Variation in polyphenol content due to commonly applied processing techniques: A review

Raushan Khan and Satish Kumar Sharma

Abstract
The present review is all about the effects of various commonly used processing methods in our country and is based upon the evaluation of previous studies depicting various food processing applications with its effects on raw ingredient. This review deals with various subclasses of phenolic compounds as phenolic acids, chalcones, flavanones, flavones, flavonols and tannins, and the changes these compounds undergo during processing. Health properties of poly-phenolic compounds are also discussed to emphasize their importance as integral part of our diet. After going through several researches it was found that the effect of same processing method can be different for different sub-classes of polyphenols and the effect can also vary according to variety of the raw ingredient. Most of the processing techniques such as blanching, boiling, microwaving etc. tend to degrade the quantity of polyphenols present in raw form but it was also seen that sometimes it increases the bioavailability of certain phytochemicals. Tables are provided to give a clear and more precise and focused view of polyphenol losses on application of various methods of processing.

Keywords: Food processing, polyphenols

Introduction
Polyphenols are a large class of chemicals which are found in plants, have grabbed much attention in the last decades due to their properties and beneficial health effects, when taken as a dietary constituent (Ming Hu, 2007) [48]. Phenolic compounds constitute one of the most extensive groups of chemicals in the plant kingdom. It is estimated that more than 8000 compounds have been isolated and described yet (Ramos, 2007) [64]. Polyphenols are secondary metabolites of plants and are generally involved in defense against ultraviolet radiation or aggression by pathogens (Pandey and Rizvi, 2009) [55]. Polyphenols may be classified into different groups as a function of the number of phenol rings that they contain and on the basis of structural elements that bind these rings to one another. The main classes include phenolic acids, flavonoids and stilbenes (Spencer et al., 2008) [77]. The most common phenolics in human diet are phenolic acids, flavonoids and tannins (King and Young, 1999) [40]. Phenolic compounds have at least one aromatic ring with one or more hydroxyl groups, and may be classified as flavonoids and non-flavonoids (Del Rio et al., 2012) [12].

Health benefits of polyphenols-
Polyphenols exert a protective action on human health and are key components of a healthy and balanced diet. Epidemiological studies correlate flavonoid intake with a reduced incidence of chronic diseases, such as cardiovascular disease, diabetes and cancer. An inverse association between the risk of chronic human diseases and the consumption of poly-phenolic rich diet is showcased (Lima et al., 2014; Scarlbert et al., 2005; Arts and Hollman, 2005) [43, 72, 6]. Phenols from numerous plant species have been actively studied as potential treatments for various metabolic and cardiovascular diseases. For example, resveratrol found in red wine (Ahn et al., 2008; Szkudelska et al., 2009) [13, 78], epigallocatechin-3-gallate from green tea (Li et al., 2006; Potenza et al., 2007) [43, 58], curcumin from turmeric (Ejaz et al., 2009) [16] and quercetin (Egert et al., 2009; Egert et al., 2010) [15, 14] from different sources have all been studied as potential therapeutic agents. As antioxidants, polyphenols have ability to protect cell constituents against oxidative damage and, therefore, limit the risk of various degenerative diseases associated with oxidative stress as cancer, cardiovascular diseases etc. (Luqman and Rizvi, 2006, Pandey et al., 2009) [46, 54]. Polyphenols may also exert antithrombotic effects by inhibiting platelet aggregation.
Consumption of red wine or nonalcoholic wine reduces bleeding time and platelet aggregation (Demrow et al., 1995) [13]. Phenolic compounds may help to protect the gastrointestinal tract against damage by reactive species present in foods or generated within the stomach and intestines (Halliwell, 2007) [27]. Tea polyphenols tend to improve endothelial function which has blood pressure reducing effects. Polyphenols also exhibit some chemo preventive actions as anti-proliferation, induction of cell cycle arrest or apoptosis, prevention of oxidation, induction of detoxification enzymes, regulation of the host immune system, anti-inflammatory activity (Gracia Lafauente et al., 2009) [25]. Tea catechins have been investigated for their anti-diabetic potential and were found to inhibit glucose absorption in gut and its uptake by peripheral tissues (Young et al., 1999, Gee et al., 1998) [18, 23]. Polyphenols are also beneficial in ameliorating the adverse effects of the aging on nervous system or brain (Harikumar and Aggarwal, 2008) [28]. These have ability to influence and modulate several cellular processes such as signaling, proliferation, apoptosis, redox balance and differentiation and thus impart neuro-protective effects (Singh et al., 2008) [74].

**Table 1: Effect of processing on total polyphenol content**

<table>
<thead>
<tr>
<th>Sr. no.</th>
<th>Raw Ingredient</th>
<th>Processing Method</th>
<th>Changes</th>
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</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Cabbage</td>
<td>Blanching + Freezing</td>
<td>20% increase on dry weight basis</td>
<td>Puupponen-Pimi’a et al. (2003) [62]</td>
</tr>
<tr>
<td>2.</td>
<td>Cherries</td>
<td>Stored at -70 °C for 6 months</td>
<td>Retained 100%</td>
<td>Chavanaiskitt and Wrolstad (2004) [16]</td>
</tr>
<tr>
<td>3.</td>
<td>Clingstone peaches</td>
<td>Freezing</td>
<td>30% increase on wet weight basis</td>
<td>Asami et al. (2002)</td>
</tr>
<tr>
<td>4.</td>
<td>Finger millet</td>
<td>Sprouting/ Pressure cooking</td>
<td>50% decrease</td>
<td>Hithamani and Srivivasan (2014) [27]</td>
</tr>
<tr>
<td>5.</td>
<td>Finger millet</td>
<td>Open pan boiling</td>
<td>12-19% decrease</td>
<td>Hithamani and Srivivasan (2014) [27]</td>
</tr>
<tr>
<td>6.</td>
<td>Finger millet</td>
<td>Roasting</td>
<td>17% increase</td>
<td>Hithamani and Srivivasan (2014) [27]</td>
</tr>
<tr>
<td>7.</td>
<td>Finger millet</td>
<td>Sprouting</td>
<td>67% increase in bio-accessible phenolics</td>
<td>Hithamani and Srivivasan (2014) [27]</td>
</tr>
<tr>
<td>8.</td>
<td>Finger millet</td>
<td>Microwave heating</td>
<td>25-32% decrease in bio-accessible polyphenols</td>
<td>Hithamani and Srivivasan (2014) [27]</td>
</tr>
<tr>
<td>9.</td>
<td>Fresh corn</td>
<td>Cooking</td>
<td>1.2-1.9 times increase</td>
<td>Song et al. (2013) [76]</td>
</tr>
<tr>
<td>10.</td>
<td>Frozen corn</td>
<td>Cooking</td>
<td>47-80% decrease</td>
<td>Song et al. (2013) [76]</td>
</tr>
<tr>
<td>11.</td>
<td>Fruits</td>
<td>Jam and Jelly processing</td>
<td>7.2-12.6% recovery of bio-accessible total phenolics</td>
<td>Kamiloglua et al. (2015) [27]</td>
</tr>
<tr>
<td>12.</td>
<td>Tomatoes</td>
<td>Baking</td>
<td>44% increase</td>
<td>Gahler et al. (2003) [37]</td>
</tr>
<tr>
<td>13.</td>
<td>Tomato juice</td>
<td>Canning</td>
<td>67% increase</td>
<td>Nagarajan and Hotchkiss (1999) [35]</td>
</tr>
<tr>
<td>14.</td>
<td>Tomato paste</td>
<td>Canning</td>
<td>40% decrease</td>
<td>Nagarajan and Hotchkiss (1999) [34]</td>
</tr>
<tr>
<td>15.</td>
<td>White cabbage</td>
<td>Microwave heating</td>
<td>44-45% decrease in hydrolysable polyphenols</td>
<td>Failer and Fialho (2009) [34]</td>
</tr>
<tr>
<td>16.</td>
<td>Wild blackberries</td>
<td>Freezing</td>
<td>8% decrease on wet weight basis</td>
<td>Mullen et al. (2002) [34]</td>
</tr>
</tbody>
</table>
Poly-phenolic compounds are water soluble; it is therefore expected that hydrothermal processes has adverse effects on their content (Sikora et al., 2014) [73]. The polyphenol losses could be due to its migration into the leaching solution. Polyphenol losses might be partially explained by the fracture of the outer layer of cells (cell membranes and cells wall) lost during cutting (Kebea et al. 2015; Rossi et al., 2003) [38, 67]. In a study conducted by Pradeep and Guha in 2011 [59], it was found that roasting significantly improves the nutraceutical properties of little millet by increasing its content in phenolic compounds and also its antioxidant activities. According to Ryan and Thondre, 2012 [69] cooking tends to increase the polyphenol release from porridge oats. It increases bio-accessibility of polyphenols. Treatment with pectolytic enzymes resulted in a better extraction of all the fruit components, as polyphenols (about 2 fold) and a decrease of turbidity (~40%) (Rinaldi et al., 2013) [66].

Processing effects on flavonoid content

Table 2: Effect of processing on total flavonoid content

<table>
<thead>
<tr>
<th>Sr. no.</th>
<th>Raw Ingredient</th>
<th>Processing Method</th>
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</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Beets</td>
<td>Canned without topping juice</td>
<td>30-50% increase on wet weight basis</td>
<td>Jiratanan and Liu (2004) [54]</td>
</tr>
<tr>
<td>2.</td>
<td>Cauliflower</td>
<td>Blanching</td>
<td>37.69% decrease</td>
<td>Ahmed and Ali (2013) [52]</td>
</tr>
<tr>
<td>3.</td>
<td>Cauliflower</td>
<td>Boiled</td>
<td>51.90% decrease</td>
<td>Ahmed and Ali (2013) [52]</td>
</tr>
<tr>
<td>5.</td>
<td>Cauliflower</td>
<td>Steam blanched</td>
<td>16.6% decrease</td>
<td>Ahmed and Ali (2013) [52]</td>
</tr>
<tr>
<td>6.</td>
<td>Cauliflower</td>
<td>Steam boiled</td>
<td>17.53% decrease</td>
<td>Ahmed and Ali (2013) [52]</td>
</tr>
<tr>
<td>7.</td>
<td>Cauliflower</td>
<td>Stir fried</td>
<td>18.05% decrease</td>
<td>Ahmed and Ali (2013) [52]</td>
</tr>
<tr>
<td>8.</td>
<td>Finger millet</td>
<td>Open pan boiling</td>
<td>10% decrease</td>
<td>Hithamani and Srinivasan (2014) [79]</td>
</tr>
<tr>
<td>9.</td>
<td>Finger millet</td>
<td>Pressure cooking</td>
<td>68% decrease</td>
<td>Hithamani and Srinivasan (2014) [79]</td>
</tr>
<tr>
<td>10.</td>
<td>Finger millet</td>
<td>Sprouting</td>
<td>40% decrease</td>
<td>Hithamani and Srinivasan (2014) [79]</td>
</tr>
<tr>
<td>11.</td>
<td>Green beans</td>
<td>Canned with brine</td>
<td>60% decrease on wet weight basis</td>
<td>Jiratanan and Liu (2004) [54]</td>
</tr>
<tr>
<td>12.</td>
<td>Little millet</td>
<td>Germination</td>
<td>4.6% increase</td>
<td>Pradeep and Guha (2011) [79]</td>
</tr>
<tr>
<td>13.</td>
<td>Little millet</td>
<td>Roasting</td>
<td>25.5% increase</td>
<td>Pradeep and Guha (2011) [79]</td>
</tr>
<tr>
<td>14.</td>
<td>Little millet</td>
<td>Steaming</td>
<td>19-22.5% increase</td>
<td>Pradeep and Guha (2011) [79]</td>
</tr>
<tr>
<td>15.</td>
<td>Red cabbage</td>
<td>Blanching</td>
<td>43% decrease</td>
<td>Volden et al. (2008) [83]</td>
</tr>
<tr>
<td>16.</td>
<td>Red cabbage</td>
<td>Boiling</td>
<td>16% decrease</td>
<td>Volden et al. (2008) [83]</td>
</tr>
<tr>
<td>17.</td>
<td>Red cabbage</td>
<td>Steaming</td>
<td>No significant changes</td>
<td>Volden et al. (2008) [83]</td>
</tr>
</tbody>
</table>

Processing effects on Phenolic acids-

The heat and SO₂ treatments of blueberries did not change the content of total phenolic acids (the sum of p-hydroxybenzoic, vanillic, chlorogenic, caffeic, syringic, ferulic and o-coumaric acids) in pressed juice, clarified juice, pasteurized juice and concentrate (Lee et al., 2004). Several researchers reported that the total phenolic content declines due to heat processing but the decline is largely due to leaching into the brine or syrup rather than oxidation (Chaovalalikit, and Wrolstad, 2004; Hong et al., 2004, Zori et al., 2014) [10, 30, 88].

Table 3: Effect of processing on total phenolic acids content

<table>
<thead>
<tr>
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</thead>
<tbody>
<tr>
<td>1.</td>
<td>Blue fleshed potatoes</td>
<td>Peeling</td>
<td>80% decrease</td>
<td>Rytela et al. (2014) [56]</td>
</tr>
<tr>
<td>2.</td>
<td>Fragmented potato</td>
<td>Cooking</td>
<td>70-80% decrease</td>
<td>Takenaca et al. (2006) [79]</td>
</tr>
<tr>
<td>3.</td>
<td>Fragmented purple fleshed potatoes</td>
<td>Blanching</td>
<td>87% decrease</td>
<td>Burgos et al. (2013) [9]</td>
</tr>
<tr>
<td>4.</td>
<td>Fragmented yellow fleshed potatoes</td>
<td>Blanching</td>
<td>97% decrease</td>
<td>Mulinacci et al. (2008) [50]</td>
</tr>
<tr>
<td>5.</td>
<td>Fruits</td>
<td>Jam and jelly processing</td>
<td>49.5-96.7% decrease</td>
<td>Kamiloglua et al. (2015) [77]</td>
</tr>
<tr>
<td>6.</td>
<td>Fruits</td>
<td>Jam and jelly processing</td>
<td>4.7-31.5% increase in bio-accessible phenolic acids</td>
<td>Kamiloglua et al. (2015) [77]</td>
</tr>
<tr>
<td>7.</td>
<td>Yellow fleshed potatoes</td>
<td>Peeling</td>
<td>60% decrease</td>
<td>Rytela et al. (2014) [56]</td>
</tr>
</tbody>
</table>

Potato skins showed much higher amounts of the polyphenols (approximately three and a half times higher) than the potato internal tissue. So, the phenolic acid content decreased by 80% after peeling the blue-fleshed potatoes and by 60% after peeling the yellow variety (Rytela et al., 2014) [70]. Takenaca et al. in 2006 [79] proved that cooking fragmented potato in water resulted in the loss of phenolic acids at the level of 70–80%, whereas according to Mulinacci et al. (2008) [50] and Burgos et al. (2013) [9] cooking the whole unpeeled potatoes did not cause any loss of phenolic compounds. Most of the phenolic groups, sugars, and organic acids showed a better extraction after storage, especially in the slow freezing treatment due to a higher degree of tissue damage by freezing (Veberic et al., 2014) [82].

Processing effects on Flavanols

A loss in flavonol content was observed in several vegetables and fruits during boiling and blanching (Franke et al., 2004) [19]. Both boiling and frying seems to cause considerable losses of quercetin derivatives from broccoli, but fewer were lost upon steaming. Steaming also caused milder losses of quercetin derivatives from carrot than did boiling (Retention Factor = 0.89 and 0.37, respectively). However, losses of quercetin derivatives from onion were similar whether blanched, boiled, fried, or microwaved. Free quercetin content increased upon the blanching and steaming of common cabbage and cauliflower, although this would usually represent only a minor portion of all quercetin derivatives. Carrots were
affected similarly by boiling and steaming. In contrast, cauliflower lost almost all quercetin through boiling but retained most through steaming (Rothwell et al., 2015) [60]. Peeling, skimming, trimming, depitting and/or leaf selection may cause a partial or total decrease in flavonol levels (Gennaro et al., 2002) [24]. Onions (Allium cepa L.) have been prepared by sautéing, boiling and baking: after baking and sautéing, quercetin concentrations increased by 7~25%, while boiling led to a decrease of 18% in its content (Lombard et al., 2005) [44]. Flavonols, total proanthocyanidins, and hydroxycinnamic acids were well retained in chokeberry juices stored for 6 months at 25 °C (Wilkes et al., 2014; Mogren et al., 2005) [85, 49].

Processing effects on Isoflavones

Each processing step in tofu manufacturing contributes to the loss of isoflavones, resulting in a considerable amount of isoflavones being lost in the resultant by-products. Wang and Murphy observed recovery of total isoflavones in traditional tofu as 33%. Grinding of soaked-soybean in boiling water seems to result in the major loss of isoflavones during processing (Jackson et al., 2002) [133].

Table 4: Effect of processing on catechins content

<table>
<thead>
<tr>
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</table>

Blanching, boiling, microwaving, and stir-frying affect the composition, phytochemical contents, antioxidant activity, and phenolic profiles of cauliflower (Mansour et al., 2015; Ahmed and Ali, 2013) [47, 2]. Processing has profound effect on the level of catechins as a result of epimerization and also due to degradation. It has been reported that even the brewing step could convert epicatechin to their corresponding epimers. These types of conversions continue to take place during the production of canned tea beverages and also during subsequent storage period (Preedy, 2014) [60]. Pasteurization increased the concentration of catechins in cold pressed juices, but it decreased concentrations in hot-pressed juices (Fuleki and Ricardoda Silva, 2002) [20].

Processing effects on Chalcones

Very few applications deal with chalcones or structurally related compounds. Cloudy juice contains more dihydrochalcon glycosides than clear apple juice and freshly home-pressed juice more than commercially produced juice (Amarowicz et al., 2009) [4]. Storage at moderate temperatures produced no considerable changes in the content of glycosides but the use of high temperatures led to its reduction (Kahle et al., 2005; Van der Sluis et al., 2005) [36, 81].

Processing effects on Tannins-

In a study conducted by Lowhard et al. (2012) [45] it was reported that tannins in blueberries, blackberries and black raspberries are susceptible to degradation during processing, with juices showing the greatest losses due to physical removal of skins and seeds.

Tannin and catechin contents in lentils (Lens culinaris var. Vulgaris and Variabilis) were also analyzed after 6 days of germination. Germination brought about an increase of tannin content for both varieties (152% and 162% retention percentages were observed, respectively). Catechin content showed an even larger increase, reaching a level twice that of the raw seed (Valverde et al., 1994) [80]. Tannins effectively lowered upon boiling and pressure cooking respectively, but significantly increased upon germination (Pushparaj and Urooj, 2011) [61].

Conclusion

Polyphenol profiles of most of the fruits and vegetables are adversely affected by the commonly used processing methods in our country as blanching, boiling, microwaving, and stir-frying. Steam blanching process generally gives products with less polyphenol losses when compared with simple blanching and time duration of the application is also related with the amount of losses in ultimate product. Peeling showed maximum losses of phenolic content as these contents are more profoundly common in the outer most portions of fruits.
and vegetables. Some processing methods as germination, roasting increased the bioavailability of certain phenolic compounds. If storage conditions are ambient then the losses of sub-classes of poly-phenolic compounds can be reduced to minimum.

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