assay. The fermentative process resulted in an increase in antioxidant activity. The absorption of turmeric powder, turmeric powder-mixed encapsulated probiotic (TP) and encapsulated fermented turmeric beverage (TB) in rats was measured in terms of antioxidant activity in the plasma. Plasma antioxidant concentration was higher in rats administrated fermented turmeric beverage than other turmeric products, at all the time points. The maximum concentration ($C_{max}$) value and area under the plasma concentration versus time curve (AUC) were higher in the rat administered with TB. The value was lower in the plasma of rats administrated with turmeric powder and TP. The results indicated that the fermentative turmeric possesses better bioavailability and in accordance with the concentrations of polyphenolic compounds in the rat plasma.

Keywords Antioxidant absorption, encapsulation, in vivo studies, lactic acid bacteria, polyphenols, turmeric rhizome.

Introduction Phenolic compounds occur naturally in fruit, vegetables, nuts, seeds, rhizomes, flowers and barks of the plants. Phenolic compounds have long been considered inert and nonessential for human health; however, in the last few years, it has been shown that these compounds affect a wide variety of biological systems in mammals, exhibiting antioxidant, anti-inflammatory, antibacterial, antiviral and anticarcinogenic effects. Phenolic compounds are recently investigated for their possible health benefits for some disorders such as Alzheimer’s disease and liver disorders. These compounds have been known to act as antioxidants because of their ability to donate electrons and their stable radical intermediates, which can effectively prevent the oxidation at cellular and physiological level (Cuvrelier et al., 1992).

Turmeric (Curcuma longa Linn.) is extensively used as a spice, food preservative and colouring material in most of the Asian countries (Chattopadhyay et al., 2004; Goel et al., 2008). Curcumin, widely attended as antioxidant, is a phenolic nontoxic compound derived from the turmeric rhizomes (Ganiger et al., 2007). However, because of its poor water solubility, poor permeability and/or poor stability, there is minimal absorption from the gut and hence avid metabolism in the body, causing the lack of systemic availability (Christopher et al., 2002). The ability to absorb the amount of dietary antioxidants is a prerequisite for their bioavailability. Very limited studies have been conducted on the absorption and bioavailability of selected dietary antioxidants.

Because of its increasing demand, the nondairy-based probiotics have recently been incorporated into healthy fruit, vegetables and herb-based beverages (Bisakowski et al., 2007; Panda et al., 2009). Probiotic-based functional foods have been found rich in bioactive components such as minerals, vitamins, dietary...
fibres, immunomodulators and antioxidants (Shah, 2001). Adding probiotics to the juices and other non-dairy beverages is more complex and difficult because of the processing conditions including the acidic conditions of juices. However, encapsulation of probiotics and other bioactive components is becoming an effective method to enhance the bioavailability and to protect from the processing conditions (e.g., high temperature, pH, enzymes, etc.) in formulation of functional foods and beverages (Anal & Singh, 2007).

The aim of this study was to isolate and identify the lactic acid bacteria (LAB) from fresh turmeric rhizomes and to determine their ability to enhance the antioxidant activity during fermentation of turmeric beverages. The enriched turmeric beverages were fed to the rats to study the absorption efficiency of antioxidants in the rat plasma and hence to enhance the bioavailability.

**Materials and methods**

**Raw materials and chemicals**

Fresh turmeric rhizomes were purchased from Thakun, Suratthani Province, Thailand. Alginate, calcium chloride dihydrate (CaCl\(_2\cdot2\)H\(_2\)O), sodium acetate, 2,4,6-tripyridyl-s-triazine (TPTZ); ferric chloride hexahydrate (FeCl\(_3\cdot6\)H\(_2\)O); glacial acetic acid; and 2,2-diphenyl-1-picrylhydrazyl radical (DPPH) were purchased from Fluka Company Limited (Buchs, Switzerland). Chloroform, ethanol, ferric chloride and all other chemicals of analytical grade used were bought from Sigma Chemical Company Limited (St Louis, MO, USA).

**Animals and diets**

Male Sprague Dawley (SD) rats and the feeding diets were obtained from The National Laboratory Animal Centre, Bangkok, Thailand. The animal experiment protocol was approved by the local ethical committee, Animal Care and Use Committee (MU-ACUC), Mahidol University, Bangkok, Thailand.

**Isolation of lactic acid bacteria (LAB)**

Lactic acid bacteria (LAB) from the turmeric rhizomes were isolated, identified and broadly characterised as previously described (Kimoto et al., 2004; Adnan & Tan, 2007; Pianpumepong & Noomhorm, 2010). Briefly, the chopped turmeric rhizome (10 g) was mixed with 90 mL of sterilised distilled water and extracted using stomacher for 2 min. The sample suspension (1 mL) was used to make a serial dilution in sterile saline (0.85% NaCl), followed by spreading the 0.1 mL of diluted solution on MRS agar plates containing 0.5% (w/v) calcium carbonate solution. The plates were further incubated anaerobically at 37 °C for 24-48 h. Following the incubation, acid-producing bacteria were identified by the appearance of clear zones around the microbial colonies. The purity of these colonies was examined repeatedly on MRS agar plates with 0.06 g L\(^{-1}\) bromocresol purple added as pH indicator. A lowering of this pH caused the change of the medium from purple to yellow. This indicates the production of abundant amount of lactic acid as the secondary metabolite during the log phase of bacterial growth. Each of the isolates was first tested for catalase test by placing a drop of 3% (v/v) hydrogen peroxide solution in sterilized distilled water on the isolated bacterial cells. Immediate formation of bubbles indicated the presence of catalase in the cells. The isolates that had catalase-negative and gram-positive characteristics were selected for further analysis by using API kits (bioMérieux SA, Marcy l’Etoile, France).

**Fermented turmeric beverage production**

LAB isolated from turmeric were used as the starter inoculum. LAB was inoculated in 100 mL of MRS broth and incubated at 37 °C until the culture reached the late log phase. The turmeric beverage was prepared by mixing three parts of chopped turmeric, one part brown cane sugar and 10 parts sterilised water. The starter culture (Lactobacillus plantarum) was inoculated at 10% (w/w) of the volume of sterilised water. The fermentative bucket was maintained at the temperature of about 30 °C in the dark condition. The turmeric was partially sterilised using 250 ppm of potassium metabisulphite (KMS) and incubated overnight before further mixing. The experimental design comprised the following three treatments: turmeric beverage with L. plantarum (LP treatment), turmeric beverage without starter (Un treatment) and the beverage contained only brown cane sugar with drinking water (Cont treatment). The details of the method of fermented turmeric beverage production using LAB from fresh turmeric rhizome were presented in our previous paper (Pianpumepong & Noomhorm, 2010).

**Encapsulation of LAB in calcium alginate capsules**

Cell encapsulation was followed by the method as described by Krasaekoopt et al., 2003 with slight modifications. Briefly, cell encapsulation was performed by mixing one part of LAB cell suspension and four parts of 2% (w/v) sodium alginate solution in sterilized distilled water. Extrusion was performed by dropping the mixture of alginate and LAB cells through a syringe needle (#24 G) drop wise into 0.1 mL CaCl\(_2\) solution (500 mL) with mild stirring at 200 rpm under ambient conditions.
temperature. The calcium alginate capsules containing LAB cells were further kept under same conditions to ensure the complete gelification and to harden the calcium alginate capsules. The capsules were washed with phosphate-buffered saline (PBS, pH 7) and separated by filtration through Whatman #1 filter paper. For another type of similar turmeric beverage product, the alginate (2 g) and the *L. plantarum* cell suspension were directly dispersed in 100 mL of fermented turmeric beverages. This mixture was then directly dropped dropwise into the 0.1 M CaCl₂ (500 mL) solution. All other conditions remained same as described earlier.

**Entrapment efficiency of LAB in alginate beads**

The entrapment efficiency was determined following the method described by Sheu & Marshall (1993) with slight modifications. Briefly, the encapsulated capsules containing LAB cells (1 g) were suspended in 9 mL of sterile saline solution. This dispersion was shaken (200 rpm) continuously on orbital shaker for 90 min at room temperature. The bacterial number of cells in the form of colony-forming units per g (CFU g⁻¹) was estimated using plating serial dilutions on MRS agar and incubated at 37 °C for 24–48 h.

Male Sprague Dawley (SD) rats (10-week-old, weighing about 320 ± 50 g) were obtained from The National Laboratory Animal Centre of Thailand, Salaya, Thailand. SD rats were randomly distributed (2–3 rats per cage) in stainless steel cages with accommodation under standard conditions of 60 ± 10% relative humidity (RH) at 22 ± 2 °C temperature. The rats were kept under a 12-h light–dark cycle and fed the standard diet and water *ad libitum*. Food and water were fed *ad libitum* to all groups.

Among the total of experimental rats used, each of five were orally administered a single dose of turmeric or turmeric added with probiotic or turmeric beverage. Oral administration was performed using a gavage needle (No. 19) attached to a syringe with 1 mL of beverage sample for each animals. At different time intervals between 0, 0.5, 1, 2, 6 and 24 h after ingestion, the animal was euthanised with Nembutal® (Hospira Inc., Lake Forest, IL, USA; 100 mg kg⁻¹ body weight of the animal), and 5 mL of blood specimens was collected. Plasma was separated by centrifugation at 16000 g for 10 min and stored at −20 °C for further analysis (Lee *et al.*, 2007; Shaikh *et al.*, 2009).

For the second experiment, the accumulation of total polyphenols in the rat plasma was analysed. The sample and the administration times used in this study were selected on the best antioxidant activity sample and the *Tₘₐₓ* from the first part of study. Rats were received a daily administration of a single dose of the sample for the consecutive 7 days.

**Determination of the total antioxidant activity**

Antioxidant activity of the various products (fermented and unfermented beverages, and the powder) was analysed by 2,2-diphenyl-1-picrylhydrazyl (DPPH) radical-scavenging activity following the method described by Su & Silva (2006) and Ferric-reducing antioxidant power (FRAP) assay as described by Benzie & Strain (1996).

**Scavenging radical-scavenging activity**

Scavenging activity of antioxidant against DPPH radical measured by 5 mL of DPPH–methanol solution (0.025 g DPPH/L of methanol) was reacted with 0.5-mL sample. The mixture was incubated for 30 min (in dark) at room temperature, and the decrease in the absorbance at 517 nm was measured. The blank contained the methanol instead of DPPH–methanol solution, while the control contained DPPH–methanol solution without the sample. The scavenging activity was calculated by using the following equation:

\[
\text{Scavenging activity (\%)} = \frac{1 - \frac{\text{absorbance of sample} - \text{absorbance of blank}}{\text{absorbance of control}}} \times 100
\]

**Ferric-reducing antioxidant power (FRAP) assay**

The working FRAP reagent was prepared by mixing 2.5 mL of 2,4,6-tripyridyl-s-triazine (TPTZ) solution (10 mM TPTZ in 40 mM HCl), 25 mL of 0.3 mM acetate buffer and 2.5 mL of 20 mM FeCl₃.6H₂O solution. The working FRAP reagent (3 mL) was mixed with 100 μL of sample. The mixture was incubated at 37 °C for 4 min, and the absorbance was measured at 593 nm using UV–visible spectrophotometer. The change in absorbance (ΔA₅₉₃nm) at zero and 4 min was used to calculate the FRAP value. The FRAP value was calculated by using the equation below:

\[
\text{FRAP value (mg FeSO₄/mL)} = \frac{\Delta A_{593nm, \text{sample}}}{\Delta A_{593nm, \text{standard}}} \times \frac{[\text{Fe}^{2+}]}{\text{standard}}
\]

**Pharmacokinetic parameters**

Maximum concentration (*Cₘₐₓ*) and time to reach maximum concentration (*Tₘₐₓ*) were the values obtained directly from concentration–time curve. Area under the plasma concentration–time curve (AUC₀→∞) was calculated using the following equation:
\[
\text{AUC}_{0-1} = \frac{Cp0 + Cp1}{2} (t1)
\]

where:
\(Cp0\) = plasma concentration at \(t = 0\)
\(Cp1\) = plasma concentration at \(t = 1\)
\(t1\) = time

Statistical analysis of animal experiments

The number of animals was computed using the statistical software MINI TAB 15 (Mini Tab Inc., State College, PA, USA) and based on the following equation:

\[
\text{Determination of sample size} : \phi^2 = \frac{nD^2}{2a\sigma^2}
\]

where: \(n\), number of replicates; \(D\), group mean difference; \(a\), number of treatments; \(\sigma\), standard deviation; \(\phi\), probability of accepting the hypothesis; \(\alpha\), the level of significance.

Data were expressed as means ± standard deviation (SD) of three replicate determinations and then analysed by SPSS V.13 (SPSS Inc. Chicago, IL, USA). One-way analysis of variance (ANOVA) test was used to determine the differences among the means. \(P\)-values <0.05 were regarded to be significant.

Results and discussion

Screening for lactic acid bacteria (LAB)

The MRS medium was used to isolate the lactic acid bacteria from fresh turmeric rhizome. The LAB was selected from the colonies that developed well on MRS plus bromocresol purple agar, in which media colour changed to yellow (representative to acid production). The isolated cells exhibited the Gram-positive and catalase-negative characteristics. The isolate was further specifically identified by API 50 CHL medium. \textit{L. plantarum} at its late log phase period was used as a starter culture to produce turmeric beverages.

Fermentation of turmeric beverage

At the beginning of fermentation, the turmeric beverage appeared as dark yellow colour with turbidity, strong turmeric smell and without gas appearance. During the first 10 days of fermentation, the gas production was observed with the strong turmeric smell. This indicated the occurrence of fermentation. At the end of the fermentation, the beverage characteristic was clear yellow coloured, less turmeric smell with a slight alcohol smell, but still lacking gas production. Instead, the alcohol could be produced by the LAB via the phosphoketolase pathway and some yeast species that originated from raw materials.

DPPH radical-scavenging activity

The scavenging activity of turmeric beverages during fermentation against free radicals (DPPH) is presented in terms of percentage of scavenging activity as shown in Fig. 1. At the beginning of the fermentation, the scavenging activity of LP treatment, Un treatment and Cont treatment had 51.6%, 51.3% and 1.3%, respectively. During fermentation, changes in the scavenging activity dramatically increased in all the treatments except Cont treatment. At 25th day of fermentation, the highest values of LP and Un treatments were recorded as 66% and 62%, respectively. After that day till 45th day, the scavenging activity of LP treatment and Un treatment was shown to be the values of ca. 59% and 55%, respectively. The decreasing trend in scavenging activity of Cont treatment was not observed. The slightly increasing scavenging activity of LP treatment and Un treatment was observed again after 55th to 75th day and then remained quite stable.

At the beginning of the fermentation, the scavenging activity was dramatically increasing in every treatment, except Cont treatment. It might be because of the production of ethanol instead. The result was agreed with the study of Hansen & Laroze (2009). The phenolic content and the antioxidant activity increased with the increase in the ethanol concentration. During 20–35 days of the fermentation, the scavenging activity of all treatments with starter had the highest values. The observed increase in these values was accompanied by increase in total phenolic contents. After that day onwards, the scavenging activity was rapidly decreased, but slightly increased again at 55 days of fermentation and maintained at higher level than without fermentation. The Un and Cont treatments showed lower level of scavenging activity than other

Figure 1 Changes in scavenging activity (%) of \textit{Lactobacillus plantarum}, LP (—), turmeric beverage without culture, Un(--), and brown sugar cane with drinking water, Cont(—).
treatments with starter. The data indicated that LAB was the predominant factor to influence scavenging activity. Scavenging activity was quite stable from Day 75 to 120, indicating that lesser denaturation of phenolic compounds. Yang et al. (2007) also found similar scavenging activity with fermented noni juice at nearly 3 months of fermentation.

**Ferric-reducing antioxidant power (FRAP) assay**

Ferric-reducing antioxidant power assay is a significant method that assessed the antioxidant activity of fermented turmeric beverage. FRAP assay performs based on the ability of antioxidant to reduce the $\text{Fe}^{3+}$ to $\text{Fe}^{2+}$ in the presence of TPTZ compound, forming an intense blue $\text{Fe}^{2+}$–TPTZ complex with absorption maximum at 593 nm. Figure 2 illustrates the FRAP value of fermented turmeric beverage during fermentation. A slight increase in the FRAP value of all the treatments was observed. This result was in the same tendency as the scavenging activity. The FRAP value of LP, Un and Cont treatments had 0.77, 0.78 and 0.16, respectively. At the end of the fermentation, the FRAP value had of 1.80 for LP treatments and 1.47 and 0.41 for Un and Cont treatments, respectively. There was not much difference in the FRAP value in Cont treatment at the beginning stage of fermentation. However, FRAP value of all treatments showed higher than nonfermented beverage.

In addition, the other ingredients in fermented turmeric beverage, such as brown sugar cane, have also been reported to show antioxidant activity (Peerajan, 2006; Prachyakij et al., 2008). These compounds enhanced the antioxidant activity of the fermented turmeric beverage before and even after fermentation. Additionally, the LAB present in the fermented turmeric beverage in addition to being capable of balancing intestinal microflora and stimulating the immune system could further affect the antioxidant activity exhibited by the fermented turmeric beverage (Silvi et al., 2003; Wang et al., 2006).

**Encapsulation efficiency of probiotic bacteria in calcium alginate beads**

The encapsulation of probiotics was performed by dropping the mixtures of alginate and LAB through the 24-G syringe needle into the calcium chloride solution as gelation bath. The entrapment efficiency was determined by comparison between samples before and after freeze-dried that were released from the calcium alginate beads in phosphate buffer at the neutral pH. The calcium ions in the cross-linked polymer are likely to react with the phosphate species to be phosphated calcium precipitates and core materials can release out (Anal & Stevens, 2005). Entrapment efficiency is expressed as the percentage of cells survival after complete disintegration and release of the LAB from the calcium alginate beads. As a result, the entrapment efficiency of cells and antioxidant activity was obtained as 67%.

**Antioxidant concentration in rat plasma**

Plasma samples of experimental rats after individual ingestion of 250 mg of encapsulated turmeric beverage, turmeric powder and turmeric powder with probiotic (added 25 mg of encapsulated *L. plantarum*) were analysed for antioxidant activity by DPPH free radical-scavenging activity and FRAP assay. Figures 3 and 4 illustrate the DPPH free radical-scavenging activity and FRAP values of plasma versus time profiles before and after oral administration of each type of products for each treatment group, respectively. Before ingestion, the concentration of total polyphenolic contents in rat plasma was undetectable. After ingestion of these three kinds of turmeric samples, the antioxidant activity was observed higher in the rat plasma with all types of treatments. The peak concentration ($C_{\text{max}}$) and time of peak concentration ($T_{\text{max}}$) were considered directly from the plasma antioxidant level versus time profiles. A sustained release of three products over 24 h was observed as shown in Fig. 3. Plasma antioxidant concentration was significantly higher ($P > 0.05$) in rats administered turmeric beverage than in those administered turmeric powder and turmeric powder with probiotics, at all time points. On DPPH free radical-scavenging activity evaluation, the $C_{\text{max}}$ value of turmeric beverage, turmeric powder with probiotic and turmeric powder alone was 28%, 21%
and 17%, respectively. In comparison with two samples of turmeric powder and turmeric with probiotic, the plasma antioxidant concentration of turmeric beverage was higher by 11% and 7%, respectively. The $T_{\text{max}}$ of three turmeric samples was 1 h. After $C_{\text{max}}$, the plasma antioxidant concentrations decreased rapidly, indicating rapid metabolism of the samples. The peak antioxidant concentration of three turmeric samples was observed at the same time, indicating that the three samples had the same rate of absorption. However, turmeric beverage showed the highest antioxidant concentration indicating improved bioavailability of turmeric as a fermented beverage product. There was a marked difference in the plasma concentration versus time curve ($\text{AUC}_{0-\infty}$), which explains the apparent volume of distribution of the substance in the body, between turmeric, turmeric with probiotic and turmeric beverage. The $\text{AUC}_{0-\infty}$ was higher in the rat administered with turmeric beverage, with a value of 191.18, and lower values of 105.2 and 142.5 in the animals fed turmeric powder and turmeric powder with probiotic, respectively, as shown in Table 1.

The antioxidant concentrations in rat plasma of three turmeric products were observed by FRAP method. The $C_{\text{max}}$ of turmeric beverage, assayed by FRAP method, was found higher (0.24) than those of turmeric powder (0.19) and turmeric powder with probiotic (0.21).

Curcumin is the phenolic compound from turmeric and has been found absorbed poorly in the gastrointestinal (GI) tract after oral administration because of its low water solubility, low stability against GI fluids and its rapid metabolism in the liver and intestinal cells. This has led to an unacceptably low oral bioavailability. The intestinal absorption of curcumin, the active principle polyphenol of turmeric, should require a transformation during absorption from the intestine. Pan et al. (1999) revealed that more than 90% of the curcumin decomposed rapidly in buffer systems at neutral–basic pH condition simulating the intestinal conditions. A major portion of ingested curcumin is excreted unmetabolised through the faeces. A small portion of absorbed curcumin is extensively converted to its water-soluble metabolites by endogenous reductase enzyme such as $\beta$-glucosidase (Ravindranath & Chandrasekhara, 1980, 1981). Tetrahydrocurcumin glucuronoside (THC) is a major metabolite of curcumin and a stronger antioxidant with higher stability in basic condition. The plasma antioxidant concentration of rats administered turmeric beverage showed the highest value. This might be curcumin structural modification by ethanol during fermentation (Ravindranath & Chandrasekhara, 1981). The structure of curcumin is the keto-enol conformation. The result was supported by previous findings that, at oral dose corresponding to 5–40 times human intake, about 60% of the dose is absorbed and is metabolised fast within

<table>
<thead>
<tr>
<th>Formulations</th>
<th>$C_{\text{max}}$ (%)</th>
<th>$T_{\text{max}}$ (h)</th>
<th>$\text{AUC}_{0-\infty}$ (percentage-h)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Turmeric</td>
<td>17.30 ± 2.21</td>
<td>1</td>
<td>105.17</td>
</tr>
<tr>
<td>Turmeric + probiotic</td>
<td>21.44 ± 1.41</td>
<td>1</td>
<td>142.50</td>
</tr>
<tr>
<td>Turmeric beverage</td>
<td>28.09 ± 3.94</td>
<td>1</td>
<td>191.18</td>
</tr>
</tbody>
</table>

Figure 3 Scavenging activity (%) value of turmeric beverage, turmeric powder with probiotic and turmeric powder only in rat ($n = 5$) plasma after a single oral administration of the sample (250 mg kg$^{-1}$ body weight).

Figure 4 Ferric-reducing antioxidant power value (mg FeSO$_4$ mL$^{-1}$) of turmeric beverage, turmeric powder with probiotic and turmeric powder only in rat ($n = 5$) plasma after a single oral administration of the sample (250 mg kg$^{-1}$ body weight).
72 h after administration (Ravindranath & Chandrasekara, 1981). Shaikh et al. (2009) revealed that the levels of simple curcumin suspension were not detectable beyond 6 h, while in the case of curcumin, nanoparticles were able to sustain the plasma levels over a period of 48 h. The absorption was observed variably in our study and might be because of the encapsulation potentials. There was a marked difference in the AUC0–∞ that turmeric was higher in the rat plasma administration with turmeric beverage.

The intestinal microbial transformation of polyphenols is subject to a wide inter-individual variability. Metabolism of polyphenol by microbiota involves the cleavage of glycosidic linkage, glycans, the product of glycosidic cleavage, and is an essential nutrient for the survival of the intestinal microbiota. The different ways of polyphenol and intestinal microbiota interactions may be possibly due to (i) different bacterial diversity along the intestinal tract and (ii) different amounts of polyphenols/phenolics metabolized and/or entered into the small intestine and (iii) different polyphenol/polyphenolic compound–degrading capabilities (Aura et al., 2005; Gardana et al., 2009). Thus, the probiotic contained in turmeric might affect the intestinal metabolism of curcumin, hence to be considered to affect its bioavailability.

Plasma antioxidant accumulation

Short-term feeding of a single dose of turmeric beverage was evaluated as shown in Figs 5 and 6. The plasma antioxidant concentrations did not show any changes over the duration of study. It is possible that curcumin undergoes rapid metabolism via glucuronidation and sulfation and being absorbed by the intestine.

Previous study revealed that after oral administration of 400 mg of curcumin to rats, no curcumin was detected in urine. The urinary excretion of conjugated glucuronides and sulphates significantly increased. Curcumin concentration in liver and kidney was observed from 15 min up to 24 h after administration of curcumin. At the end of 24 h, the concentration of curcumin remained in the lower part of the caecum and large intestine (Pan et al., 1999).

Conclusion

The study was carried out to isolate and identify the lactic acid bacteria from fresh turmeric rhizomes as well as to investigate their efficacy on the antioxidant activities of turmeric beverages during the 120 days of fermentation. The fermentative process resulted in an increase in the antioxidant activity. In addition, the samples with lactic acid bacteria had a higher antioxidant activity than without lactic acid bacteria (Un and Cont treatments) samples. At the end of the trial of in vivo study, a difference in the plasma antioxidant activity in the rats administered turmeric powder, turmeric powder with L. plantarum and fermented turmeric beverage administration was observed. Plasma antioxidant concentration was higher in rats administered with the fermented turmeric beverages than in those administered turmeric powder with probiotics. Conclusion of this study indicates that turmeric beverage contains higher phenolic compounds and possess high antioxidant potential.

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