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Effect of Thermal Processing on Key Phytochemical Compounds in Green Leafy Vegetables: A Review

Nandya Putriani, Jimmy Perdana, Meiliana, and Probo Y. Nugrahedi

ABSTRACT
Green leafy vegetables are widely cultivated and consumed in South East Asia. These vegetables are rich in phytochemicals, which have been associated to particular health benefits. Preparation/processing, particularly those involving heat, prior to consumption can change the level of phytochemicals in the vegetables following various mechanisms, including thermal breakdown, oxidation, leaching, and matrix degradation. Appropriate processing should minimize degradation of phytochemicals so that the optimum intake toward health promotion be achieved. Better understanding of how processing influence the retention of phytochemical compounds is therefore crucial to provide guidelines on the processing of green leafy vegetables while maximizing their nutritional values.

KEYWORDS
Green leafy vegetables; phytochemicals; thermal processing; degradation; nutritional values

Introduction
For centuries, green leafy vegetables have been staples in the diets of South East Asian people. These vegetables contribute significantly to fulfill human nutrition needs. The vegetables contain a substantial amount of protein, carbohydrate, lipids, fibers, minerals, vitamins, and particularly, phytochemical compounds.

Green leafy vegetables are consumed either raw or cooked/processed. Various types of processing are commonly applied to inactivate microorganism and enzymes leading to improved product safety and quality. Processings are also aimed to enhance palatability and to inactivate antinutritional compounds. Thermal processing methods commonly applied to green leafy vegetables are Blanching, steaming, boiling, drying, microwave cooking, pressure cooking, and frying. Processing may cause significant changes in nutritional and especially phytochemical content in green leafy vegetables. Different methods of thermal processing can lead to various degree of changes of the phytochemical contents.

Therefore, the selection of an appropriate method to process green leafy vegetables should be critically considered. In this paper, we review the effect of processing methods on the retention of phytochemical compounds in green leafy vegetables. The retention level is calculated from previous publications reporting concentration of the phytochemicals both in the raw and the processed green leafy vegetables. The underlying mechanism leading to changes of phytochemical compounds in green leafy vegetables during processing are discussed by providing thorough information of each processing method, such as...
time and temperature, pressure, and amount of water or oil, which lead to the changes via mechanisms of, e.g. cell lysis, matrix degradation, enzyme inactivation, thermal degradation, and oxidation. Previous studies have been reviewed the interaction of processing and bioavailability and bioaccessibility of phytochemicals in vegetables.\textsuperscript{[8–11]} The mechanism of absorption, distribution, metabolism, and excretion of phytochemicals have also been reviewed.\textsuperscript{[7,8,12–15]}

**Phytochemicals in green leafy vegetables and their potential health benefits**

Vegetable consumption has been identified to promote health, e.g. against chronic diseases such as cardiovascular disease, diabetes, obesity, alzheimer, and cancer.\textsuperscript{[4,16]} These health benefits have been associated to, for example antioxidant and anticarcinogenic activities of phytochemical compounds in vegetables. Key phytochemicals in green leafy vegetables are phenolic compounds,\textsuperscript{[17]} carotenoids,\textsuperscript{[18]} chlorophyll,\textsuperscript{[19]} ascorbic acid,\textsuperscript{[20]} flavonoids,\textsuperscript{[21]} and glucosinolates,\textsuperscript{[22]} which will be briefly discussed in the following subsection.

**Polyphenols**

The phenolic compound is chemically defined as a compound containing an aromatic ring, which is linked with one or more hydroxyl group.\textsuperscript{[23]} The number and position of hydroxyl groups affect its ability to scavenge free radicals and chelate metal cations, which can decrease the risk of chronic disease.\textsuperscript{[24,25]} Total polyphenol concentration in green leafy vegetables varies between 23 and 231 mg GAE/100 g fresh weight (FW) (Table 1). Most of the polyphenols in green leafy vegetables degrade during processing at 100°C or higher.\textsuperscript{[6,26,39]}

<table>
<thead>
<tr>
<th>Phytochemical compounds</th>
<th>Vegetables</th>
<th>Concentration (mg/100 g FW)</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Total polyphenol</strong></td>
<td>Spinach</td>
<td>23</td>
<td>[26]</td>
</tr>
<tr>
<td></td>
<td>Water spinach</td>
<td>42</td>
<td>[27]</td>
</tr>
<tr>
<td></td>
<td>Celery</td>
<td>35</td>
<td>[28]</td>
</tr>
<tr>
<td></td>
<td>Coriander leaves</td>
<td>42</td>
<td>[26]</td>
</tr>
<tr>
<td></td>
<td>Cassava leaves</td>
<td>50</td>
<td>[29]</td>
</tr>
<tr>
<td></td>
<td>Papaya leaves</td>
<td>231</td>
<td>[30]</td>
</tr>
<tr>
<td></td>
<td>Chinese mustard</td>
<td>63</td>
<td>[31]</td>
</tr>
<tr>
<td><strong>Carotenoid</strong></td>
<td>Spinach</td>
<td>2</td>
<td>[32]</td>
</tr>
<tr>
<td></td>
<td>Water spinach</td>
<td>2</td>
<td>[32]</td>
</tr>
<tr>
<td></td>
<td>Coriander leaves</td>
<td>5</td>
<td>[33]</td>
</tr>
<tr>
<td></td>
<td>Drumstick leaves</td>
<td>7</td>
<td>[32]</td>
</tr>
<tr>
<td></td>
<td>Sweet potato leaves</td>
<td>8</td>
<td>[32]</td>
</tr>
<tr>
<td></td>
<td>Lettuce</td>
<td>3</td>
<td>[34]</td>
</tr>
<tr>
<td></td>
<td>Chinese mustard</td>
<td>2</td>
<td>[31]</td>
</tr>
<tr>
<td><strong>Chlorophyll</strong></td>
<td>Spinach</td>
<td>1</td>
<td>[20]</td>
</tr>
<tr>
<td></td>
<td>Water spinach</td>
<td>2</td>
<td>[35]</td>
</tr>
<tr>
<td></td>
<td>Celery</td>
<td>4</td>
<td>[36]</td>
</tr>
<tr>
<td></td>
<td>Coriander leaves</td>
<td>4</td>
<td>[36]</td>
</tr>
<tr>
<td></td>
<td>Drumstick leaves</td>
<td>216</td>
<td>[37]</td>
</tr>
<tr>
<td><strong>Ascorbic acid</strong></td>
<td>Spinach</td>
<td>69</td>
<td>[20]</td>
</tr>
<tr>
<td></td>
<td>Water spinach</td>
<td>16</td>
<td>[35]</td>
</tr>
<tr>
<td></td>
<td>Celery</td>
<td>3</td>
<td>[38]</td>
</tr>
<tr>
<td></td>
<td>Drumstick leaves</td>
<td>271</td>
<td>[37]</td>
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<tr>
<td></td>
<td>Cassava leaves</td>
<td>48</td>
<td>[29]</td>
</tr>
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<td></td>
<td>Papaya leaves</td>
<td>40</td>
<td>[30]</td>
</tr>
<tr>
<td></td>
<td>Chinese mustard</td>
<td>31</td>
<td>[31]</td>
</tr>
</tbody>
</table>
The bioavailability of polyphenols depends on the matrix composition and chemical structure that could be induced by food processing.\textsuperscript{[9,12]} Food processing causes degradation and modification of cell wall composition that can increase the bioavailability of polyphenols.\textsuperscript{[9]} The bioactive metabolites could be absorbed into the circulatory system and exert antioxidant activity that gives beneficial effect on human health.\textsuperscript{[40]} Cory et al.\textsuperscript{[41]} have also reviewed the impact of polyphenols on human health. The antioxidant and anti-inflammatory properties of polyphenols were reported to reduce the risk of cancer, cardiovascular diseases, type 2 diabetes, obesity, and neurodegenerative diseases.

**Carotenoids**

Carotenoids are oil-soluble yellow-orange pigments that consist of isoprene units linked covalently in either a head-to-tail or tail-and-tail to form a symmetrical molecule.\textsuperscript{[20,42]} Carotenoids in vegetables are mostly located in chloroplasts and covered by chlorophylls. Therefore, the yellow-orange color of carotenoids becomes more evident when chlorophyll decomposes.\textsuperscript{[42]} Carotenoids commonly found in plants are in forms of lutein, zeaxanthin, lycopene, β-carotene, α-carotene, dan β-cryptoxanthin.\textsuperscript{[18]} Lutein and β-carotene are the most dominant carotenoids in green vegetables.\textsuperscript{[43]}

In green leafy vegetables, the carotenoid content ranges between 2 and 8 g/100 g FW (Table 1). Carotenoids are mostly bound to proteins that may decrease their bioavailability. The absorption of carotenoids is also influenced by dietary fat. Dietary fat and bile salt could be bound with the carotenoid to form micelles that allow carotenoid absorption to the intestine. Fortunately, appropriate processing could increase carotenoid bioavailability by breaking down the cell wall and protein-carotenoid complexes. Processing combined with oils also can increase the bioavailability of carotenoids.\textsuperscript{[40,43]}

The diffusion of carotenoids from the blood circulatory system to various tissues by lipoprotein could provide beneficial effects on human health.\textsuperscript{[43]} Carotenoids could protect the cellular membranes and lipoproteins against photooxidative damage in plant and human due to their ability to scavenge reactive oxygen species, singlet molecular oxygen, and peroxyl radicals. Carotenoids also contribute to macular pigment formation that could absorb harmful blue light. Thus, increased consumption of a diet rich in carotenoids could reduce the risk of diseases such as erythema, cancer, cardiovascular-linked diseases, light blindness, keratomalacia, xerophthalmia, cataract, and macular degeneration.\textsuperscript{[44,45]}

**Chlorophyll**

Chlorophyll structurally consists of a porphyrin ring containing a magnesium ion located at the center.\textsuperscript{[42]} Various levels of chlorophyll in green leafy vegetables were reported, ranging from 1 to 216 mg/100 g FW (Table 1). Heat treatment can lead to the formation of pheophytin because magnesium in chlorophyll can be easily displaced by two hydrogen atoms. The harsher thermal load may eventually remove the carbomethoxy group in chlorophyll to form pirochlorophyll. Further heating can release either magnesium atom in pirochlorophyll or carbomethoxy group in pheophytin to form piropheophytin.\textsuperscript{[46]}

Interestingly, the conversion of chlorophyll to pheophytin, pyropheophytin, and phaeophorbide during processing can increase the bioavailability of chlorophyll. Chao et al.\textsuperscript{[47]} showed that pheophytin and phaeophorbide are the main chlorophyll derivates found in the
human blood, indicating chlorophyll derivates might be easily absorbed. Chlorophyll derivates are reported to possess antioxidant, antimutagenic, and anticancer activity.\(^{48}\)

Moreover, an in vivo and in vitro study reported chlorophyll could suppress pancreatic cancer cell viability by inhibiting heme oxygenase mRNA expression and enzymatic activity.\(^{49}\) Antioxidant activity in chlorophylls and their derivates can prevent oxidative DNA damage and lipid peroxidation by chelating reactive ions and scavenging free radicals.\(^{19}\)

**Ascorbic acid**

Ascorbic acid, or commonly known as vitamin C that presents mostly in L-ascorbic acid form, is the enolic form of 3-keto-L-glucofuranolactone.\(^{50}\) Table 1 shows the broad spread of ascorbic acid content in various green leafy vegetables. Among others, drumstick leaves notably contain the highest level of ascorbic acid, while celery has the lowest.\(^{20,29-31,35,37,38}\)

L-ascorbic acid can terminate radical chain reaction, scavenge reactive species, donate an electron to a substrate, and regenerate other antioxidant compounds that may protect DNA and protein from oxidative stress.\(^{13}\) Accordingly, ascorbic acid was reported to improve the utilization of iron and prevent cardiovascular diseases, cancer, cataracts, type 2 diabetes, and inflammation due to their antioxidant and antihistamine effects.\(^{38,51}\) Unfortunately, ascorbic acid is easily degraded via oxidation reaction, especially when catalyzed by metal ions (i.e. Cu\(^{2+}\) and Fe\(^{3+}\)). Heat, light, and oxygen may accelerate oxidation.\(^{42}\) The enediol groups at carbon atom numbers 2 and 3 are prone to oxidation and can be easily altered to diketo groups. This transforms ascorbic acid to dehydroascorbic acid.\(^{50}\) Dehydroascorbic acid is unstable at physiological pH and it is easily converted to 2,3 diketogulonic acid. The alteration of ascorbic acid to dehydroascorbic acid is reversible but the products of the latter oxidation stages are irreversible.\(^{38}\) Most ascorbic acid is therefore lost during processing, cooking, and storage.

**Glucosinolates**

Glucosinolates are a group of secondary plant metabolites in family Cruciferae or Brassicaceae, such as broccoli, Chinese mustard, pak choi, kale, and cabbage.\(^{52}\) A glucosinolate consists of β-D-thioglucoside N-hydroxysulphate, which is a sulphur-linked β-D-glucopyranose moiety and a side chain \((R)\).\(^{53}\) Natella, Maldini, Leoni, & Scaccini\(^{52}\) reported that glucosinolates have a weak antioxidant capacity. Two glucosinolates, i.e. sinalbin and gluconasturtiin were found to quench ABTS radical and to chelate copper that leads to low-density lipoprotein inhibition, respectively. Nevertheless, isothiocyanates, ones of the derivative products of glucosinolates were reported to play a role as cancer chemo-preventive.\(^{54,55}\) Reviews on the effect of thermal processing on glucosinolates in vegetables can be found elsewhere.\(^{22,56,57}\)

**Processing methods and their impacts on phytochemical compounds in green leafy vegetables**

**Blanching**

During blanching, vegetables are briefly exposed to hot water or steam. It is usually carried out preceding other processes (e.g. freezing, canning, or drying) to inactivate enzymes, modify the textures, and preserve color. Hot water blanching is performed at temperatures
between 70°C and 100°C for 2 to 5 min, followed by rapid cooling. Steam blanching is carried out at 100°C at a considerably shorter time than water blanching because the heat transfer of condensing steam is more efficient than hot water.\textsuperscript{[58]}

The impact of blanching on phytochemical compounds varies depending on the type of vegetables and the blanching parameters as summarized in Table 2. Hot water blanching reduced phenolic compounds, carotenoids, and flavonoids in water spinach, celery, pak choy, Chinese mustard, black night shade, and jute mallow. Decrease of phenolic compounds, flavonoids, and carotenoid are often associated with thermal degradation, leaching from vegetable tissue into the blanching water\textsuperscript{[26,39,60]}, oxidation reaction, and isomerization.\textsuperscript{[61]} In contrast, various levels of increase of total phenolic content after blanching have been reported in coriander leaves (36% to 156% after water blanching and 11% to 131% after steam blanching) and nearly eight-fold in basil.\textsuperscript{[27,59]} Blanching can liberate phenolic compounds such as hydroxycinnamic acid (which is bound to cell polymer and chlorogenic acid), thus improves its extractability upon analytical measurement. Inversely, the prolonged or higher temperature of blanching decreased the retention of total polyphenolic content in coriander leaves.\textsuperscript{[59]}

Increase of flavonoids bioavailability in spinach and cassava leaves have also been reported.\textsuperscript{[62]} The underlying mechanisms involve disruption of hydrogen bonding of complex molecules, which then liberates flavonoids from leaf matrices. Blanching for a short time (30 s) increased chlorophyll content in basil and coriander leaves of 23% and 169%, respectively. This short time blanching facilitates the breakdown of organelles that contain phytochemical compounds, while the degradation can be maintained minimal.\textsuperscript{[27]}

In general, blanching decreases of phytochemical compounds due to oxidation reaction, thermal degradation, enzymatic degradation, and disruption of vegetable tissue which release water-soluble phytochemical compounds into the processing medium. However, this disruption may also lead to higher extractability of the compounds.

**Boiling**

Boiling is the most common method to cook green leafy vegetables. Cooking affects membrane disruption, loss of turgor, and reduction of cell adhesion strength, which will lead to loss of firmness or softening.\textsuperscript{[63]} Boiling time of green leafy vegetables may vary, depending on the type of vegetables and consumer preferences in relations to, e.g. texture, color, and taste.\textsuperscript{[22,64]} From the phytochemical retention perspective, boiling is more suitable for processing vegetables that contain fat-soluble compounds, such as carotenoid, due to less diffusion and leaching into cooking water.\textsuperscript{[65,66]}

Generally, boiling reduces phytochemicals in vegetables (Table 3), which is considered higher than that of blanching, and the magnitude is highly varied. Boiling leads leaching of water-soluble phytochemical compounds into the cooking medium.\textsuperscript{[39]} Thermal degradation of heat-sensitive compounds such as ascorbic acid\textsuperscript{[81,85]}, oxidation, and degradation of, e.g. chlorophyll into their derivates such as pheophytin further reduces the phytochemical compounds of vegetable subjected to boiling. Acidic cooking condition and longer cooking times facilitate the formation of pheophytin.\textsuperscript{[17,79]} Leaching and degradation of the phytochemical compounds are higher during boiling than blanching due to the extended time and temperature applied during boiling.\textsuperscript{[39,61]}
Table 2. The effect of blanching on the phytochemical compounds in green leafy vegetables.

<table>
<thead>
<tr>
<th>Phytochemical compounds</th>
<th>Vegetables</th>
<th>Method</th>
<th>Temperature</th>
<th>Time (min)</th>
<th>Ratio or Mass</th>
<th>Phytochemical retention (%)</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td>Phenolic acid</td>
<td>Celery (Apium graviolens)</td>
<td>Hot water blanching</td>
<td>96–98°C</td>
<td>3</td>
<td>1:10 (vegetable: water)</td>
<td>80</td>
<td>[39]</td>
</tr>
<tr>
<td>Total polyphenol</td>
<td>Water spinach (Ipomoea aquatica)</td>
<td>Hot water blanching</td>
<td>Boiling water</td>
<td>0.5</td>
<td>1:5 (vegetable: water)</td>
<td>77</td>
<td>[27]</td>
</tr>
<tr>
<td></td>
<td>Spinach (Spinacea oleracea)</td>
<td>Boiling water</td>
<td>100°C</td>
<td>2</td>
<td>100 g</td>
<td>92</td>
<td>[26]</td>
</tr>
<tr>
<td></td>
<td>Basil (Ocimum basilicum)</td>
<td>Boiling water</td>
<td>96–98°C</td>
<td>3</td>
<td>1:10 (vegetable: water)</td>
<td>893</td>
<td>[27]</td>
</tr>
<tr>
<td></td>
<td>Celery (Apium graviolens, Cryptotaenia japonica Hassk)</td>
<td>Hot water blanching</td>
<td>Boiling water</td>
<td>90°C</td>
<td>1, 5, 7, 10</td>
<td>500 g</td>
<td>136–250</td>
</tr>
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<td></td>
<td>Coriander leaves (Coriander sativum)</td>
<td>Boiling water</td>
<td>100°C</td>
<td>1, 5, 7, 10</td>
<td>500 g</td>
<td>97–256</td>
<td>[59]</td>
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<td>Boiling water</td>
<td>96–98°C</td>
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<td>1:10 (vegetable: water)</td>
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<td>Coriander leaves (Coriander sativum)</td>
<td>Boiling water</td>
<td>100°C</td>
<td>2</td>
<td>100 g</td>
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<td></td>
<td>Pak choi (Brassica rapa var chinensis)</td>
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<td>5</td>
<td>1:5 (vegetable: water)</td>
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<td>[60]</td>
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<td></td>
<td>Chinese mustard (Brassica juncea)</td>
<td>Boiling water</td>
<td>98°C</td>
<td>5</td>
<td>1:5 (vegetable: water)</td>
<td>76</td>
<td>[60]</td>
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<td></td>
<td>Green cabbage (Brassica oleracea var capitata)</td>
<td>Boiling water</td>
<td>98°C</td>
<td>5</td>
<td>1:5 (vegetable: water)</td>
<td>80</td>
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<td>Chinese cabbage (Brassica rapa Pekinensis)</td>
<td>Boiling water</td>
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<td>1:5 (vegetable: water)</td>
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<td>Steam blanching</td>
<td>100°C</td>
<td>1, 5, 7, 10</td>
<td>500 g</td>
<td>111 – 231</td>
<td>[59]</td>
</tr>
<tr>
<td></td>
<td>Water spinach (Ipomoea aquatica)</td>
<td>Hot water blanching</td>
<td>Boiling water</td>
<td>95 ± 3°C</td>
<td>1</td>
<td>1:200 (vegetable: water)</td>
<td>69</td>
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<tr>
<td></td>
<td>Spinach (Amaranthus tricolor)</td>
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<td>92°C</td>
<td>2</td>
<td>30 g</td>
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<td></td>
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<td>2</td>
<td>30 g</td>
<td>2</td>
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<tr>
<td></td>
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<td>Boiling water</td>
<td>92°C</td>
<td>2</td>
<td>30 g</td>
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<td>92°C</td>
<td>2</td>
<td>30 g</td>
<td>2</td>
<td>[61]</td>
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<tr>
<td>Phytochemical</td>
<td>Vegetable</td>
<td>Processing Method</td>
<td>Process Parameters</td>
<td>Retention Level</td>
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<td></td>
</tr>
<tr>
<td>Flavonoid</td>
<td>Spinach (Amaranthus viridis)</td>
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<td>[62]</td>
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<td>Spinach (Spinacea oleracea)</td>
<td></td>
<td>100°C 2 100 g</td>
<td>90</td>
<td>[26]</td>
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<td>Cassava leaves (Manihot esculenta)</td>
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<td>Coriander leaves (Coriander sativum)</td>
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<td>100°C 2 100 g</td>
<td>68</td>
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<td>Water spinach (Ipomoea aquatic)</td>
<td>Hot water blanching</td>
<td>Boiling water 100 g 0.5 1:5 (vegetable:water)</td>
<td>69</td>
<td>[27]</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Spinach (Amaranthus tricolor)</td>
<td></td>
<td>Boiling water 3, 6, 9, 12, 15 250 g</td>
<td>48-26</td>
<td>[46]</td>
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<td></td>
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<td>Spinach (Amaranthus tricolor)</td>
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<td>95 ± 3°C 1 1:200 (vegetable:water)</td>
<td>57</td>
<td>[20]</td>
<td></td>
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</tr>
<tr>
<td></td>
<td>Basil (Ocimum basilicum)</td>
<td></td>
<td>Boiling water 0.5 1:5 (vegetable:water)</td>
<td>123</td>
<td>[27]</td>
<td></td>
<td></td>
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<tr>
<td></td>
<td>Coriander leaves (Coriander sativum)</td>
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<td>Boiling water 0.5 1:5 (vegetable:water)</td>
<td>269</td>
<td>[27]</td>
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<tr>
<td>Ascorbic acid</td>
<td>Spinach (Amaranthus tricolor)</td>
<td>Hot water blanching</td>
<td>95 ± 3°C 1 1:200 (vegetable:water)</td>
<td>33</td>
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<td></td>
</tr>
</tbody>
</table>

*The retention level is calculated from the concentration of the phytochemicals both in the raw and the processed green leafy vegetables.*
### Table 3. The effect of boiling and steaming on the phytochemical compounds in green leafy vegetables.

<table>
<thead>
<tr>
<th>Phytochemical compounds</th>
<th>Method</th>
<th>Vegetables</th>
<th>Temperature (°C)</th>
<th>Time (min)</th>
<th>Amount of water (mL)</th>
<th>Mass (g)</th>
<th>Phytochemical retention</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Boiling</strong></td>
<td>Phenolic acid</td>
<td>Celery (<em>Apium graviolens, Cryptotaenia japonica</em> Hassk)</td>
<td>Boiling water (celery added into water at 70°C)</td>
<td>10</td>
<td>400</td>
<td>100</td>
<td>61%</td>
<td>[39]</td>
</tr>
<tr>
<td><strong>Boiling</strong></td>
<td>Water soluble phenol</td>
<td>Water spinach (<em>Ipomoea aquatica</em>)</td>
<td>Boiling water</td>
<td>5</td>
<td>100</td>
<td>150</td>
<td>181%</td>
<td>[67]</td>
</tr>
<tr>
<td><strong>Boiling</strong></td>
<td>Total polyphenol</td>
<td>Water spinach (<em>Ipomoea aquatica</em>)</td>
<td>100°C</td>
<td>2</td>
<td>-</td>
<td>200</td>
<td>121%</td>
<td>[6] [68]</td>
</tr>
<tr>
<td><strong>Boiling</strong></td>
<td></td>
<td>Water spinach (<em>Ipomoea aquatica</em>)</td>
<td>Boiling water</td>
<td>Cooked until tender</td>
<td>150</td>
<td>100</td>
<td>160b</td>
<td>[68]</td>
</tr>
<tr>
<td><strong>Boiling</strong></td>
<td></td>
<td>Spinach (<em>Spinacea oleracea</em>)</td>
<td>Boiling water</td>
<td>5</td>
<td>300</td>
<td>300</td>
<td>83%</td>
<td>[69] [68]</td>
</tr>
<tr>
<td><strong>Boiling</strong></td>
<td></td>
<td>Spinach (<em>Spinacea oleracea</em>)</td>
<td>Boiling water</td>
<td>Cooked until tender</td>
<td>150</td>
<td>100</td>
<td>145b</td>
<td>[68]</td>
</tr>
<tr>
<td><strong>Boiling</strong></td>
<td></td>
<td>Celery (<em>Apium graviolens, Cryptotaenia japonica</em> Hassk)</td>
<td>Boiling water (celery added into water at 70°C)</td>
<td>10</td>
<td>400</td>
<td>100</td>
<td>59%</td>
<td>[39]</td>
</tr>
<tr>
<td><strong>Boiling</strong></td>
<td></td>
<td>Drumstick leaves (<em>Moringa oleifera</em>)</td>
<td>100°C</td>
<td>20–25</td>
<td>2000</td>
<td>290 mg/100 g</td>
<td>[70]</td>
<td></td>
</tr>
<tr>
<td><strong>Boiling</strong></td>
<td></td>
<td>Drumstick leaves (<em>Moringa oleifera</em>)</td>
<td>Boiling water</td>
<td>5</td>
<td>250</td>
<td>50</td>
<td>165</td>
<td>[71]</td>
</tr>
<tr>
<td><strong>Boiling</strong></td>
<td></td>
<td>Drumstick leaves (<em>Moringa oleifera</em>)</td>
<td>Boiling water</td>
<td>10</td>
<td>250</td>
<td>50</td>
<td>121</td>
<td>[71]</td>
</tr>
<tr>
<td><strong>Boiling</strong></td>
<td></td>
<td>Drumstick leaves (<em>Moringa oleifera</em>)</td>
<td>Boiling water</td>
<td>20</td>
<td>250</td>
<td>50</td>
<td>169</td>
<td>[71]</td>
</tr>
<tr>
<td><strong>Boiling</strong></td>
<td></td>
<td>Sweet potato leaves (<em>Ipomoea batatas</em>)</td>
<td>100°C</td>
<td>5</td>
<td>100</td>
<td>159%</td>
<td>186%</td>
<td>[74]</td>
</tr>
<tr>
<td><strong>Boiling</strong></td>
<td></td>
<td>Chinese mustard (<em>Brassica juncea</em>)</td>
<td>100°C</td>
<td>13</td>
<td>200</td>
<td>137%</td>
<td>[31]</td>
<td></td>
</tr>
<tr>
<td><strong>Boiling</strong></td>
<td></td>
<td>Chinese mustard (<em>Brassica juncea</em>)</td>
<td>100°C</td>
<td>5</td>
<td>300</td>
<td>200</td>
<td>120%</td>
<td>[72]</td>
</tr>
<tr>
<td><strong>Boiling</strong></td>
<td></td>
<td>Tatsoi (<em>Brassica narinosa</em>)</td>
<td>Boiling water</td>
<td>10</td>
<td>300</td>
<td>300</td>
<td>125%</td>
<td>[73]</td>
</tr>
<tr>
<td><strong>Boiling</strong></td>
<td></td>
<td>Bush Sorrel (<em>Hibiscus surattensis</em>)</td>
<td>Boiling water</td>
<td>5</td>
<td>50</td>
<td>5</td>
<td>25%</td>
<td>[74]</td>
</tr>
<tr>
<td><strong>Boiling</strong></td>
<td></td>
<td>Bush Sorrel (<em>Hibiscus surattensis</em>)</td>
<td>Boiling water</td>
<td>10</td>
<td>50</td>
<td>100%</td>
<td>159%</td>
<td>[74]</td>
</tr>
<tr>
<td><strong>Flavonoid</strong></td>
<td></td>
<td>Water spinach (<em>Ipomoea aquatica</em>)</td>
<td>100°C</td>
<td>2</td>
<td>-</td>
<td>200</td>
<td>155%</td>
<td>[6] [68]</td>
</tr>
<tr>
<td><strong>Flavonoid</strong></td>
<td></td>
<td>Water spinach (<em>Ipomoea aquatica</em>)</td>
<td>Boiling water</td>
<td>Cooked until tender</td>
<td>150</td>
<td>100</td>
<td>125b</td>
<td>[68]</td>
</tr>
<tr>
<td><strong>Flavonoid</strong></td>
<td></td>
<td>Spinach (<em>Spinacea oleracea</em>)</td>
<td>Boiling water</td>
<td>Cooked until tender</td>
<td>150</td>
<td>100</td>
<td>115b</td>
<td>[68]</td>
</tr>
<tr>
<td><strong>Flavonoid</strong></td>
<td></td>
<td>Spinach (<em>Spinacea oleracea</em>)</td>
<td>Boiling water</td>
<td>Cooked until tender</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Flavonoid</strong></td>
<td></td>
<td>Celery (<em>Apium graviolens, Cryptotaenia japonica</em> Hassk)</td>
<td>Boiling water (celery added into water at 70°C)</td>
<td>10</td>
<td>400</td>
<td>100</td>
<td>54%</td>
<td>[39]</td>
</tr>
<tr>
<td><strong>Carotenoid</strong></td>
<td></td>
<td>Chinese mustard (<em>Brassica juncea</em>)</td>
<td>100°C</td>
<td>5</td>
<td>200</td>
<td>100</td>
<td>165%</td>
<td>[72]</td>
</tr>
<tr>
<td><strong>Carotenoid</strong></td>
<td></td>
<td>Galega Kale (<em>Brassica oleracea var. achepala cv. galega</em>)</td>
<td>100°C</td>
<td>30</td>
<td>200</td>
<td>36%</td>
<td>33%</td>
<td>[75]</td>
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<td><strong>Carotenoid</strong></td>
<td></td>
<td>Bush Sorrel (<em>Hibiscus surattensis</em>)</td>
<td>100°C</td>
<td>5</td>
<td>50</td>
<td>5</td>
<td>25%</td>
<td>[74]</td>
</tr>
<tr>
<td><strong>Carotenoid</strong></td>
<td></td>
<td>Bush Sorrel (<em>Hibiscus surattensis</em>)</td>
<td>Boiling water</td>
<td>10</td>
<td>50</td>
<td>100%</td>
<td>159%</td>
<td>[74]</td>
</tr>
</tbody>
</table>

References:
- [39]
- [67]
- [6]
- [68]
- [69]
- [70]
- [71]
- [72]
- [73]
- [74]
- [75]
- [76]
- [77]
- [78]
- [79]
<table>
<thead>
<tr>
<th>Phytochemical compounds</th>
<th>Method</th>
<th>Vegetables</th>
<th>Temperature</th>
<th>Time (min)</th>
<th>Ratio or Mass</th>
<th>Phytochemical retention</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total polyphenol</td>
<td>Steaming</td>
<td>Spinach (Amaranthus currens)</td>
<td>-</td>
<td>10</td>
<td>40 g</td>
<td>134%</td>
<td>[84]</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Water spinach (Ipomoea aquatica)</td>
<td>100°C</td>
<td>3–5</td>
<td>2000 g</td>
<td>65 mg/100 g</td>
<td>[70]</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Water spinach (Ipomoea aquatica)</td>
<td>100°C</td>
<td>2</td>
<td>200 g</td>
<td>75%</td>
<td>[6]</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Celery (Apium gravidens, Cryptotaenia japonica Hassk)</td>
<td>Boiling water</td>
<td>10</td>
<td>1:2 (vegetable: water)</td>
<td>98%</td>
<td>[39]</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Drumstick leaves (Moringa oleifera)</td>
<td>100°C</td>
<td>3–5</td>
<td>2000 g</td>
<td>109%</td>
<td>[79]</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Sweet potato leaves (Ipomoea batatas)</td>
<td>-</td>
<td>2</td>
<td>100 g</td>
<td>117%</td>
<td>[76]</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Chinese mustard (Brassica juncea)</td>
<td>Boiling water</td>
<td>7.5</td>
<td>100 g</td>
<td>122%</td>
<td>[72]</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Chinese mustard (Brassica juncea)</td>
<td>Boiling water</td>
<td>8</td>
<td>200 g</td>
<td>117%</td>
<td>[31]</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Tatsoi (Brassica narinosa)</td>
<td>-</td>
<td>30</td>
<td>300 g</td>
<td>18%</td>
<td>[73]</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Celery (Apium gravidens, Cryptotaenia japonica Hassk)</td>
<td>Boiling water</td>
<td>10</td>
<td>1:2 (vegetable: water)</td>
<td>93%</td>
<td>[39]</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Galega Kale (Brassica oleracea var. achepala cv. galega)</td>
<td>Boiling water</td>
<td>5</td>
<td>3:1 (vegetable: water)</td>
<td>93%</td>
<td>[73]</td>
</tr>
<tr>
<td>Phenolic Acid</td>
<td></td>
<td>Spinach (Amaranthus currens)</td>
<td>-</td>
<td>10</td>
<td>40 g</td>
<td>125%</td>
<td>[84]</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Water spinach (Ipomoea aquatica)</td>
<td>100°C</td>
<td>2</td>
<td>200 g</td>
<td>62%</td>
<td>[6]</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Celery (Apium gravidens, Cryptotaenia japonica Hassk)</td>
<td>Boiling water</td>
<td>10</td>
<td>1:2 (vegetable: water)</td>
<td>92%</td>
<td>[39]</td>
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<td></td>
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<td>Chinese mustard (Brassica juncea)</td>
<td>Boiling water</td>
<td>7.5</td>
<td>100 g</td>
<td>66%</td>
<td>[72]</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Galega Kale (Brassica oleracea var. achepala cv. galega)</td>
<td>Boiling water</td>
<td>20</td>
<td>1:20 (vegetable: water)</td>
<td>90%</td>
<td>[73]</td>
</tr>
</tbody>
</table>

(Continued)
<table>
<thead>
<tr>
<th>Phytochemical compounds</th>
<th>Method</th>
<th>Vegetables</th>
<th>Temperature</th>
<th>Time (min)</th>
<th>Amount of water (mL)</th>
<th>Mass (g)</th>
<th>Phytochemical retention</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carotenoid</td>
<td>Water spinach (Ipomoea aquatica)</td>
<td>100°C</td>
<td>3–5</td>
<td>2000</td>
<td>2000 g</td>
<td>20 mg/100 g</td>
<td>60%</td>
<td>[70]</td>
</tr>
<tr>
<td>Carotenoid</td>
<td>Water spinach (Ipomoea aquatica)</td>
<td>100°C</td>
<td>2</td>
<td>200</td>
<td>200 g</td>
<td>60%</td>
<td></td>
<td>[6]</td>
</tr>
<tr>
<td>Carotenoid</td>
<td>Drumstick leaves (Moringa oleifera)</td>
<td>110°C</td>
<td>15</td>
<td>2 g</td>
<td>2 g</td>
<td>93%</td>
<td></td>
<td>[79]</td>
</tr>
<tr>
<td>Carotenoid</td>
<td>Drumstick leaves (Moringa oleifera)</td>
<td>100°C</td>
<td>3–5</td>
<td>2000</td>
<td>2000 g</td>
<td>39 mg/100 g</td>
<td></td>
<td>[70]</td>
</tr>
<tr>
<td>Carotenoid</td>
<td>Chinese mustard (Brassica juncea)</td>
<td>-</td>
<td>8</td>
<td>200</td>
<td>200 g</td>
<td>77%</td>
<td></td>
<td>[31]</td>
</tr>
<tr>
<td>Chlorophyll</td>
<td>Water spinach (Ipomoea aquatica)</td>
<td>100°C</td>
<td>2</td>
<td>200</td>
<td>200 g</td>
<td>90%</td>
<td></td>
<td>[6]</td>
</tr>
<tr>
<td>Chlorophyll</td>
<td>Spinach (Spinacea oleracea)</td>
<td>Boiling water</td>
<td>7, 15, 30, 45, 60</td>
<td>250</td>
<td>25 g</td>
<td>25%</td>
<td>6%</td>
<td>[46]</td>
</tr>
<tr>
<td>Ascorbic acid</td>
<td>Tatsoi (Brassica narinosa)</td>
<td>Boiling water</td>
<td>5</td>
<td>3:1 (vegetable: water)</td>
<td>98%</td>
<td></td>
<td>[73]</td>
<td></td>
</tr>
<tr>
<td>Ascorbic acid</td>
<td>Spinach (Spinacea oleracea)</td>
<td>Boiling water</td>
<td>8</td>
<td>1 g</td>
<td>66%</td>
<td></td>
<td>[81]</td>
<td></td>
</tr>
<tr>
<td>Ascorbic acid</td>
<td>Spinach (Amaranthus curentus)</td>
<td>-</td>
<td>10</td>
<td>40 g</td>
<td>71%</td>
<td></td>
<td>[84]</td>
<td></td>
</tr>
<tr>
<td>Ascorbic acid</td>
<td>Tatsoi (Brassica narinosa)666</td>
<td>Boiling water</td>
<td>5</td>
<td>3:1 (vegetable: water)</td>
<td>81%</td>
<td></td>
<td>[73]</td>
<td></td>
</tr>
<tr>
<td>Ascorbic acid</td>
<td>Galega Kale (Brassica oleracea var. acheon cv. galega)</td>
<td>-</td>
<td>20</td>
<td>1:2 (vegetable: water)</td>
<td>78%</td>
<td></td>
<td>[75]</td>
<td></td>
</tr>
</tbody>
</table>

*The retention level is calculated from the concentration of the phytochemicals both in the raw and the processed green leafy vegetables.

*Numbers are estimated from the data reported in the graphs.

*No data on the amount of phytochemical compounds before processing.
In contrast, Ng et al.\textsuperscript{[67]} reported that the concentration of water-soluble polyphenol compounds in boiled water spinach was 81% higher as compared to the ones in raw spinach.\textsuperscript{[67]} Boiling notably increased total polyphenol and flavonoid contents in water spinach, drumstick leaves, and Chinese mustard.\textsuperscript{[6,71,72]} Accordingly, a slight increase of β-carotene after boiling was found in basil, coriander leaves, sweet potato leaves, and pak choi.\textsuperscript{[78]}

Similar to blanching, the increase of phytochemical compounds is likely an artifact due to the softening of the vegetable matrix due to heat, which subsequently increases extractability.\textsuperscript{[71,74]} An in vitro study reported that boiling could enhance the extractability of polyphenols in \textit{Bidens pilosa} leaf matrix. Although bioaccessibility of polyphenols reduced after duodenal digestion, polyphenols still have sufficient antioxidant activity to protect cells from oxidative damage.\textsuperscript{[66]} Gehse et al.\textsuperscript{[86]} also reported short boiling time (less than 10 min) could increase the bioavailability of carotenoid in vegetables. This is due to disruption of the carotenoid-protein complexes, inactivation of carotenoid oxidizing enzymes,\textsuperscript{[78]} the formation of secondary plant metabolites, destruction of complex phenolics,\textsuperscript{[6,66,69]} and release of active aglycones from flavonoid conjugates.\textsuperscript{[67]}

**Steaming**

Steaming is probably the most appropriate cooking method to retain water-soluble phytochemical compounds in vegetables.\textsuperscript{[75,81]} This is due to the fact that during steaming vegetables are actually not in direct contact with water.\textsuperscript{[87]} Loss of nutritional contents after steaming is, however, still observed in green leafy vegetables (Table 3). Thi & Hwang\textsuperscript{[6]} reported that steaming at temperature 100°C for 2 min reduced the concentration (in dry weight basis) of polyphenol, flavonoid, carotenoid, and chlorophyll in water spinach. Minor loss of carotenoid in drumstick leaves,\textsuperscript{[79]} total polyphenol and flavonoid in celery,\textsuperscript{[39]} and ascorbic acid in tatasoi\textsuperscript{[73]} were also observed. Thermal degradation is suspected of playing a major role in the loss of phytochemical compounds during steaming.\textsuperscript{[6,79,84]}

Teng & Chen\textsuperscript{[46]} reported a slight increase in chlorophyll degradation in spinach with heating time and temperature. The formation of pheophytin (a marker of chlorophyll degradation) is higher during wet heating methods (steaming, blanching) than dry heating methods (baking, microwaving cooking). This is probably because the liberation of organic acids from the leaf matrices due to moist heat are greater than due to dry heat. Moreover, higher heating time and temperature may facilitate the removal of the carboxymethoxy group from chlorophyll.\textsuperscript{[46]}

In contrast, an increase of total polyphenol concentration in sweet potato leaves (by about 9%) and in spinach (34%) and increase of flavonoid compounds in spinach (25%) after steaming have been also reported.\textsuperscript{[17]} It is likely that the strength of the cell walls influences the amount of extracted phytochemicals after steaming.\textsuperscript{[88]} It was reported that the breakdown of cell wall due to heating might promote the release of phenolic compounds from vegetable tissue\textsuperscript{[84]} and the breakdown of complex structures, thus liberating the phenolic compounds.\textsuperscript{[17]}

Yao and Ren\textsuperscript{[39]} reported that steaming retains more polyphenol, phenolic acid, and flavonoid in celery than blanching or boiling. In steaming, direct contact between vegetables tissue and water is avoided, which significantly minimize losses of water-soluble phytochemical compounds through leaching. Steaming may also increase the bioaccessibility of
micronutrients such as lutein, β-carotene, and α-tocopherol through cell ruptures. Breakdown of cellulose structure and denaturation of carotenoid-protein complexes may be responsible for the increase of carotenoid content of vegetables after steaming.

**Drying**

Drying is often applied to increase shelf life by preventing the microbial growth and enzymatic reaction through the reduction of water content and water activity. Proper selection of appropriate drying methods is crucial to retain aroma, appearance, and nutritional characteristics while optimizing the energy (cost) efficiency. Various drying methods are commonly applied to green leafy vegetables, such as shade drying, sun drying, oven drying, cabinet drying, and freeze-drying.

During shade drying, significant reduction of ascorbic acid in drumstick leaves, papaya leaves, and spinach was reported. To a lesser degree, shade drying also reduced the availability of carotenoid and flavonoid content. During shade drying, despite carried out at relatively low temperatures (30–35°C), long drying time (1–3 weeks) significantly decreased phytochemical contents in vegetables. Shorter drying time during oven drying and the absence of thermal load during freeze-drying ensured a lower degree of thermally induced degradation of heat-sensitive chlorophylls. In contrast, the increase of available chlorophyll of 147% and carotenoid of 36% has been reported for shade drying of spinach. Raja et al. also reported the increase of total phenolic content in papaya leaves between 6% and 15% after shade drying. This could be due to the formation of new products from Maillard reaction during heating.

Sun drying has been reported to decrease phytochemical compounds (phenolic, flavonoid, carotenoid, ascorbic acid, and chlorophyll) in green leafy vegetables ranging from 35% to 100% (Table 4). Sriwichai et al. reported a 63% decrease of carotenoid content in drumstick leaves upon sun drying, which is more severe than that of steaming, freezing, and sterilization. Direct light exposure is hypothesized to induce the oxidation reaction of heat-sensitive phytochemical compounds in green leafy vegetables. Moreover, grinding prior to drying can increase the contact area of vegetable and air/light, which subsequently increases the rate of autooxidation.

Speek et al. reported the decrease of carotenoid in spinach (51%) and basil (55%) after sun drying, which likely relates to decomposition and trans-cis isomerization of carotenoid. During sun drying, chlorophyll may be transformed into pheophytin via the displacement of magnesium by a hydrogen atom. Chlorophyll A is more susceptible to thermal degradation than chlorophyll B. Thus, after sun drying the decrease of chlorophyll A is usually more pronounced than chlorophyll B.

After sun drying total polyphenol, carotenoid, and chlorophyll in spinach increased by 223%, 5%, and 109%, respectively. Similarly, a dramatic increase of total polyphenol in cassava leaves and chlorophyll in water spinach after drying has been reported. This may be explained by the increase of dry solid in the vegetable matrices, increase extractable carotenoid via release from matrix cell, and/or breakdown of the cell wall during drying, which disturbs the bond of phenolic compounds.

After oven drying, most of the phytochemical compounds (phenolic, flavonoid, carotenoid, chlorophyll, and ascorbic acid) in green leafy vegetables decreased between 4% and 100% (Table 4). Saini et al. reported that cabinet drying of drumstick leaves decreased
Table 4. The effect of drying on the phytochemical compounds of green leafy vegetables.

<table>
<thead>
<tr>
<th>Phytochemical compounds</th>
<th>Method</th>
<th>Vegetables</th>
<th>Temperature or Power</th>
<th>Time</th>
<th>Mass (g)</th>
<th>Phytochemical retention (^a)</th>
<th>References</th>
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<tbody>
<tr>
<td>Total Polyphenol</td>
<td>Shade drying</td>
<td>Drumstick leaves (Moringa oleifera)</td>
<td>Shade place</td>
<td>1 week</td>
<td>-</td>
<td>9535 mg/100 g (^c)</td>
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<td>Coriander leaves (Coriander sativum)</td>
<td>Shade place (35°C)</td>
<td>2 days</td>
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<td>78(^b)</td>
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<td>Papaya leaves (Carica papaya)</td>
<td>28°C</td>
<td>3 days</td>
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<td>106%</td>
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<td>Sun drying</td>
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<td></td>
<td>Drumstick leaves (Moringa oleifera)</td>
<td>Sun light</td>
<td>2–3 days</td>
<td>2000</td>
<td>65%</td>
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<td>Oven drying</td>
<td>Cassava leaves (Manihot esculenta)</td>
<td>35–38°C</td>
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<td>250</td>
<td>520% (^b)</td>
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<tr>
<td></td>
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<td>Spinach (Spinacea oleracea)</td>
<td>50 ± 2°C</td>
<td>3 days</td>
<td>250</td>
<td>70 mg/g (^c)</td>
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<td>Celery (Apium graviolens)</td>
<td>48°C</td>
<td>60 minutes</td>
<td>-</td>
<td>114% (^b)</td>
<td>[102]</td>
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<td>Drumstick leaves (Moringa oleifera)</td>
<td>50°C</td>
<td>12.5 hours</td>
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<td>Drumstick leaves (Moringa oleifera)</td>
<td>50°C</td>
<td>2.5 hours</td>
<td>2000</td>
<td>96% (^b)</td>
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<td>Coriander leaves (Coriander sativum)</td>
<td>70°C</td>
<td>4 hours</td>
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<td>22 mg/g (^c)</td>
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<td>Spinach (Spinacea oleracea)</td>
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<td>10-12 hours</td>
<td>100</td>
<td>97%</td>
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<td></td>
<td>Drumstick leaves (Moringa oleifera)</td>
<td>50°C</td>
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<td>2000</td>
<td>61%</td>
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<td>57%</td>
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<td>Microwave drying</td>
<td>Drumstick leaves (Moringa oleifera)</td>
<td>850 W</td>
<td>30 seconds</td>
<td>2000</td>
<td>59%</td>
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<td>Coriander leaves (Coriander sativum)</td>
<td>100°C</td>
<td>3 minutes</td>
<td>500</td>
<td>57% (^b)</td>
<td>[36]</td>
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<td>Freeze drying</td>
<td>Drumstick leaves (Moringa oleifera)</td>
<td>−35°C, 0.312 mbar</td>
<td>24 hours</td>
<td>2000</td>
<td>58%</td>
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<td>Papaya leaves (Carica papaya)</td>
<td>−100°C, 0.001 mbar</td>
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<td>147% (^b)</td>
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<td>Flavonoid</td>
<td>Drumstick leaves (Moringa oleifera)</td>
<td>Shade place</td>
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<td>Shade drying</td>
<td>Oven drying</td>
<td>Celery (Apium graviolens)</td>
<td>48°C</td>
<td>60 minutes</td>
<td>-</td>
<td>40%</td>
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<th>Temperature or Power</th>
<th>Time</th>
<th>Mass (g)</th>
<th>Phytochemical retention</th>
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<td>Cabinet drying</td>
<td>Kenikir leaves (<em>Cosmos caudatus</em>)</td>
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<td>-</td>
<td>-</td>
<td>78%</td>
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<td>Spinach (<em>Spinacea oleracea</em>)</td>
<td>60°C</td>
<td>10-12 hours</td>
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<td>89%</td>
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<td>10-12 hours</td>
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<td>59%</td>
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<tr>
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<td>Shade drying</td>
<td>Spinach (<em>Amaranthus tricolor</em>)</td>
<td>Room temperature</td>
<td>6 days</td>
<td>100</td>
<td>183%</td>
<td>[91]</td>
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<td></td>
<td>Drumstick leaves (<em>Moringa oleifera</em>)</td>
<td>Shade place (35°C)</td>
<td>2 days</td>
<td>500</td>
<td>52% (^b)</td>
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<td></td>
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<td>Black nighshade (<em>Solanum scabrum Mill.</em>)</td>
<td>25.8–31.4 °C</td>
<td>3 days</td>
<td>30 g</td>
<td>11%</td>
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<td>Sun drying</td>
<td>Spinach (<em>Amaranthus tricolor</em>)</td>
<td>Sun light</td>
<td>2 days</td>
<td>-</td>
<td>49%</td>
<td>[20]</td>
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<td></td>
<td>Spinach (<em>Amaranthus tricolor</em>)</td>
<td>Sun light</td>
<td>Until the vegetables contain 7-9% moisture</td>
<td>-</td>
<td>105%</td>
<td>[20]</td>
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<td>Basil (<em>Ocimum bacillicum</em>)</td>
<td>Sun light</td>
<td>2 days</td>
<td>-</td>
<td>45%</td>
<td>[76]</td>
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<td>Drumstick leaves (<em>Moringa oleifera</em>)</td>
<td>Sun light</td>
<td>2-3 days</td>
<td>2000</td>
<td>53%</td>
<td>[37]</td>
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<td>Drumstick leaves (<em>Moringa oleifera</em>)</td>
<td>30°C</td>
<td>8 hours</td>
<td>2</td>
<td>37%</td>
<td>[79]</td>
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<td>Drumstick leaves (<em>Moringa oleifera</em>)</td>
<td>Sun light</td>
<td>4 days</td>
<td>100</td>
<td>187%</td>
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<td>35–38°C</td>
<td>3 days</td>
<td>250</td>
<td>3% (^b)</td>
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<td>Drumstick leaves (<em>Moringa oleifera</em>)</td>
<td>60–80°C</td>
<td>24 hours</td>
<td>-</td>
<td>36 – 17 mg/100 g (^c)</td>
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<td>60°C</td>
<td>12 hours</td>
<td>2000</td>
<td>58%</td>
<td>[37]</td>
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<td></td>
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<td>Drumstick leaves (<em>Moringa oleifera</em>)</td>
<td>60°C</td>
<td>3 hours</td>
<td>2</td>
<td>81%</td>
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<td>Drumstick leaves (<em>Moringa oleifera</em>)</td>
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<td>4-5 hours</td>
<td>100</td>
<td>182%</td>
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<td></td>
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<td>Coriander leaves (<em>Coriander sativum</em>)</td>
<td>70°C</td>
<td>4 hours</td>
<td>500</td>
<td>34% (^b)</td>
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<td>Jute mallow (Corchorus olitorius L.)</td>
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<td>30 g</td>
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<tr>
<td></td>
<td></td>
<td>50 °C</td>
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<td></td>
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<td>60 °C</td>
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<td>6 hours</td>
<td>2000</td>
<td>60%</td>
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<td>61%</td>
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<td>2 days</td>
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<td>Sun drying</td>
<td>Water spinach (Ipomoea aquatica)</td>
<td>Sun light (27-32°C)</td>
<td>48 hours</td>
<td>1000</td>
<td>221%b</td>
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<td>-</td>
<td>209%</td>
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<td>2-3 days</td>
<td>2000</td>
<td>65%</td>
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<td>65%</td>
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<td>35%c</td>
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<td>Basil (Ocimum basilicum)</td>
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<td>4.5 hours</td>
<td>18</td>
<td>13%*</td>
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<td>Cabinet drying</td>
<td>Spinach (Amaranthus tricolor)</td>
<td>65 ± 5°C</td>
<td>Until the vegetables contain 7-9% moisture</td>
<td>-</td>
<td>144%</td>
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<td>70%</td>
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<tr>
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<td>850 W</td>
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<td>56%</td>
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<td>Basil (Ocimum bacillicum)</td>
<td>−35°C − 20°C</td>
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<td>74%</td>
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<td>Until the vegetables contain 7-9% moisture</td>
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<td>78%</td>
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<td>Papaya leaves (Carica papaya)</td>
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<td>3 days</td>
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<td>25-63%b</td>
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<td>Water spinach (Ipomoea aquatica)</td>
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<td>1000</td>
<td>49%</td>
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<td>Sunlight</td>
<td>Until the vegetables contain 7-9% moisture</td>
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<td>-</td>
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<td>Sunlight</td>
<td>2-3 days</td>
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<td>38%</td>
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<td>Cassava leaves (Manihot esculenta)</td>
<td>35–38°C</td>
<td>3 days</td>
<td>250</td>
<td>0%b</td>
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<tr>
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<td>Water spinach (Ipomoea aquatica)</td>
<td>65 ± 5°C</td>
<td>12 hours</td>
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<td>82%</td>
<td>[35]</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Celery (Apium graviolens)</td>
<td>48°C</td>
<td>60 minutes</td>
<td>-</td>
<td>94%</td>
<td>[102]</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Drumstick leaves (Moringa oleifera)</td>
<td>60–80°C</td>
<td>24 hours</td>
<td>-</td>
<td>450 – 436 μm/100 g^c</td>
<td>[105]</td>
</tr>
<tr>
<td></td>
<td>Cabinet drying</td>
<td>Papaya leaves (Carica papaya)</td>
<td>50°C</td>
<td>12 hours</td>
<td>2000</td>
<td>40%</td>
<td>[37]</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Spinach (Amaranthus tricolor)</td>
<td>40°C</td>
<td>7 hours</td>
<td>2000</td>
<td>72–78%b</td>
<td>[30]</td>
</tr>
<tr>
<td></td>
<td>Microwave drying</td>
<td>Papaya leaves (Carica papaya)</td>
<td>50°C</td>
<td>6 hours</td>
<td>2000</td>
<td>44%</td>
<td>[37]</td>
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<tr>
<td></td>
<td>Freeze drying</td>
<td>Drumstick leaves (Moringa oleifera)</td>
<td>850 W</td>
<td>30 seconds</td>
<td>2000</td>
<td>64%</td>
<td>[37]</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Water spinach (Ipomoea aquatica)</td>
<td>-</td>
<td>72 hours</td>
<td>1000</td>
<td>346%</td>
<td>[35]</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Drumstick leaves (Moringa oleifera)</td>
<td>−35°C, 0.312 mbar</td>
<td>24 hours</td>
<td>2000</td>
<td>98%</td>
<td>[37]</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Papaya leaves (Carica papaya)</td>
<td>−100°C, 0.001 mbar</td>
<td>24 hours</td>
<td>2000</td>
<td>82%b</td>
<td>[30]</td>
</tr>
</tbody>
</table>

aThe retention level is calculated from the concentration of the phytochemicals both in the raw and the processed green leafy vegetables.
bNumbers are estimated from the data reported in the graphs.
cNo data on the amount of phytochemical compounds before processing.
total polyphenol, carotenoid, chlorophyll, and ascorbic acid. Cabinet tray drying was also reported to decrease total polyphenol and flavonoid in spinach and in coriander leaves.\textsuperscript{[26]}

The retention of chlorophyll A and B is higher during cabinet drying than oven drying, thus cabinet drying produces the dark green color of the powder, which consumers prefer to choose. It is mostly due to forced convection of heated air in the cabinet dryer which can reduce the drying time.\textsuperscript{[37]}

Carotenoids retention in vegetables was higher after oven drying than after sun drying because the closed condition in oven drying mitigates the risk of photooxidation.\textsuperscript{[18]} Compared to shade drying, the decrease of total polyphenol, carotenoid, and chlorophyll in coriander leaves\textsuperscript{[36]} and \(\beta\)-carotene of black nightshade and jute mallow leaves\textsuperscript{[61]} after oven drying was higher, which relate to the imposed thermal load. High drying temperature needs to be avoided to mitigate trans-cis isomerization of \(\beta\)-carotene and lutein. The provitamin activity of the cis- form of carotenoid is lower than the trans- form.\textsuperscript{[37,61,79]}

Drying at 60°C decreased flavonoid content in kenikir (\textit{Cosmos caudatus}) leaves because the increase of flavonoid degrading enzyme activity such as polyphenoloxidase enzyme.\textsuperscript{[104]} However, the enzyme activity could be reduced by drying at temperatures higher than 70°C. The content of phytochemical compounds in vegetables can also have further losses during storage.\textsuperscript{[102]} Grinding could increase the surface area of the dried product that leads to further losses through autooxidation. Therefore, dried or powdered vegetables must be protected from air and light.\textsuperscript{[37]}

Wangcharoen & Gomolmanee\textsuperscript{[103]} reported that drying of drumstick leaves at 50°C decreases total phenolic contents in vegetables. However, when drying was performed at a higher temperature (100°C), phenolic contents initially decrease then increase again in the later stage. The fluctuation of total phenolic contents could be due to the formation of new antioxidant compounds of non-enzymatic browning and due to thermal degradation of insoluble and bound phenolic compounds that occurs at high temperature. Raja \textit{et al.}\textsuperscript{[30]} also observed the formation of maillard products formed due to heat treatment, which increased total phenolic contents in papaya leaves between 6% and 64%. Similarly, Negi & Roy\textsuperscript{[20]} reported that drying could increase carotenoid and vitamin C in spinach. This relates to the increase of solid fraction, thus concentrating the phytochemical compounds.\textsuperscript{[26]}

Table 4 shows that most of the phytochemical compounds in vegetables decreased during microwave drying ranging between 36% and 91%, which was more pronounced than that of oven-, freeze-, or cabinet drying.\textsuperscript{[36,37,107]} This might be due to the imposed higher temperature during microwave drying than the other drying methods. Dev \textit{et al.}\textsuperscript{[111]} also reported that the color change of drumstick leaves was more severe after microwave drying than that of oven drying. Retention of chlorophyll was however higher after microwave drying than after air drying. The degradation of chlorophyll pigment to pheophytin is shown by color transformation from bright green to olive brown. The formation of pheophytin was affected by the liberation of plant acid compounds and the release of chlorophyll from protein complex.\textsuperscript{[107]} Divya \textit{et al.}\textsuperscript{[106]} found that microwave drying increased carotenoid in coriander leaves ranging from about 35% to 40%. This is due to heating that could liberate carotenoid bound to membranes and other pigments, such as chlorophyll. This study found no trans-cis isomerization of \(\beta\)-carotene during microwave drying.

Lyophilization or freeze drying is a dehydration process that involves freezing then sublimation of ice. Freeze drying is slower and more energy intensive than another conventional drying.\textsuperscript{[92,112]} Freeze drying was reported to decrease total polyphenol,
carotenoid, chlorophyll, and ascorbic acid in drumstick leaves.\textsuperscript{[37]} Other studies also reported the decrease of ascorbic acid in papaya leaves and chlorophyll in basil.\textsuperscript{[79,107]} Formation of ice crystal can damage cell walls and release oxidative- and hydrolytic-enzymes, which degrade phytochemicals such as phenolic compounds.\textsuperscript{[30]}

Compared to other drying methods, freeze drying remains the best method to retain trans-lutein, trans-luteoxanthin, trans-\(\beta\)-carotene, total carotenoid, \(\alpha\)-tocopherol, ascorbic acid, chlorophyll A, and chlorophyll B.\textsuperscript{[37]} Increase of total phenolic contents in papaya leaves, and chlorophyll and ascorbic acid in water spinach have also been reported.\textsuperscript{[30,35]} It is believed that the use of low temperature during freeze-drying prevents thermal degradation of these heat sensitive compounds.\textsuperscript{[110]} Furthermore, the formation of ice crystals can rupture cell walls, thus allowing the release of cellular components, which consequently improves extractability.\textsuperscript{[97]}

\textbf{Microwave cooking}

Water is often added during microwave cooking of vegetables. This may lead to leaching of water-soluble phytochemical compounds.\textsuperscript{[67,69]} Microwave cooking has been reported to decrease chlorophyll contents in spinach\textsuperscript{[46]} and tatsoi.\textsuperscript{[73]} Induced by heat, the removal of magnesium or carbomethoxy group from chlorophylls may occur to form pheophytins and may subsequently transform to pirochlorophylls. Microwave cooking reduced phenolic compounds in water spinach,\textsuperscript{[67]} drumstick leaves,\textsuperscript{[113]} sweet potato leaves,\textsuperscript{[17]} Chinese mustard,\textsuperscript{[72]} tatsoi,\textsuperscript{[39]} and bush sorrel.\textsuperscript{[74]} Microwave cooking also reduced a significant amount of flavonoid,\textsuperscript{[72]} carotenoid,\textsuperscript{[31]} and ascorbic acid\textsuperscript{[31]} in Chinese mustard, and chlorophyll and ascorbic acid in tatsoi.\textsuperscript{[39]} Thermal breakdown, leaching (when water is added during cooking), and oxidation are the responsible mechanisms of phytochemical degradation during microwave cooking.\textsuperscript{[31,67,69,113]}

In contrast, increase of total polyphenols in Chinese mustard\textsuperscript{[31]} and drumstick leaves,\textsuperscript{[71]} ascorbic acid in spinach,\textsuperscript{[80]} and flavonoid in drumstick leaves have been reported.\textsuperscript{[80]} Breakdown of cell walls and complex phenolic compounds during heating may increase the availability of these phytochemical compounds.\textsuperscript{[71,74,80,114]}

\textbf{Pressure cooking}

Employing high pressure enables cooking at temperatures higher than the normal boiling point of water. Heat sensitive phytochemicals are better retained because cooking time can be considerably reduced. However, water-soluble phytochemical compounds may be leached due to the presence of added water during pressure-cooking.\textsuperscript{[67]} Veda \textit{et al.}\textsuperscript{[33]} reported that pressure-cooking at 15 psi for 10 min decreased carotenoid in spinach, in drumstick leaves, and in coriander leaves. Pressure-cooking also decreased carotenoid and ascorbic acid content in Chinese mustard by about 13% and 69%, respectively\textsuperscript{[31]}, which likely relates to leaching, oxidation, and formation of cis isomers from all trans-\(\beta\)-carotene.\textsuperscript{[33]}

Pressure cooking, however, has been reported to increase total phenolic concentration in Chinese mustard\textsuperscript{[31]} and in drumstick leaves.\textsuperscript{[115]} This is likely due to the softening of vegetable matrices that improve extractability, the liberation of phenolic compounds from pectin or cellulose networks, the formation of secondary plant metabolites, inactivation of
oxidative enzymes (e.g. polyphenol oxidase), and release of active aglycones from flavonoid conjugates during heating.\textsuperscript{67,114,115}

\subsection*{Frying}

Frying is performed by increasing the surface temperature of food and then vaporizing a proportion of water.\textsuperscript{112} Based on the media for heat transfer, frying can be categorized into frying in oil (stir frying and deep frying) and frying with the addition of water such as stewing and sauteing.\textsuperscript{32} Frying is usually applied at high temperatures to maximize the heat transfer.

Frying generally decreased carotenoid content in basil leaves, drumstick leaves, coriander leaves, sweet potato leaves, and pak choi (Table 5). The decrease of \(\beta\)-carotene in vegetables was reported to be higher in deep fat frying than in shallow contact frying.\textsuperscript{33} This may relate to degradation or isomerization of carotenoids, the release of carotenoids to oil, and cell disruption during frying.\textsuperscript{65,79} Moreover, the release of carotenoid into oil is affected by the amount of oil, frying time, location, and chemical and physical structure of carotenoid.\textsuperscript{32}

Frying, especially stir-frying, could increase the availability of \(\beta\)-carotene in water spinach and spinach.\textsuperscript{33} The presence of oil during frying may improve the bioaccessibility of \(\beta\) carotene and the loosening of food matrices facilitates carotenoid absorption.\textsuperscript{11,32,33} Sun \textit{et al.}\textsuperscript{17} found a 16\% reduction of total phenolic concentration in sweet potato leaves due to the breakdown of phenolic compounds during processing. Frying also decreased phenolic compounds in spinach by 17\%, bush sorrel by 29-39\%, and tatsoi by 4\% likely due to decomposition and liberation of phenolic compounds.\textsuperscript{69,73,74} On the contrary, frying has been found to increase considerably the total polyphenol and flavonoid contents in drumstick leaves, spinach, water spinach, and Chinese mustard and, to a lesser degree, increased ascorbic acid availability. Previous studies suggested that the apparent increase of these phytochemical compounds can be related to the breakdown of the cell wall and softening vegetable tissues, thus liberating the phytochemical compounds and making it more accessible. Other mechanisms include inactivation of oxidative enzymes, thus minimizing the risk of the enzyme rendering phytochemicals into, e.g. its inactive form.\textsuperscript{33,68,73,114,116}

\subsection*{Conclusion}

Changes of phytochemical compounds in vegetables during cooking/processing are influenced by various factors such as characteristics of the compounds, type of vegetables, and processing methods. Loss of phytochemical compounds during blanching, boiling, microwave cooking, and pressure cooking of green leafy vegetables are often found related to leaching and thermal degradation. Significant losses during frying and drying could be due to the thermal degradation, oxidation reaction, and isomerization of phytochemical structures. Steaming can be the most suitable method to retain phytochemical compounds because of the low impact on thermal degradation, oxidation reaction, and leaching of water-soluble phytochemical compounds, such as polyphenols and ascorbic acid. Increase the bioavailability of phytochemical compounds in vegetables during processing is due to the breakdown of complex bound, cell wall disruption, and inactivation of oxidation enzymes. Processing should therefore be optimized to minimize the loss of phytochemical compounds.
Table 5. The effect of microwave cooking, pressure cooking, and frying on the phytochemical compounds of green leafy vegetables.

<table>
<thead>
<tr>
<th>Phytochemical compounds</th>
<th>Method</th>
<th>Vegetables</th>
<th>Power (W)</th>
<th>Times (minutes)</th>
<th>Amount of water (mL)</th>
<th>Mass (g)</th>
<th>Phytochemical retention (%)&lt;sup&gt;a&lt;/sup&gt;</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total polyphenol</td>
<td>Microwave cooking</td>
<td>Drumstick leaves <em>(Moringa oleifera)</em></td>
<td>-</td>
<td>5</td>
<td>-</td>
<td>100</td>
<td>88</td>
<td>[113]</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Drumstick leaves <em>(Moringa oleifera)</em></td>
<td>1000</td>
<td>5</td>
<td>250</td>
<td>50</td>
<td>165</td>
<td>[71]</td>
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<td>1000</td>
<td>10</td>
<td>250</td>
<td>50</td>
<td>153</td>
<td>[71]</td>
</tr>
<tr>
<td></td>
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<td>1000</td>
<td>20</td>
<td>250</td>
<td>50</td>
<td>166</td>
<td>[71]</td>
</tr>
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<td></td>
<td></td>
<td>Sweet potato leaves <em>(Ipomoea batatas)</em></td>
<td>1000</td>
<td>2</td>
<td>-</td>
<td>100</td>
<td>74</td>
<td>[17]</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Chinese mustard <em>(Brassica juncea)</em></td>
<td>550</td>
<td>5</td>
<td>150</td>
<td>100</td>
<td>81</td>
<td>[72]</td>
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<td></td>
<td></td>
<td>Chinese mustard <em>(Brassica juncea)</em></td>
<td>-</td>
<td>5</td>
<td>10</td>
<td>200</td>
<td>107</td>
<td>[51]</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Bush Sorrel <em>(Hibiscus surattensis)</em></td>
<td>300</td>
<td>3</td>
<td>5</td>
<td>5</td>
<td>116</td>
<td>[74]</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Tatsoi <em>(Brassica narinosa)</em></td>
<td>450</td>
<td>5</td>
<td>10</td>
<td>300</td>
<td>96</td>
<td>[73]</td>
</tr>
<tr>
<td>Water soluble phenolic</td>
<td>Pressure cooking</td>
<td>Water spinach <em>(Ipomoea aquatica)</em></td>
<td>1000</td>
<td>5</td>
<td>100</td>
<td>150</td>
<td>87</td>
<td>[67]</td>
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<td>Spinach <em>(Spinacea oleracea)</em></td>
<td>500</td>
<td>5</td>
<td>12</td>
<td>200</td>
<td>110</td>
<td>[69]</td>
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<td>-</td>
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<td>60</td>
<td>100</td>
<td>105</td>
<td>[113]</td>
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<td>5</td>
<td>150</td>
<td>100</td>
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<td>5</td>
<td>5</td>
<td>127</td>
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<td>5</td>
<td>10</td>
<td>200</td>
<td>70</td>
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<td>Chlorophyll</td>
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<td>700</td>
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<td>-</td>
<td>50</td>
<td>82</td>
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<td>10</td>
<td>300</td>
<td>70</td>
<td>[73]</td>
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<td>Ascorbic acid</td>
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<td>Spinach <em>(Spinacea oleracea)</em></td>
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<td>2.5</td>
<td>-</td>
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<td>-</td>
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<td>10</td>
<td>200</td>
<td>27</td>
<td>[31]</td>
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<td>450</td>
<td>5</td>
<td>10</td>
<td>300</td>
<td>78</td>
<td>[73]</td>
</tr>
<tr>
<td>Phytochemical compounds</td>
<td>Method</td>
<td>Vegetables</td>
<td>Pressure</td>
<td>Time (minutes)</td>
<td>Amount of water (mL)</td>
<td>Mass (g)</td>
<td>Phytochemical retention (%)&lt;sup&gt;a&lt;/sup&gt;</td>
<td>References</td>
</tr>
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<td>Pressure cooking</td>
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<td>100</td>
<td>150</td>
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<td>-</td>
<td>-</td>
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<td>-</td>
<td>128</td>
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<td>-</td>
<td>4</td>
<td>150</td>
<td>200</td>
<td>135</td>
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<td>-</td>
<td>7</td>
<td>80</td>
<td>100</td>
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<td>-</td>
<td>-</td>
<td>1000</td>
<td>-</td>
<td>92</td>
<td>[115]</td>
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</table>
Phytochemical compounds | Method | Vegetables | Temperature (°C) | Time (minutes) | Amount of Oil | Mass (g) | Phytochemical retention (%) | References |
<table>
<thead>
<tr>
<th></th>
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<th></th>
<th></th>
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<tr>
<td><strong>Water soluble phenolic</strong></td>
<td>Frying</td>
<td>Spinach (<em>Spinacea oleracea</em>)</td>
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<td>5</td>
<td>2 tablespoons sunflower oil</td>
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<td>83</td>
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<td><strong>Total polyphenol</strong></td>
<td></td>
<td>Water spinach (<em>Ipomoea aquatica</em>)</td>
<td>-</td>
<td>Cooked until crisp-tender</td>
<td>10 ml soybean oil</td>
<td>100</td>
<td>197&lt;sup&gt;b&lt;/sup&gt;</td>
<td>[68]</td>
</tr>
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<td></td>
<td></td>
<td>Spinach (<em>Spinacea oleracea</em>)</td>
<td>-</td>
<td>Cooked until crisp-tender</td>
<td>10 ml soybean oil</td>
<td>100</td>
<td>180&lt;sup&gt;b&lt;/sup&gt;</td>
<td>[68]</td>
</tr>
<tr>
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<td></td>
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<td>180</td>
<td>2</td>
<td>50 mL corn oil</td>
<td>100</td>
<td>84</td>
<td>[17]</td>
</tr>
<tr>
<td></td>
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<td>5</td>
<td>3 mL mustard oil</td>
<td>100</td>
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<td>[72]</td>
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<td></td>
<td></td>
<td>Bush Sorrel (<em>Hibiscus surattensis</em>)</td>
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<td>3</td>
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<td>5</td>
<td>66</td>
<td>[74]</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Tatsoi (<em>Brassica narinosa</em>)</td>
<td>130</td>
<td>5</td>
<td>10 mL blend oil</td>
<td>300</td>
<td>96</td>
<td>[73]</td>
</tr>
<tr>
<td><strong>Flavonoid</strong></td>
<td></td>
<td>Water spinach (<em>Ipomoea aquatica</em>)</td>
<td>-</td>
<td>Cooked until crisp-tender</td>
<td>10 ml soybean oil</td>
<td>100</td>
<td>225&lt;sup&gt;b&lt;/sup&gt;</td>
<td>[68]</td>
</tr>
<tr>
<td></td>
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<td>Spinach (<em>Spinacea oleracea</em>)</td>
<td>-</td>
<td>Cooked until crisp-tender</td>
<td>10 ml soybean oil</td>
<td>100</td>
<td>145&lt;sup&gt;b&lt;/sup&gt;</td>
<td>[68]</td>
</tr>
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<td></td>
<td></td>
<td>Bush Sorrel (<em>Hibiscus surattensis</em>)</td>
<td>229 – 230</td>
<td>3</td>
<td>5 mL refined sunflower oil</td>
<td>5</td>
<td>130</td>
<td>[74]</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Chinese mustard (<em>Brassica juncea</em>)</td>
<td>-</td>
<td>5</td>
<td>3 mL mustard oil</td>
<td>100</td>
<td>133</td>
<td>[72]</td>
</tr>
<tr>
<td><strong>Carotenoid</strong></td>
<td></td>
<td>Water spinach (<em>Ipomoea aquatica</em>)</td>
<td>160</td>
<td>1</td>
<td>50 g</td>
<td>50</td>
<td>268</td>
<td>[32]</td>
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<tr>
<td></td>
<td></td>
<td>Spinach (<em>Amaranthus mangostanus</em>)</td>
<td>160</td>
<td>1</td>
<td>50 g</td>
<td>50</td>
<td>177</td>
<td>[32]</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Spinach (<em>Amaranthus mangostanus</em>)</td>
<td>160</td>
<td>1</td>
<td>50 g</td>
<td>50</td>
<td>177</td>
<td>[32]</td>
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<tr>
<td>Phytochemical compounds</td>
<td>Method</td>
<td>Vegetables</td>
<td>Power (W)</td>
<td>Times (minutes)</td>
<td>Amount of water (mL)</td>
<td>Mass (g)</td>
<td>Phytochemical retention (%)a</td>
<td>References</td>
</tr>
<tr>
<td>-------------------------</td>
<td>--------</td>
<td>------------</td>
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<td>-----------------</td>
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<tr>
<td>Chlorophyll</td>
<td></td>
<td>Tatsoi (Brassica napus)</td>
<td>130</td>
<td>5</td>
<td>10 mL blend oil</td>
<td>300</td>
<td>63</td>
<td>[73]</td>
</tr>
<tr>
<td>Ascorbic acid</td>
<td></td>
<td>Tatsoi (Brassica napus)</td>
<td>130</td>
<td>5</td>
<td>10 mL blend oil</td>
<td>300</td>
<td>75</td>
<td>[73]</td>
</tr>
<tr>
<td>Basil (Ocimum basilicum)</td>
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<td>-</td>
<td>10</td>
<td>10</td>
<td>51</td>
<td>[78]</td>
</tr>
<tr>
<td>Drumstick leaves (Moringa oleifera)</td>
<td>100</td>
<td>10</td>
<td>185 mg groundnut oil</td>
<td>2</td>
<td>58</td>
<td>[33]</td>
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<td>3</td>
<td>-</td>
<td>2</td>
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<tr>
<td>Coriander leaves (Coriander sativum)</td>
<td>100</td>
<td>10</td>
<td>185 mg groundnut oil</td>
<td>2</td>
<td>61</td>
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<tr>
<td>Coriander leaves (Coriander sativum)</td>
<td>190</td>
<td>1</td>
<td>-</td>
<td>10</td>
<td>53</td>
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<td>Pak choi (Brassica rapa var parachinensis)</td>
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<td>5</td>
<td>10 mL blend oil</td>
<td>300</td>
<td>63</td>
<td>[73]</td>
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<td>Tatsoi (Brassica napus)</td>
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<td>130</td>
<td>5</td>
<td>10 mL blend oil</td>
<td>300</td>
<td>75</td>
<td>[73]</td>
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</tr>
</tbody>
</table>

a The retention level is calculated from the concentration of the phytochemicals both in the raw and the processed green leafy vegetables.
b Numbers are estimated from the data reported in the graphs.
Declarations of Interest

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

References


