Curcumin: Analysis and Stability

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ABSTRACT

Curcumin is a polyphenol extracted from Curcuma longa, used as a spice, in food coloring, and as a traditional herbal medicine. It has wide therapeutic platform as anti-oxidant, anticancer, anti-inflammatory and anti-infection properties. This review discusses the analytical methods used in determination of curcumin in various matrices with degradation profile, expected degradation products and stability tests.

Keywords: Anti-cancer; Anti-inflammatory; Anti-oxidant; Curcumin analysis; Curcumin degradation; Curcumin stability

INTRODUCTION

Curcumin, (1E,6E)-1,7-bis(4-hydroxy-3-methoxyphenyl)hepta-1,6-diene-3,5-dione also known as diferuloylmethane Figure 1, is a phenolic compound1 present in many kinds of medicinal plants, especially in Curcuma longa (turmeric)2, and was first discovered and isolated in 1815 by Harvard College laboratory scientists Vogel and Pelletier3. The first article referring to the use of Curcumin in human diseases was published in 19374. Curcumin possesses many pharmacological activities including antioxidant, anti-infection, anti-inflammation, anti-Alzheimer and anticancer5-18. Curcumin is a special spice which is the functional ingredient in curry powder19, and a potential natural food coloring20; it impairs an attractive yellowish-orange color to food, authorized as a food additive by the Joint FAO/WHO Expert Committee on Food Additives (JECFA) in 1974, it's E number is E 10021. It is widely used in food applications including dairy products, fat emulsions, confectionery, soups and sauces22-31. In this review paper we are highlighting various analytical techniques (focusing on spectrophotometric and chromatographic techniques) used to detect curcumin in different matrices (biofluids, rhizomes, food and different pharmaceutical dosage forms) also with degradation, degradation products and stability indicating methods under different stress conditions. Moreover, this review summarizes in table forms different conditions of each analytical technique. We hope this review will be helpful to all scientists interested in curcumin therapeutic effects and/or applications on food industry.

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Table 1. Reported HPTLC methods for curcumin estimation

<table>
<thead>
<tr>
<th>Ref.</th>
<th>Matrix Sample</th>
<th>Mobile phase</th>
<th>Stationary phase</th>
<th>Densitometric scanning</th>
</tr>
</thead>
<tbody>
<tr>
<td>59</td>
<td>Rhizomes</td>
<td>Chloroform: ethanol: glacial acetic acid (94:5:1 v/v/v)</td>
<td>Silica gel 60 F&lt;sub&gt;254&lt;/sub&gt;</td>
<td>Scanned at 366nm</td>
</tr>
<tr>
<td>60</td>
<td>Polyherbal capsule dosage form</td>
<td>n-hexane, ethyl acetate, acetic acid, and methanol (7:2:0.5:0.5, v/v/v)</td>
<td>Silica gel 60 F&lt;sub&gt;254&lt;/sub&gt;</td>
<td>Camag TLC scanner III using absorbance mode at 404 nm.</td>
</tr>
<tr>
<td>61</td>
<td>Rhizomes</td>
<td>Chloroform: methanol (97:3 v/v/v)</td>
<td>Silica gel 60 F&lt;sub&gt;254&lt;/sub&gt;</td>
<td>Camag TLC scanner III using absorbance mode at 254, 366 and 427 nm.</td>
</tr>
<tr>
<td>62</td>
<td>Rhizomes</td>
<td>Chloroform: Ethanol: Glacial acetic acid (9.4:0.5:0.1 v/v/v)</td>
<td>Silica gel 60 F&lt;sub&gt;254&lt;/sub&gt;</td>
<td>Camag TLC Scanner–III using absorbance mode at 254.</td>
</tr>
<tr>
<td>64</td>
<td>Rhizomes</td>
<td>Chloroform: Methanol (9.5: 0.5 v/v)</td>
<td>Silica gel 60 F&lt;sub&gt;254&lt;/sub&gt;</td>
<td>Camag TLC scanner–III using absorbance mode at 421 nm.</td>
</tr>
<tr>
<td>65</td>
<td>Rhizomes</td>
<td>Toluene- chloroform-methanol (5:4:1, v/v/v)</td>
<td>Silica gel 60 F&lt;sub&gt;254&lt;/sub&gt;</td>
<td>Camag TLC scanner–III using absorbance mode at 430 nm.</td>
</tr>
<tr>
<td>66</td>
<td>Rhizomes</td>
<td>Chloroform: Methanol: Acetic acid; (9.5: 0.5: 0.1 v/v/v)</td>
<td>Silica gel 60 F&lt;sub&gt;254&lt;/sub&gt;</td>
<td>Camag TLC scanner III using absorbance mode at 254 and 366 nm.</td>
</tr>
<tr>
<td>68</td>
<td>Rhizomes</td>
<td>Chloroform hexane–Methanol (1:1:0.1, v/v/v)</td>
<td>Silica gel 60 F&lt;sub&gt;254&lt;/sub&gt;</td>
<td>Camag TLC scanner–II using absorbance mode at 254 nm.</td>
</tr>
<tr>
<td>69</td>
<td>Rhizomes</td>
<td>Chloroform–methanol–formic acid (80:4:0.8, v/v/v) &amp; petroleum ether–ethyl acetate (90:10, v/v/v)</td>
<td>Silica gel 60 F&lt;sub&gt;254&lt;/sub&gt;</td>
<td>Scanned at 254 and 365 nm.</td>
</tr>
<tr>
<td>70</td>
<td>pharmaceutical dosage forms</td>
<td>Chloroform: methanol (9.25:0.75 v/v/v).</td>
<td>Silica gel 60 F&lt;sub&gt;254&lt;/sub&gt;</td>
<td>Scanned at 430 nm.</td>
</tr>
</tbody>
</table>

Figure 1. Chemical structure of curcumin

1. Curcumin analysis
1.1 Spectroscopic techniques
1.1.1. Infrared spectroscopy

These techniques had been widely used for determination of curcumin as they allowed rapid and sensitive, ease in sample preparation, and non destructive technique meaning that the used samples can be used for further analysis. In addition, IR spectroscopy could identify and differentiate between curcumin of different geographical origin or between curcumin and other Curcuminooids in rhizomes. Curcumin had near infrared spectroscopy at regions of 1500-2500 and 2040–2486nm for total Curcuminooids. Curcumin had near infrared spectroscopy at regions of 1500-2500 and 2040–2486nm for total Curcuminooids.

1.1.2. UV-Vis spectrophotometry

Being yellow colored; the most easy and simple method for curcumin estimation is via direct UV-Vis spectrophotometry, as the official standard AOAC method which depends on direct estimation of curcumin content in certain solvents, absorption intensity at wavelength of 420 – 430 nm (depending on the solvent system). The absorption band is found to have an asymmetric profile in non-polar solvents (as chloroform, acetic acid, toluene, and carbon tetrachloride). The type and nature of the solvent affects the absorption profile of curcumin causing only a small red-shift (ca. 0~20 nm) when going from n-hexane to methanol. The PH of solvent also affects the absorption spectrum of curcumin: λ max is 520 nm when measuring curcumin in acetone-bicarbonate buffer (pH 11), while in methanol or ethanol solutions...
containing 1M HCl λ max is 540 nm. Curcumin may be complexed with cyclodextrin in aqueous solutions.

### Table 2. Reported HPLC methods for determination of curcumin

<table>
<thead>
<tr>
<th>Ref</th>
<th>Matrix Sample</th>
<th>Mobile phase</th>
<th>Detection</th>
<th>Column</th>
</tr>
</thead>
<tbody>
<tr>
<td>71</td>
<td>Rhizomes</td>
<td>Methanol:water (75:25 v/v)</td>
<td>UV at 397 nm</td>
<td>RP-C18 column</td>
</tr>
<tr>
<td>72</td>
<td>Biofluids (Plasma)</td>
<td>Acetonitrile and triple distilled water (40/60, v/v)</td>
<td>UV at 230 nm</td>
<td>RP-C8 column</td>
</tr>
<tr>
<td>73</td>
<td>Pharmaceutical dosage forms</td>
<td>Acetonitrile: ammonium acetate (45:55, v/v, pH 3.5)</td>
<td>UV at 425 nm</td>
<td>RP-C18 column</td>
</tr>
<tr>
<td>74</td>
<td>Rhizomes</td>
<td>Acetonitrile and 0.1% formic acid (50:50 v/v)</td>
<td>UV at 425 nm</td>
<td>RP-C18 column</td>
</tr>
<tr>
<td>75</td>
<td>Rhizomes and Pharmaceutical dosage forms</td>
<td>(A) 0.1% formic acid in water &amp; (B) 0.1% formic acid in acetonitrile</td>
<td>UV at 425 nm</td>
<td>RP-C18 column</td>
</tr>
<tr>
<td>76</td>
<td>Rhizomes</td>
<td>Acetonitrile-2% acetic acid (55:45 v/v)</td>
<td>UV at 425 nm</td>
<td>RP-C18 column</td>
</tr>
<tr>
<td>77</td>
<td>Pharmaceutical dosage forms</td>
<td>Acetonitrile and water (50:50 v/v) acidified with 2% acetic acid</td>
<td>UV at 425 nm</td>
<td>RP-C18 column</td>
</tr>
<tr>
<td>78</td>
<td>Rhizomes</td>
<td>Acetonitrile, methanol and water at 40:20:40 (v/v/v) and pH 3.0</td>
<td>UV at 370 nm</td>
<td>RP-C18 column</td>
</tr>
<tr>
<td>79</td>
<td>Rhizomes</td>
<td>Aqua bidestilata and acetonitrile (65:35 v/v) containing 1% acetic acid.</td>
<td>UV at 425 nm</td>
<td>RP-C18 column</td>
</tr>
<tr>
<td>80</td>
<td>Rhizomes</td>
<td>Acetonitrile–methanol–water (40:20:40, v/v)</td>
<td>UV at 360 nm</td>
<td>RP-(phenyl) column</td>
</tr>
<tr>
<td>81</td>
<td>Rhizomes</td>
<td>Acetonitrile and 10 mM Na₂HPO₄–H₃PO₄ (pH 5.0) (50:50,v/v)</td>
<td>Electrochemical detector potential set at 0.9 V. UV at 425 and 254 nm</td>
<td>RP-C18 column</td>
</tr>
<tr>
<td>82</td>
<td>Rhizomes</td>
<td>Solvent A (water/acetic acid = 99.9/0.1, v/v) &amp; solvent B (acetonitrile/acetic acid = 99.9/0.1, v/v).</td>
<td>UV at 425 nm</td>
<td>RP-C18 column</td>
</tr>
<tr>
<td>83</td>
<td>Rhizomes</td>
<td>Water and acetonitrile (60/40 vol %).</td>
<td>UV at 425 nm</td>
<td>RP-C18 column</td>
</tr>
<tr>
<td>84</td>
<td>Pharmaceutical dosage forms</td>
<td>0.1% ortho phosphoric acid and acetonitrile (45:55, v/v)</td>
<td>UV at 262 nm</td>
<td>RP-C18 column</td>
</tr>
<tr>
<td>85</td>
<td>Rhizomes</td>
<td>5 mM acetonitrile : phosphoric acid (45:55, v/v)</td>
<td>UV at 425 nm</td>
<td>RP-C18 column</td>
</tr>
<tr>
<td>86</td>
<td>Pharmaceutical dosage forms</td>
<td>Ethanol, water and acetonitrile (80:10:10, v/v/v)</td>
<td>Fluorescence detector: Excitation at 365 nm &amp; Emission at 512 nm</td>
<td>RP-C18 column</td>
</tr>
<tr>
<td>87</td>
<td>Biofluids (plasma and liver homogenates)</td>
<td>Acetonitrile-methanol-water (pH =3.0)</td>
<td>UV at 425 nm</td>
<td>RP-C18 column</td>
</tr>
<tr>
<td>88</td>
<td>Biofluids (plasma)</td>
<td>Acetonitrile-tetrahydrofuran-water containing 0.1% formic acid.</td>
<td>UV at 425 nm</td>
<td>RP-C18 column</td>
</tr>
<tr>
<td>89</td>
<td>Rhizomes</td>
<td>Acetonitrile and 0.1% formic acid</td>
<td>UV at 270 and 380 nm</td>
<td>RP-C18 column</td>
</tr>
<tr>
<td>90</td>
<td>Biofluids (plasma)</td>
<td>Acetonitrile-methanol-trifluoroacetic acid-water (17:6:35:30:1:47.0, v/v/v/v)</td>
<td>UV at 415 nm</td>
<td>RP-C18 column</td>
</tr>
<tr>
<td>91</td>
<td>Biofluids (plasma)</td>
<td>Acetonitrile-5% and acetic acid (75:25, v/v/v/v)</td>
<td>UV at 420 nm</td>
<td>RP-C18 column</td>
</tr>
<tr>
<td>92</td>
<td>Rhizomes</td>
<td>Acetonitrile and 2% v/v acetic acid (40:60, v/v)</td>
<td>UV at 425 nm</td>
<td>RP-C18 column</td>
</tr>
<tr>
<td>93</td>
<td>Biofluids (plasma)</td>
<td>Acetonitrile (55%) and citric buffer, pH 3.0 (45%)</td>
<td>UV at 300 and 428 nm</td>
<td>RP-C18 column</td>
</tr>
<tr>
<td>94</td>
<td>Rhizomes</td>
<td>Acetonitrile:0.1% trifluoro-acetic acid (50:50)</td>
<td>UV at 420 nm</td>
<td>RP-C18 column</td>
</tr>
</tbody>
</table>
### Table 3. Reported LC/MS methods for determination of curcumin.

<table>
<thead>
<tr>
<th>Ref.</th>
<th>Column</th>
<th>Detection</th>
<th>Ionization/ Mass Spectrometry mode</th>
<th>Transitions (m/z)</th>
<th>Mobile phase</th>
<th>Matrix</th>
<th>Internal standard</th>
</tr>
</thead>
<tbody>
<tr>
<td>95</td>
<td>Agilent Poroshell SB-C18 (2.7 μm, 4.6×150 mm)</td>
<td>Agilent</td>
<td>Thermo TSQ Quantum, SRM</td>
<td>ESI +/MS2 with Quadrupole</td>
<td>369-245-213</td>
<td>0.2 % formic acid and acetonitrile (50:50, v/v)</td>
<td>Plasma</td>
</tr>
<tr>
<td></td>
<td>Halo C8 (2.7 μm, 4.6 × 50 mm)</td>
<td>AB Sciei Q trap® 6500 MRM</td>
<td>ESI +/MS2 with Triple-Quadrupole</td>
<td>369-177</td>
<td>Acetonitrile-0.2% formic acid in water (73:27 v/v)</td>
<td>Plasma</td>
<td>Dimethyl curcumin</td>
</tr>
<tr>
<td>97</td>
<td>Waters Acuity UPLC-BEH-C18 (1.7 μm, 100× 2.1 mm) MRM</td>
<td>AB Sciei Q trap® 5500 MRM</td>
<td>ESI/MS2 with Quadrupole</td>
<td>369-177</td>
<td>Acetonitrile and 0.1% formic acid in water with gradient elution</td>
<td>Plasma</td>
<td>Glibenclamide</td>
</tr>
<tr>
<td>98</td>
<td>Sepax BRC18 (5 μm, 1.0 ×100 mm)</td>
<td>Thermo</td>
<td>AB Sciex Q trap® 6500 MRM</td>
<td>ESI/MS2 with Quadrupole</td>
<td>369-285</td>
<td>Acetonitrile and 0.1% formic acid in water (50:50, v/v)</td>
<td>Plasma</td>
</tr>
<tr>
<td></td>
<td>Agilent Zorbax Eclipse XDB C18 (3.5 μm, 4.6 × 50 mm)</td>
<td>Thermo Finnigan LTQ XL iontrap MRM</td>
<td>ESI/MS3 with Ion Trap MS</td>
<td>369-245-213</td>
<td>Acetonitrile and 0.1% formic acid in water, B: acetonitrile (25:75 v/v)</td>
<td>Plasma</td>
<td>CUR-d6 (Deuterium Labeled Curcumin)</td>
</tr>
<tr>
<td>100</td>
<td>Water XBridge BEH C18 (100 mm ×2.1 mm i.d., 2.5 μm)</td>
<td>Shimadzu</td>
<td>Coupled with QTRAP 4500 system</td>
<td>(ESI -) with quadrupole (MRM)</td>
<td>367.1-134</td>
<td>A: [acetotinyl containing 0.1% (v/v) formic acid] B: [Water containing 0.1% (v/v) formic acid]. (43% A: 57% B)</td>
<td>Plasma</td>
</tr>
<tr>
<td></td>
<td>BEH C18 (2.1 mm, 100 mm; 1.7mm)</td>
<td>Waters Q-TOF Premier quadrupole</td>
<td>ESI-Q-TOF-MS</td>
<td>367.07-217.06</td>
<td>Acetonitrile: 10 mM ammonium formate: formic acid (90:10:0.05v/v/v),</td>
<td>Brain homogenate</td>
<td>Nimesulide</td>
</tr>
<tr>
<td></td>
<td>Chromolith rod TM (50 mm, 4.6 mm, 5 mm)</td>
<td>API 4000; LC/MS/MS triple quadrupole system</td>
<td>ESI equipped with triple quadrupole mass</td>
<td>367-217</td>
<td>Acetonitrile:10mMammoniumcetat buffer (pH 3.5) (80:20, v/v)</td>
<td>Plasma</td>
<td>Nimesulide</td>
</tr>
<tr>
<td></td>
<td>Discovery1 HS C18, 3 mm, 15cm, 2.1 mm</td>
<td>Agilent LC/ MSD Trap-SL ion trap</td>
<td>positive and negative ESI /MS- quadrupole mass spectrometer</td>
<td>367-217</td>
<td>A:buffer (5mM ammonium formate, 0.1% formic acid, in ddH2O) B: acetonitrile; gradient (in buffer A)</td>
<td>Herbal extract</td>
<td>Not mentioned</td>
</tr>
<tr>
<td>105</td>
<td>Phenomnex Luna, C18 (250mx4.6 mm)</td>
<td>Sciex API 4000 tandem mass</td>
<td>(ESI- ) with quadrupole (MRM)</td>
<td>373.2 – 137.1</td>
<td>Acetonitrile/water (70:30, v/v) with 0.005% acetic acid 0.05 mL/L.</td>
<td>Plasma</td>
<td>Salbutamol</td>
</tr>
<tr>
<td>106</td>
<td>Zorbax Extend-C18 (150 × 4.6 mm I.D.; 5 m)</td>
<td>Micromass Quattro Ultima tandem quadrupole</td>
<td>(ESI-) with quadrupole (MRM)</td>
<td>367 -217</td>
<td>70% Acetonitrile and 30% 1 mM formic acid</td>
<td>Plasma and herbal extract</td>
<td>Honokiol</td>
</tr>
</tbody>
</table>
giving $\lambda$ max = 430 nm$^{59}$, while curcumin metal complexes (which have better anti-oxidant therapeutic activity) show a main absorption band at 415–430 nm and compared to curcumin alone$^{7,50,51}$. Further more curcumin may be encapsulated in nanoparticles (for better solubility) as poly(l-lactic acid) nanoparticles giving absorption band at 465 nm$^{52}$. However, using this technique it is not possible to separate and to quantify the curcumin from raw Curcuminoids mixture$^{52-58}$.

1.2. Chromatographic-based methods

1.2.1 Thin layer chromatography (TLC) and (HPTLC)

Developed TLC methods could be used as a technique for quality control of Curcuma rhizomes. Some of the recent published researches related to the use of TLC coupled with high performance liquid chromatography (HPTLC) for analysis of curcumin are collected in the Table 1.

1.2.2. High performance liquid chromatography (HPLC).

HPLC techniques are usually the methods of choice for determination of curcumin, the most common detectors used are UV or PDA (as curcumin has absorbance in the visible range). Table 2 illustrates recent reported analytical methods of curcumin either in food, pharmaceutical formulations, biological fluids (biofluids) or even alone.

1.2.3. Liquid chromatography coupled with mass spectrometry (LC/MS).

LC/MS can be used to detect even trace amounts of curcumin in biological fluids, food or in other complex matrices and provide fast and accurate analysis as an on-line technique. Moreover, it can be used to differentiate from other Curcuminoids. Furthermore it can be used not only to identify and quantify known Curcuminoids, but also to identify unknown Curcuminoids in extracts from turmeric or related plant material. Recent LC/MS methods and their conditions are listed in Table 3.

2. Curcumin Degradation

2.1. Oxidation of curcumin

The major product of the autoxidation of curcumin is a bicyclopentadione, formed by oxygenation and double cyclization of the heptadienedione chain connecting the two methoxypbenol rings of curcumin$^{107,108}$.

Products of curcumin oxidative transformation are eight compounds (Bicyclopentadione, Dihydroxy cyclopentadione, Hemiacetal cyclopentadione, Ketohydroxy cyclopentadione, Spiroepoxide cyclopentadione, Vinyl ether cyclopentadione, Cyclobutyl cyclopentadione and Diguaiacol).$^{109}$ Six of these products had oxygen substitutions at C-1 and C-7. Two products that did not incorporate oxygen were a cyclobutyl cyclopentadione and, an obvious cleavage product. Two of the isolated products, the Spiroepoxide and the vinyl ether cyclopentadiones, were intermediates in the reaction to the Bicyclopentadione. The others were end products formed in addition to the Bicyclopentadione.$^{110}$ Neither vanillin nor ferulic acid was formed in sufficient amount to be detected.$^{111}$

2.2. Degradation of curcumin in buffered solutions

Decomposition was pH dependent and occurs faster at neutral-basic conditions. The stability was proven to be more in acidic pH and decrease as the pH increases. It was more stable at pH of 1.2; less than 1% of curcumin decomposed within 6hrs of the total curcumin in the absence of light.$^{112,113}$

When curcumin was incubated in phosphate buffer, pH 7.2 at 37˚C (biological media), it was found that 90% was degraded in 30 min. Trans-6-(4-hydroxy-3-methoxyphenyl)-2,4-dioxo-5-hexenal, vanillin, ferulic acid and feruloyl methane were identified as degradation products.$^{114,115}$

Curcumin exhibits a red color at pH less than 1, curcumin (due to the presence of the protonated form), and a yellow color at pH ranging from 1 to 7 (as the majority of the curcumin molecules present in the neutral form), while at pH values higher than 7.5 a distinct dark red color rapidly appeared which fade rapidly with time leaving an yellowish orange solution. Furthermore, for the buffer system being used, curcumin forms complexes with borate, citrate, and phthalate, while being inert towards KCl, KH$_2$PO$_4$, and NaHCO$_3$.$^{116}$

2.3. Photo degradation of curcumin

Exposure to visible light inflicts more degradation than UV light. The photochemical degradation of solid state curcumin exposed to sunlight for 120 h yielded vanillin (34 %), ferulic aldehyde (0.5 %), ferulic acid (0.5 %), vanillic acid (0.5 %). $p$-hydroxybenzaldehyde, $p$-hydroxybenzoic acid $^{117,118}$ Curcumin was found to be more stable in the dried form against sunlight exposure than in solution$^{119}$.

Besides the photo-sensitivity of curcumin, it is also self-degradable in the dark, this self-degradation process is enhanced in basic medium, and it was found that this process was fairly dependent on salt (NaCl) concentration.$^{120}$

2.4. Thermal degradation of curcumin

Curcumin is heat sensitive (however it is stable up to 70 ºC$^{121}$), current researches suggest that curcumin undergoes thermal degradation due to

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Table 4. Expected degradation product/s of curcumin for each degradation type

<table>
<thead>
<tr>
<th>Stress conditions</th>
<th>Degradation products</th>
<th>Ref</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oxidation</td>
<td>Eight compounds: Bicyclopentadione, Dihydroxy cyclopentadione, Hemiacetal cyclopentadione, Ketohydroxy cyclopentadione, Spiroepoxide cyclopentadione, Vinylether cyclopentadione, Cyclobutyl cyclopentadione and Diguaiacol</td>
<td>110</td>
</tr>
<tr>
<td>Buffered solutions</td>
<td>Trans-6-(4-hydroxy-3-methoxyphenyl)-2,4-dioxo-5-hexenal, vanillin, ferulic acid and feruloyl methane</td>
<td>125</td>
</tr>
<tr>
<td>Photo-degradation</td>
<td>Vanillin (34%), ferulic aldehyde (0.5 %), ferulic acid (0.5 %), vanillic acid (0.5 %), p-hydroxybenzaldehyde , p-hydroxybenzoic acid</td>
<td>117</td>
</tr>
<tr>
<td>Thermal degradation</td>
<td>Vanillin, ferulic acid, and 4-vinyl guaiacol.</td>
<td>122</td>
</tr>
</tbody>
</table>

Table 5. The recent reported HPLC methods to assay curcumin degradation

<table>
<thead>
<tr>
<th>Ref</th>
<th>Column</th>
<th>Mobile phase</th>
<th>Detection</th>
<th>Degradation conditions</th>
</tr>
</thead>
<tbody>
<tr>
<td>127</td>
<td>C18 column.</td>
<td>A: 0.05 M KH2PO4 adjusted at pH 2.3. B: Methanol. C: Acetonitrile.</td>
<td>FDA at 288 nm</td>
<td>Acidic, alkaline and neutral hydrolysis, photo-degradation, Oxidative degradation and dry heat. Hydrolysis (acidic and alkaline), oxidation, photolysis, and thermal stress</td>
</tr>
<tr>
<td>128</td>
<td>C18 column</td>
<td>Acetonitrile and 10 mM ammonium acetate buffer (pH adjusted to 3.5)</td>
<td>Tandem mass detector with ESI⁻</td>
<td>Acid, base, neutral, oxidative, photo and thermal degradation.</td>
</tr>
<tr>
<td>129</td>
<td>C18 column</td>
<td>A: acetonitrile B: Phosphate buffer pH 3, at the ratio of 70:30, 60:40, 55:45, 50:50 and 45:55</td>
<td>PDA At 422 nm</td>
<td>Acid, base, neutral, oxidative, photo and thermal degradation.</td>
</tr>
<tr>
<td>130</td>
<td>C18 column</td>
<td>A: acetonitrile /water 5:95 v/v, B: acetonitrile</td>
<td>(ESI-MS). The scan range was 140–415 m/z</td>
<td>Acid, base, neutral, oxidative, photo and thermal degradation.</td>
</tr>
<tr>
<td>112</td>
<td>C18 column</td>
<td>Toluene, Chloroform, and methanol in the ratio of 4:4:2 v/v</td>
<td>UV at 428 nm</td>
<td>Buffer degradation</td>
</tr>
</tbody>
</table>

roasting (heating at 180 °C up to 70 minutes) and its degradation products are vanillin, ferulic acid, and 4-vinyl guaiacol. If curcumin was used as food coloring agent, the processing temperature of the food should not exceed 190 °C. Around 27-53 % of curcumin was lost by heat processing of turmeric and major loss was observed by pressure cooking, with maximum loss in pressure cooking for 10 min.

Conflict of Interest

The authors declare that they don’t have any kind of interest.

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