Polyphenols in Common Beans (*Phaseolus vulgaris* L.): Chemistry, Analysis, and Factors Affecting Composition

Qiong-Qiong Yang, * Ren-You Gan, ‡, * Ying-Ying Ge, Dan Zhang, and Harold Corke

Abstract: Common bean (*Phaseolus vulgaris* L.) is one of the most important grain legumes worldwide. Polyphenols are the predominant bioactive components with multifold bioactivities in diverse common bean cultivars. Phenolic acids, flavonoids, and proanthocyanidins are the main polyphenols in common beans, and colorful common beans are overall rich in polyphenols, mainly in their pigmented seed coats. In addition, factors of influence, such as genotype, environmental conditions, storage, and processing methods, play a critical role in the content and composition of common bean polyphenols. Besides, analytical methods, including extraction, separation, and identification, are of importance for precise and comparable evaluation of polyphenols in common beans. Therefore, in order to provide a comprehensive and updated understanding of polyphenols in common beans, this review first summarizes the content and different compositions of polyphenols in common beans, and next discusses the factors affecting these compositions, followed by introducing the analytical methods for common bean polyphenols, and finally highlights the antioxidant activity of polyphenols in common beans. Considering the recent surge in interest in the use of grain legumes, we hope this review will further stimulate work in this field by providing a blueprint for further analytical studies to better utilize common bean polyphenols in food products to improve human nutrition.

Keywords: common bean, processing methods, analytic methods, antioxidant activity, phenolic composition

Introduction

Common beans (*Phaseolus vulgaris* L.), also known as navy, pinto, red kidney, or French beans, are a valuable food source for humans around the world. They are regarded as an important constituent of healthy diets not merely because of their high nutritional value (rich in protein and low in fat) but also owing to their functional properties. The main functional components of common beans are carbohydrates, vitamins, phytate, lectins, soluble fiber, and phenolics. Phenolics, which include phenolic acids, flavonoids, and proanthocyanidins, are particularly notable because of their potent antioxidant properties (Garcia-Lafuente et al., 2014). For example, small red beans (*Phaseolus vulgaris* L.) showed the highest antioxidant activity out of 100 common foods (Wu et al., 2004). Epidemiological investigations have indicated that the consumption of legumes with high phenolic content and high antioxidant value was associated with reduced risk of many chronic conditions such as obesity, diabetes, heart diseases, and even certain types of cancer (Curran, 2012). Moreover, common bean extracts rich in polyphenols were reported to show anti-inflammatory, antio-
to identify and quantify phenolic compounds in common beans. Numerous groups of phenolic compounds have been isolated and identified in common beans, including phenolic acids, flavonoids, anthocyanins, and proanthocyanidins.

Since the demand for phenolics is steadily increasing, it is worthwhile to review the TPC, total flavonoid content (TFC), total proanthocyanidins content (TPAC), and composition of phenolic compounds in common beans. Furthermore, considerable research efforts have been devoted to finding more specific and efficient phenolics with minimum side effects and high health benefits. Then, these phenolics may be applied in the food and pharmaceutical fields. Therefore, based on Web of Science, we searched for English articles on common beans from 1990 to 2017. In this review, we summarize the TPC, TFC, TPAC, and main polyphenols in common beans, summarize the factors influencing phenolic content and composition, including environmental conditions, genotype, storage, germination, and thermal processing, briefly describe current methods used for the extraction, separation, and identification of common bean phenolics, and finally highlight the antioxidant activities of common beans.

**Polyphenols in Common Beans**

**Total phenolic content**

Phenolics, which have at least one phenol unit with one or more hydroxyl substituents, are a type of secondary metabolites in plants (Akyl, Ricupiti, Capanoglu, Caboni, & Verardo, 2016; Gan, Li, Gunaratne, Sui, & Corke, 2017). Phenolics are broadly classified as phenolic acids, flavonoids, proanthocyanidins, stilbenes, and coumarins (Nayak, Liu, & Tang, 2015). Their presence gives common bean seeds diverse colors. Phenolics are found in both the cotyledons and seed coats of common beans, but most are concentrated in the seed coats (Aquino-Bolaños et al., 2016). The TPC of common beans has been extensively reported and the data are scattered across many research articles. We have compiled this scattered information and summarized it (Table 1), showing that the TPC of common beans has been determined in the range of not detectable (ND) to 4871 mg gallic acid equivalents per 100 g dry weight (mg GAE/100 g DW). The remarkable position of pinto kidney bean should be emphasized because its TPC in seed coats had the highest level (4871 mg GAE/100 g DW) among diverse common bean cultivars (Gan et al., 2017).

**Polyphenol composition**

In the past few decades, many studies have investigated the phenolic composition of various common bean cultivars. Here, we summarize the main phenolic compounds identified in common beans (Figure 1), including phenolic acids, flavonoids, proanthocyanidins, and coumarins.

**Phenolic acids**

According to the chemical structure, phenolic acids in plants can be divided into hydroxycinnamic acids and hydroxybenzoic acids. Sixteen hydroxycinnamic acids and 12 hydroxybenzoic acids have been identified in common beans (Figure 1). Caffeic, p-coumaric, sinapic, and ferulic acids are the most common hydroxycinnamic acids in common beans. In addition, gallic, p-hydroxybenzoic, protocatechuic, vanillic, and syringic acids are the most frequently occurring hydroxybenzoic acids in common beans (Table 2). Hydroxycinnamic acids frequently occur in foods as esters with quinic acid or sugars, while hydroxybenzoic acids are mainly present in foods as glycosides. In the plant kingdom, phenolic acids mainly exist in free or bound forms in plant cells. Recently, free and bound phenolic acids in regular- and non-darkening cranberry beans (*Phaseolus vulgaris* L.) were studied, and three hydroxycinnamic acids (p-coumaric, ferulic, and sinapic acid) and 1 hydroxybenzoic acid (p-hydroxybenzoic acid) were identified (Chen et al., 2015b). López et al. (2013) investigated the phenolic composition in dark beans (*Phaseolus vulgaris* L.) and identified 22 phenolic compounds in either free or conjugated forms, the majority of which were phenolic acids consisting of protocatechuic, feruloyl aldaric, trans-ferulic, p-coumaryl aldaric, sinapyl aldaric, and sinapic acids. They also reported that feruloyl aldaric acid was the predominant phenolic acid at a level of 46.2 μg/g and that ferulic acid derivatives accounted for the highest percentage of TPC in raw and boiled beans (19% and 24%, respectively). Duenas et al. (2016) identified seven hydroxycinnamonic compounds and five hydroxybenzoic compounds in dark beans (*Phaseolus vulgaris* L.), most of which were bound phenolic acids, while only a few were free phenolic acids. Therefore, the total bound phenolics in common beans are at a comparable level to that of free phenolics, which means that the content of phenolics in common beans may be significantly underestimated if only soluble phenolic content is considered (Chan, Gan, & Corke, 2016). In addition, a complete assessment of all forms of phenolics helps to better understand and explain the overall health benefits of consuming common beans.

**Flavonoids**

Flavonoids are the most abundant secondary metabolites in the plant kingdom and their presence influences the flavor and color of common beans. The TFC of common bean seeds and seed coats have been widely reported. Pinto bean seed coats were recorded to have the highest TFC among pigmented bean seed coats (4477 mg CE/100 g DW), followed by small speckled kidney bean (oval) coats (3529 mg CE/100 g DW), and big speckled kidney bean seed coats (3513 mg CE/100 g DW) (Gan et al., 2016).

Flavonoids have six subclasses, including flavonols, flavones, isoflavonoids, flavanols, flavanones, and anthocyanins. Normally, they accumulate in the vacuoles of plant tissues as conjugates in glycosylated or esterified forms, but occasionally they can be found as aglycones (Nayak et al., 2015).

Twenty-two flavonoids have been identified in common bean cultivars. Flavonols, like kaempferol, quercetin, myricetin, and their derivatives, are widely identified in common bean cultivars (Table 2). Duenas et al. (2016) concluded that kaempferol glycosides and quercetin glycosides accounted for approximately 6% and 26% of total phenolic compounds in raw and germinated dark common beans, respectively.

It is surprising that only two flavonols (apigenin-7-O-glucoside and luteolin-7-O-glucoside) have been detected in common beans (Figure 1), an issue which may need further investigation. In contrast, isoflavonoids like genistein, daidzein, glycitein, formononetin, and their derivatives are widely found in various common beans such as dark beans (López et al., 2013), zolfinol landraces (Romani et al., 2004), wild and cultivated Mexican common beans (*Phaseolus vulgaris* L.; Díaz-Batalla, Widholm, Fahey, Castaño-Tostado, & Paredes-López, 2006), and others (Dinelli, Aloisio, Bonetti, Marotti, & Cifuentes, 2007).

Flavanols, including catechin, epicatechin, epigallocatechin, and epicatechin gallate, are the most abundant flavonoids detected in common beans with the range of ND to 611 mg/g DW (Gan et al., 2016; Ombra et al., 2016; Ranilla, Genovese, & Lajolo, 2009)
Table 1—Total phenolic, total flavonoid, and total proanthocyanidin content of common beans (all *Phaseolus vulgaris* L.).

<table>
<thead>
<tr>
<th>Bean sample</th>
<th>Extracts</th>
<th>Content Unit</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td>Green bean</td>
<td>80% Acetone</td>
<td>0.80 mg GAE/g DW</td>
<td>(Jiratanan &amp; Liu, 2004)</td>
</tr>
<tr>
<td>Storage-induced hard-to-cook bean</td>
<td>Water</td>
<td>2.34–4.66 mg GAE/g DW</td>
<td>(Martín-Cabrejas et al., 1997)</td>
</tr>
<tr>
<td>Fresh dry bean</td>
<td>Water</td>
<td>2.66–4.14 mg GAE/g DW</td>
<td>(Ross et al., 2009)</td>
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<tr>
<td>Maverick pinto bean</td>
<td>Acidified methanol + 10 N NaOH + 12 N HCl</td>
<td>3.49 mg GAE/g DW</td>
<td></td>
</tr>
<tr>
<td>Redhawk dark red kidney bean</td>
<td>Water</td>
<td>3.45 mg GAE/g DW</td>
<td></td>
</tr>
<tr>
<td>Cdc jet black bean</td>
<td>80% Chilled acetone</td>
<td>1.54 mg GAE/g DW</td>
<td></td>
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<tr>
<td>Kidney bean</td>
<td>4 mol/L NaOH</td>
<td>1.52 mg GAE/g DW</td>
<td></td>
</tr>
<tr>
<td>Common bean</td>
<td>Methanol</td>
<td>6.80 mg GAE/g DW</td>
<td></td>
</tr>
<tr>
<td>Pinto bean</td>
<td>Methanol</td>
<td>7.40 mg GAE/g DW</td>
<td></td>
</tr>
<tr>
<td>Black bean</td>
<td>Methanol</td>
<td>0.85 mg GAE/g DW</td>
<td></td>
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<tr>
<td>Regular darkening cranberry bean</td>
<td>Methanol + 1% HCl</td>
<td>2.60 mg GAE/g DW</td>
<td></td>
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<tr>
<td>Non-darkening cranberry bean</td>
<td>Methanol + 1% acetic acid</td>
<td>0.60 mg GAE/g DW</td>
<td></td>
</tr>
<tr>
<td>White kidney bean</td>
<td>Methanol</td>
<td>4.63 mg GAE/g DW</td>
<td></td>
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<tr>
<td>Round purple bean</td>
<td>Methanol</td>
<td>13.4 mg GAE/g DW</td>
<td></td>
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<tr>
<td>Common bean</td>
<td>Methanol + 0.3% HCl</td>
<td>6.66–32.0 mg GAE/g DW</td>
<td></td>
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<tr>
<td>Common bean</td>
<td>Ethanol with 1% acetic acid</td>
<td>1.20 mg GAE/g DW</td>
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<tr>
<td>Phaseolus vulgaris L dry bean</td>
<td>Ethanol (pH 2)</td>
<td>1.17–4.40 mg GAE/g DW</td>
<td>(Heimler et al., 2005)</td>
</tr>
<tr>
<td>Turkish white bean</td>
<td>Ethanol (pH 4)</td>
<td>0.33–0.63 mg GAE/g DW</td>
<td>(Orak, Karamač, Orak, &amp; Amarowicz, 2016)</td>
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<tr>
<td>Red kidney bean seed coat</td>
<td>Methanol</td>
<td>33.9 mg GAE/g DW</td>
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<tr>
<td>Big speckled kidney bean seed coat</td>
<td>Methanol</td>
<td>43.4 mg GAE/g DW</td>
<td></td>
</tr>
<tr>
<td>Small speckled kidney bean (oval) seed coat</td>
<td>Methanol</td>
<td>43.1 mg GAE/g DW</td>
<td></td>
</tr>
<tr>
<td>Violet red kidney bean seed coat</td>
<td>Methanol</td>
<td>30.0 mg GAE/g DW</td>
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<tr>
<td>Brown string bean seed coat</td>
<td>Methanol</td>
<td>5.18 mg GAE/g DW</td>
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<tr>
<td>Pinto bean seed coat</td>
<td>Methanol</td>
<td>48.7 mg GAE/g DW</td>
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<tr>
<td>Phaseolus vulgaris L dry bean</td>
<td>Ethanol (pH 2)</td>
<td>0.24–1.43 mg CE/g DW</td>
<td>(Heimler et al., 2005)</td>
</tr>
<tr>
<td>Red kidney bean seed coat</td>
<td>Ethanol</td>
<td>26.4 mg CE/g DW</td>
<td></td>
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</table>

(Continued)
<table>
<thead>
<tr>
<th>Bean sample</th>
<th>Extracts</th>
<th>Content</th>
<th>Unit</th>
<th>References</th>
</tr>
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<tbody>
<tr>
<td><strong>TPC</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Big speckled kidney bean seed coat</td>
<td>80% Methanol</td>
<td>35.1</td>
<td>mg CE/g DW</td>
<td>(Ranilla et al., 2007)</td>
</tr>
<tr>
<td>Small speckled kidney bean (oval) seed coat</td>
<td>80% Methanol</td>
<td>35.3</td>
<td>mg CE/g DW</td>
<td>(Oomah et al., 2005)</td>
</tr>
<tr>
<td>Violet red kidney bean seed coat</td>
<td>80% Methanol</td>
<td>26.0</td>
<td>mg CE/g DW</td>
<td>(Aquino-Bolaños et al., 2016)</td>
</tr>
<tr>
<td>Brown string bean seed coat</td>
<td>80% Methanol</td>
<td>2.66</td>
<td>mg CE/g DW</td>
<td>(Diaz, Caldas, &amp; Blair, 2010)</td>
</tr>
<tr>
<td>Pinto bean seed coat</td>
<td>80% Methanol</td>
<td>44.8</td>
<td>mg CE/g DW</td>
<td>(Hernández-Saavedra et al., 2013)</td>
</tr>
<tr>
<td>Phaseolus vulgaris L. seed coat</td>
<td>70% Methanol and 5% acetic acid</td>
<td>ND–7.65</td>
<td>mg CE/g DW</td>
<td>(Starzyńska-Janiszewska et al., 2015)</td>
</tr>
<tr>
<td>Common bean</td>
<td>80% Ethanol</td>
<td>0.41–1.02</td>
<td>mg RE/g DW</td>
<td>(Arévalo et al., 2015)</td>
</tr>
<tr>
<td>Common bean</td>
<td>70% Methanol and 5% acetic acid</td>
<td>5.90–21.5</td>
<td>mg CE/g DW</td>
<td>(Starzyńska-Janiszewska et al., 2015)</td>
</tr>
<tr>
<td>Common bean</td>
<td>70% Methanol and 5% acetic acid</td>
<td>0.10–0.78</td>
<td>mg C3GE/g DW</td>
<td>(Diaz, Caldas, &amp; Blair, 2010)</td>
</tr>
<tr>
<td>Common bean</td>
<td>70% Methanol with 0.5% HCl</td>
<td>0.01–0.21</td>
<td>mg C3GE/g DW</td>
<td>(Hernández-Saavedra et al., 2013)</td>
</tr>
<tr>
<td>Common bean</td>
<td>70% Methanol</td>
<td>0.50</td>
<td>mg C3GE/g DW</td>
<td>(Diaz, Caldas, &amp; Blair, 2010)</td>
</tr>
<tr>
<td>Common bean</td>
<td>80% Acetone</td>
<td>0.29</td>
<td>mg QE/g DW</td>
<td>(Pinto et al., 2005)</td>
</tr>
<tr>
<td>Black Jamapa bean flour</td>
<td>Methanol</td>
<td>0.69</td>
<td>mg C3GE/g DW</td>
<td>(Diaz, Caldas, &amp; Blair, 2010)</td>
</tr>
<tr>
<td>Two years stored black Jamapa bean flour</td>
<td>Methanol</td>
<td>0.17</td>
<td>mg C3GE/g DW</td>
<td>(Aquino-Bolaños et al., 2016)</td>
</tr>
<tr>
<td>Common bean</td>
<td>50% Methanol</td>
<td>0.14</td>
<td>mg CE/g DW</td>
<td>(Starzyńska-Janiszewska et al., 2015)</td>
</tr>
<tr>
<td>Pinto bean</td>
<td>Methanol</td>
<td>1.87</td>
<td>mg C3GE/g DW</td>
<td>(Starzyńska-Janiszewska et al., 2015)</td>
</tr>
<tr>
<td>Green bean</td>
<td>4 mol/L NaOH</td>
<td>≈6.00</td>
<td>mg CE/g DW</td>
<td>(Valdez-González et al., 2017)</td>
</tr>
<tr>
<td>80% Acetone</td>
<td></td>
<td>≈0.52</td>
<td>mg CE/g DW</td>
<td>(Starzyńska-Janiszewska et al., 2015)</td>
</tr>
<tr>
<td><strong>TPAC</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pinto bean</td>
<td>Water</td>
<td>≈280–158</td>
<td>mg CE/g DW</td>
<td>(Bearinger et al., 2005)</td>
</tr>
<tr>
<td>Dry bean</td>
<td>Water</td>
<td>0.57–0.72</td>
<td>mg TAE/g DW</td>
<td>(Nergiz &amp; Gökgöz, 2007)</td>
</tr>
<tr>
<td>Kidney bean</td>
<td>Water</td>
<td>5.37</td>
<td>mg CE/g DW</td>
<td>(Starzyńska-Janiszewska et al., 2015)</td>
</tr>
<tr>
<td>Kidney bean flour</td>
<td>Methanol</td>
<td>13.8</td>
<td>mg C3GE/g DW</td>
<td>(Aparicio-Fernández et al., 2005)</td>
</tr>
<tr>
<td>Black Jamapa bean flour</td>
<td>Methanol</td>
<td>222</td>
<td>mg CE/g DW</td>
<td>(Aparicio-Fernández et al., 2005)</td>
</tr>
<tr>
<td>Fresh common bean</td>
<td>Methanol with 0.0027 mol/L HCl</td>
<td>0.90</td>
<td>mg CE/g FW</td>
<td>(Starzyńska-Janiszewska et al., 2015)</td>
</tr>
<tr>
<td>Common bean</td>
<td>80% Acetone</td>
<td>3.05</td>
<td>mg CE/g DW</td>
<td>(Starzyńska-Janiszewska et al., 2015)</td>
</tr>
<tr>
<td>Phaseolus vulgaris L.</td>
<td>Methanol</td>
<td>4.60</td>
<td>mg CE/g DW</td>
<td>(Valdez-González et al., 2017)</td>
</tr>
<tr>
<td>Common bean</td>
<td>70% Acetone with 0.1% ascorbic acid</td>
<td>10.7–30.9</td>
<td>mg CE/g DW</td>
<td>(Starzyńska-Janiszewska et al., 2015)</td>
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<tr>
<td>Peruano</td>
<td>Water</td>
<td>2.00</td>
<td>mg CE/g FW</td>
<td>(Coelho et al., 2007)</td>
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<td>Parasol</td>
<td>Water</td>
<td>23.0</td>
<td>mg CE/g FW</td>
<td>(Madhujith et al., 2004)</td>
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<tr>
<td>Common bean seed</td>
<td>80% Acetone</td>
<td>ND</td>
<td>mg CE/g DW</td>
<td>(Aparicio-Fernández et al., 2005)</td>
</tr>
<tr>
<td>Common bean seed coat</td>
<td>80% Acetone</td>
<td>0.01–0.03</td>
<td>mg CE/g DW</td>
<td>(Aparicio-Fernández et al., 2005)</td>
</tr>
<tr>
<td>Common bean with red seed coat</td>
<td>Water</td>
<td>4.25</td>
<td>mg CE/g DW</td>
<td>(Jyothi &amp; Sumathi, 1995)</td>
</tr>
<tr>
<td>Bean</td>
<td>Methanol</td>
<td>4.67–6.62</td>
<td>mg CE/g DW</td>
<td>(Aparicio-Fernández et al., 2005)</td>
</tr>
<tr>
<td>Regular darkening cranberry bean</td>
<td>70% Methanol with 1% HCl</td>
<td>1.63–2.89</td>
<td>mg PAC/g DW</td>
<td>(Treviño-Mejía et al., 2016)</td>
</tr>
<tr>
<td>Non-darkening cranberry bean</td>
<td>70% Methanol with 1% HCl</td>
<td>0.02–0.05</td>
<td>mg PAC/g DW</td>
<td>(Chen et al., 2015a; Coutin et al., 2017)</td>
</tr>
<tr>
<td>Black bean</td>
<td>Methanol with 0.5% HCl</td>
<td>7.60</td>
<td>mg CE/g DW</td>
<td>(Sancho et al., 2015)</td>
</tr>
<tr>
<td>Small red bean</td>
<td>Methanol with 0.5% HCl</td>
<td>5.40</td>
<td>mg CE/g DW</td>
<td>(Sancho et al., 2015)</td>
</tr>
<tr>
<td>Regular darkening cranberry bean</td>
<td>65% Acetone with 1% acetic acid</td>
<td>2.20</td>
<td>mg PAC/g DW</td>
<td>(Chen et al., 2015a)</td>
</tr>
<tr>
<td>Non-darkening cranberry bean</td>
<td>65% Acetone with 1% acetic acid</td>
<td>0.04</td>
<td>mg PAC/g DW</td>
<td>(Hernández-Saavedra et al., 2013)</td>
</tr>
<tr>
<td>Common bean</td>
<td>Water</td>
<td>0.01–0.02</td>
<td>mg CE/g DW</td>
<td>(Starzyńska-Janiszewska et al., 2015)</td>
</tr>
<tr>
<td>Black bean</td>
<td>Water</td>
<td>54.6</td>
<td>mg GAE/g DW</td>
<td>(Hernández-Saavedra et al., 2013)</td>
</tr>
</tbody>
</table>

TPC, total phenolic content; TFC, total flavonoid content; TPCA, total proanthocyanidin content; GAE, gallic acid equivalent; CE, catechin equivalent; DW, dry weight; ND, not determined; FW, fresh weight; C3GE, cyanin 3-glucoside equivalent; RE, rutin equivalent; QE, quercetin equivalent; PAC, proanthocyanidin; TAE, tannic acid equivalent.
Common bean polyphenols

Phenolic acids
- Hydroxybenzoic acids
  - Gallic acid, protocatechuic acid, vanillic acid, syringic acid, p-hydroxybenzoic acid, vanillin aldehyde, protocatechuic aldehyde, p-hydroxybenzoic aldehyde, 4-trihydroxybenzoic acid, vanillin, 3, 4-dihydroxybenzoic acid
- Hydroxycinnamic acids
  - p-coumaric acid, m-coumaric acid, o-coumaric acid, trans-cinnamic acid, caffeic acid, ferulic acid, sinapic acid, chlorogenic acid, cichoric acid, 1,3-dicaffeoylquinic acid, rosmarinic acid, p-comaric aldaric acid, sinapyl aldaric acid, feruloyl aldaric acid, coumaroyl aldaric acid, sinapic aldaric acid

Phenolics
- Tannins
  - Procyanidin, procyanidin dimer, procyanidin trimer
- Coumarins
  - Coumestrol

Phenolics
- Flavonoids
  - Quercetin, kaempferol, myricetin, rutin, kaempferol 3-O-glucoside, kaempferol 3-O-xylosylglucoside, kaempferol 3-O-rutinosides, myricetin 3-O-glucoside, hyperoside, taxifolin, spiraeoside, 3', 4', 5, 7-tetrahydroxyflavanonol-3-O-β-D-glucopyranosyl (2→1) O-β-D-xlyopyranoside, kaempferol 3-O-(6'-O-malonyl) glucoside, quercetin 3-O-(6'-O-malonyl) glucoside, quercetin 3-O-xylosylglucoside, kaempferol 3-O-(malonyl) glucoside, kaempferol dihexoside-rhamnosed, kaempferol 3-O-acylhexoside, quercetin 3, 4-diglcoside, quercetin 3-O-galactoside, quercetin 3-O-glucoside acetate, kaempferol 3-O-rutinoside acylated

Flavonoids
- Isoflavonoids
  - Genistein, daidzein, glycitein, formononetin, biochanin b 7-O-glucoside, biochanin a 7-O-glucoside, genistein hexose

Flavonoids
- Flavanones
  - Naringenin, eriodictyol glucoside, hesperetin 7-neohesperidose, hesperetin 7-rutinoside, hesperetin 7-O-glucoside, naringenin 7-O-neohesperidose, naringenin 7-O-rutinoside, naringenin 7-O-glucoside, naringenin-7-methyl ether 2

Flavonoids
- Anthocyanidines
  - Cyanidin, delphinidin, petunidin, malvidin, pelargonidin 3-O-glucoside, cyanidin 3-O-glucoside, cyanidin 3, 5-diglcoside, pelargonidin 3-O-(6'-O-malonyl) glucoside, cyanidin 3-O-(6'-O-malonyl) glucoside, delphinidin 3-O-glucoside, malvidin 3-O-glucoside, pelargonidin 3, 5-O-diglcoside, malvidin 3, 5-diglcoside, malvidin 3-galactoside, delphinidin 3,5-O-diglcoside, petunidin 3, 5-O-diglcoside, delphinidin feruloyl glucoside, delphinidin glucoside acylated, pelargonidin glucoside acylated, pelargonidin 3- malonylglucoside

Figure 1–Main common bean phenolics and chemical structures for major compound classes.
### Table 2–Flavonoids and phenolic acids in common beans (*Phaseolus vulgaris* L.).

<table>
<thead>
<tr>
<th>Bean sample</th>
<th>Major compounds</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dark bean</td>
<td>Hesperetin 7-neohesperidose, hesperetin 7-rutinoside, hesperetin 7-O-glucoside,</td>
<td>(López et al., 2013)</td>
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<tr>
<td></td>
<td>hesperetin derivatives, naringenin 7-O-neohesperidose, naringenin 7-O-rutinoside,</td>
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<td></td>
<td>naringenin 7-O-glucoside, naringenin 7-methyl ether 2, naringenin, quercetin 3-O-</td>
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<td></td>
<td>Rutinoside, quercetin 3-O-galactoside, quercetin 3-O-glucoside, quercetin 3-O-</td>
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<td>Glucoside acetate, quercetin, kaempferol 3-O-glucoside, kaempferol 3-O-rutinoside,</td>
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<td>acylated, kaempferol, myricetin, apigenin 7-O-glucoside, biochanin b 7-O-glucoside,</td>
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<td>biochanin a 7-O-glucoside, daidzein derivatives, genistein hexose, genistein</td>
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<td>derivatives, delphinidin 3-O-glucoside, cyanidin 3-O-glucoside, pelargonidin 3,</td>
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<td></td>
<td>5-diglucoside, pelargonidin 3-O-glucoside, delphinidin glucoside acylated,</td>
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<td>pelargonidin 3-malonylglycoside, pelargonidin 3-O-(6&quot;-malonyl) glucoside,</td>
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<td>petunidin feruloyl glucose, petunidin derivatives, gallic acid,</td>
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<td>protocatechuic acid, ferulyl aldaric acid, <em>trans</em> ferulic acid, <em>p</em>-coumaric</td>
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<td>acid, <em>trans</em> p-coumaric acid, sinapyl aldaric acid, sinapic acid</td>
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<td></td>
<td><strong>Phaseolus vulgaris</strong> L.</td>
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<tr>
<td>Brazilian common bean germplasm</td>
<td>Kaempferol</td>
<td>(Perazzini et al., 2008)</td>
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<tr>
<td>Alubia bean</td>
<td><em>p</em>-Coumaric acid derivatives, ferulic acid derivatives, kaempferol 3-O-xylolyl-</td>
<td>(Lin et al., 2008)</td>
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<tr>
<td></td>
<td>glucoside, delphinidin 3-O-glucosyl-glucoside, petunidin 3-O-((6&quot;-acetyl glucoside)</td>
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<td>Black bean</td>
<td><em>p</em>-Coumaric acid derivatives, ferulic acid derivatives, sinapic acid, ferulic acid,</td>
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<td>Cranberry bean</td>
<td>delphinidin 3-O-glucoside, petunidin 3-O-glucoside, malvidin 3-O-glucoside,</td>
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<td>Great northern bean</td>
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<td>Pinto bean</td>
<td>Kaempferol, kaempferol 3-O-glucoside, quercetin 3-O-(6&quot;-O-malonyl) glucoside,</td>
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<td>derivatives, sinapic acid, ferulic acid</td>
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<td>Red Mexican bean</td>
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<td>acid derivatives, ferulic acid derivatives, sinapic acid, ferulic acid</td>
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<td>Light red kidney bean</td>
<td><em>p</em>-Coumaric acid derivatives, ferulic acid derivatives, sinapic acid, ferulic acid,</td>
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<td>Navy bean</td>
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<td>Dark red kidney bean</td>
<td><em>p</em>-Coumaric acid derivatives, ferulic acid derivatives, sinapic acid, ferulic acid,</td>
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<td>quercetin diglycosides, kaempferol diglycosides, <em>p</em>-coumaric acid derivatives,</td>
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<td>ferulic acid derivatives, sinapic acid, ferulic acid, kaempferol</td>
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<td>Pink kidney bean</td>
<td>Quercetin diglycosides, kaempferol diglycosides, <em>p</em>-coumaric acid derivatives,</td>
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<td>ferulic acid derivatives, sinapic acid, ferulic acid, kaempferol 3-O-xylolylglucoside,</td>
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<td>kaempferol 3-O-xylolylglucoside, quercetin, kaempferol</td>
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<td>Small red bean</td>
<td>Kaempferol 3-O-glucoside, pelargonidin 3-O-glucoside</td>
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<td>Common bean (verdone)</td>
<td>Daidzein, glycitein, genistein, kaempferol</td>
<td>(Dinelli et al., 2007)</td>
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<tr>
<td>Common bean (zolfino)</td>
<td>Daidzein, glycitein, genistein, kaempferol</td>
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<td>Common bean (lingua difuco)</td>
<td>Daidzein, glycitein, genistein, kaempferol</td>
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<td>Wild and cultivated Mexican common bean</td>
<td>Quercetin, kaempferol, daidzein, genistein, coumestrol, <em>p</em>-hydroxybenzoic acid,</td>
<td>(Díaz-Batalla et al., 2006)</td>
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<tr>
<td>Black-ed bean</td>
<td>vanillic acid, <em>p</em>-coumaric acid, ferulic acid</td>
<td>(Hungria, Joseph, &amp; Phillips, 1991)</td>
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<td>Montcalm dark red kidney bean</td>
<td>3', 4', 5', 7-Tetrahydroxyflavonoid 3-O-β-D-glucopyranosyl (2→1) O-β-D-glucopyranoside,</td>
<td>(Beninger &amp; Hosfeld, 1999b)</td>
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<td>quercetin 3-O-β-D-glucopyranoside, kaempferol 3-O-D-glucopyranoside,</td>
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<tr>
<td>Cranberry bean</td>
<td><em>p</em>-Coumaric acid derivatives, sinapic acid, ferulic acid,</td>
<td>(Dinelli et al., 2006)</td>
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<tr>
<td>Common bean</td>
<td>quercetin, genistein, ferulic acid</td>
<td>(Chen et al., 2015a)</td>
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<td>Green french bean</td>
<td>Kaempferol 3-O-glucoside, kaempferol 3-O-xylolylglucoside</td>
<td>(Chen et al., 2015a)</td>
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<td>Sarconi bean</td>
<td>Catechin, kaempferol, pelargonidin 3-O-glucoside, cyanidin 3-O-glucoside,</td>
<td>(Doria et al., 2012)</td>
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<td>cyanidin, ferulic acid, <em>p</em>-coumaric acid, sinapic acid, <em>p</em>-hydroxybenzoic</td>
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<td>acid</td>
<td>(Hempel &amp; Böhm, 1996)</td>
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<td>Quercetin, genistein derivatives, pelargonidin 3-O-glucoside, cyanidin 3-O-glucoside,</td>
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<td>pelargonidin 3-O-glucoside, pelargonidin 3-O-(6&quot;-malonyl) glucoside,</td>
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<td></td>
<td>pelargonidin 3-O-(6&quot;-malonyl) glucoside</td>
<td>(Romani, Vignolini, Falvino, &amp; Heimler, 2013)</td>
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<td>Dry edible bean</td>
<td>*Caffeic acid, <em>p</em>-coumaric acid, ferulic acid, sinapic acid</td>
<td>(Luthria &amp; Pastor-Corrales, 2006)</td>
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<tr>
<td>New Manteca-type dry bean</td>
<td>Kaempferol 3-O-glucoside, kaempferol 3-O-glucosylxyllose</td>
<td>(Beninger et al., 1998)</td>
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<td>Red bean</td>
<td>Cyanidin 3-O-glucoside, pelargonidin 3-O-glucoside</td>
<td>(Tsuda, Osawa, Ohshima, &amp; Kawakishi, 1994)</td>
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<tr>
<td>Black bean</td>
<td>Delphinidin 3-O-glucoside</td>
<td>(Beninger &amp; Hosfeld, 1999a)</td>
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<tr>
<td>Dry bean</td>
<td>Kaempferol 3-O-glucoside</td>
<td>(Yoshida et al., 1996)</td>
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<td>Black turtle bean</td>
<td>Delphinidin 3-O-glucoside, malvidin 3-O-glucoside, pelargonidin 3-O-glucoside,</td>
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<td></td>
<td>petunidin, malvidin</td>
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<tr>
<td>Red kidney bean</td>
<td>Delphinidin 3-O-glucoside, pelargonidin 3-O-glucoside, cyanidin 3-O-(6&quot;-malonyl)</td>
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<td>glucoside, cyanidin 3-O-glucoside</td>
<td>(Choung et al., 2003)</td>
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<tr>
<td>Black kidney bean</td>
<td>Delphinidin 3-O-glucoside, petunidin 3-O-glucoside</td>
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<tr>
<td>Wild and weedy Mexican common bean</td>
<td>Quercetin, kaempferol, coumestrol, daidzein, ferulic acid derivatives, <em>p</em>-coumaric</td>
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<tr>
<td></td>
<td>vanillic acid</td>
<td>(Guevara-Lara et al., 2007)</td>
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</tbody>
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(Continued)
<table>
<thead>
<tr>
<th>Bean sample</th>
<th>Major compounds</th>
<th>Reference</th>
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<td>Myricetin 3-O-glucoside, quercetin 3-O-glucoside, quercetin 3-O-(6&quot;-O-malonyl)</td>
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<td>glucoside, kaempferol 3-O-glucoside, myricetin, kaempferol 3-O-(6&quot;-O-malonyl)</td>
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<td>glucoside, quercetin, kaempferol, quercetin 3-O-xysolglycoside, quercetin 3-</td>
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<td>O-runotinoside, kaempferol 3-O-xylgosylglucoside, kaempferol 3-O-(</td>
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<td>malonyl) glucoside, delphinidin 3-O-glucoside, pelargonidin 3, 5-O-diglucoside,</td>
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<td>petunidin 3-O-glucoside, malvidin 3-O-glucoside, cyanidin 3-O-glucoside,</td>
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<td>pelargonidin 3-O-glucoside, cyanidin 3-O-f-</td>
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<td>malonyl) glucoside, pelargonidin. p-coumaric acid derivatives, ferulic acid</td>
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<td>derivatives, p-coumaric acid, sinapic acid, vanililn aldehyde, syringic acid</td>
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<td>Kaempferol dixhesoside-rhamnoside, kaempferol 3-O-aclyhexoside, sinapic acid,</td>
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<td>3-hydroxybenzoic acid, gallic aldehyde, protocatechuic acid, protocatechu</td>
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<td>c acid, d-hydroxybenzoic aldehyde, trans-feruloyl aldic acid, sinapoyl aldr</td>
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<td>ic acid, trans-p-coumaric acid, trans-ferulic acid</td>
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<td>Common bean</td>
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<td>1, 3 dicafeoylquinonic acid, rosamric acid</td>
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<td>Regular darkening cranberry</td>
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<td>bean</td>
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<td>propelargonidin dimer</td>
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<td>Non-darkening cranberry</td>
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<td>derivate, p-coumaric aldaric acid isomer</td>
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<td>Black bean 8025</td>
<td>p-coumaric acid isomer, sinapoyl aldaric acid</td>
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<td>Naringenin derivatives, hesperitin derivatives, feruoyl aldaric acid,</td>
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<td>Round purple bean</td>
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<td>myricetin delphinindin-3-O-glucose, malvidin-3, 5-diglucose,</td>
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<td>Red bean</td>
<td>(+)-Catechin, p-coumaric acid, hydroxybenzoic acid, ferulic acid, caffeic</td>
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<td>Phaselus vulgaris L</td>
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<td>ferulic acid, caffeic acid</td>
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<td>Uli 911 black bean</td>
<td>Kaempferol 3-O-glucoside, kaempferol 3-O-xysolglycoside, quercetin</td>
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<td>Zolfino landraces</td>
<td>Kaempferol 3-O-xysolglycoside, kaempferol 3-O-glucoside, daidzein,</td>
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<td>Red and black bean seed coat</td>
<td>Delphinidin 3-O-glucoside, petunidin 3-O-glucoside, cyanidin-3-O-glucoside</td>
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<td>Uli 911 black bean</td>
<td>Delphinidin 3-O-glucoside, petunidin 3-O-glucoside, malvidin 3-O-glucoside</td>
<td></td>
</tr>
<tr>
<td>Black bean seed coat</td>
<td>Myricetin 3-O-glucoside, quercetin 3-O-glucoside, kaempferol 3-O-glucoside,</td>
<td></td>
</tr>
<tr>
<td>Black bean seed coat</td>
<td>Myricetin 3-O-glucoside, quercetin 3-O-glucoside, kaempferol 3-O-glucoside,</td>
<td></td>
</tr>
<tr>
<td>Aged pinto bean</td>
<td>Kaempferol, kaempferol 3-O-glucoside, kaempferol 3-O-xysolglycoside,</td>
<td></td>
</tr>
</tbody>
</table>

**Table 2—Continued.**
Nine flavanones have been identified in common bean cultivars, seven of which were obtained from dark common beans (López et al., 2013). Naringenin and hesperetin glucosides are the main flavanones detected in common beans. Eriodictyol glucoside is mainly found in Pinto durango (Phaseolus vulgaris L.) and Bayo victoria (Phaseolus vulgaris L.). Anthropodictyol glucoside is mainly found in Pinto durango (Phaseolus vulgaris L.) and Bayo victoria (Phaseolus vulgaris L.).

Proanthocyanidins

Apart from phenolic acids and flavonoids, proanthocyanidins have also been widely detected in common beans (Table 1). Proanthocyanidins mainly distribute in the common bean seed coats and are the main component of polyphenols in common beans. Black bean seed coats and small red bean seed coats were recorded to possess the highest level of proanthocyanidins (760 mg CE/g and 540 mg CE/g, respectively) (Sancho, Pavan, & Pastore, 2015) among common bean cultivars (Table 1). Our group has determined the TPAC of pigmented bean coats and discovered that four kidney bean seed coats were rich in proanthocyanidins with the range of 46.7 to 79.9 mg CE/g DW and small speckled kidney bean seed coats had the highest content (Gan et al., 2016). Compared to phenolic acids and flavonoids, studies on the identification of proanthocyanidins in common beans are relatively scarce. Mostly, the identified proanthocyanidins are procyanidin dimers and trimers. López et al. (2013) determined procyanidin dimers and trimers in dark beans with a total content of 1006 μg/g, which was the highest concentration of non-anthocyanin compounds in raw dark beans. García-LaFuente et al. (2014) identified procyanidin dimers and trimers in round purple beans (Phaseolus vulgaris L.) with contents of 6336 and 130 μg/g, respectively. Chen et al. (2015a) identified procyanidin B1 dimer, procyanidin C1 trimer, and proanthocyanidin in cranberry beans with contents of 7.04 to 56.9, 12.8 to 33.9, and 15.0 to 35.3 μg/g, respectively.

Coumarins

Coumarins are a type of phenolic derivatives widely found in plants. These compounds can be used for anticoagulation and antithrombotic treatment of cardiovascular diseases (Li, Yao, & Li, 2017). Like proanthocyanidins, there is relatively little comprehensive research on the coumarin profiles in beans. Only coumestrol was identified in germinated Mexican common beans (Phaseolus vulgaris L.) at a level of 2.40 to 35.6 mg/g DW (Díaz-Batalla et al., 2006).

In conclusion, common bean polyphenols in different matrices exhibit difference in TPC, TFC, TPAC, and phenolic compounds. The general trends of common bean polyphenols have been summarized in Figure 2.

Factors Influencing Phenolic Content and Composition

The TPC, TFC, TPAC, and composition of common beans are influenced by several factors, such as environmental conditions, genotypes, storage, and processing methods. Generally, processing methods have the greatest influence in altering the genetically determined phenolic content and composition (Nayak et al., 2015). The effect of processing methods on the polyphenols has been summarized in Figure 3. The following sections briefly describe the factors that affect the TPC, TFC, TPAC, and composition of common beans.

Environmental conditions and genotypes

In the last decade, many studies have been conducted to investigate the effect of environmental conditions (location of experimental production) (de Mejía et al., 2003; Dinelli et al., 2006; Islam et al., 2003) and genotype (Beninger et al., 1999a; Beninger et al., 1999b; Beninger et al., 1999c).
Common bean polyphenols...

Storage

Longtime storage can alter the color, texture, flavor, cooking time, TPC, and TPAC of beans (*Phaseolus vulgaris* L.) (Coelho, de Mattos Bellato, Santos, Ortega, & Tsai, 2007). Martin-Cabrejas, Esteban, Pérez, Maina, and Waldron (1997) pointed out that long-term storage could lower TPC while increasing TPAC. The results of Mariotto-Cezar, Coelho, Christ, Schoeninger, and de Almeida (2013) were consistent with this finding and showed that the TPAC increased with storage time and reached the highest concentration at 180 days. Beninger et al. (2005) reported that the TPC of different pinto bean genotypes varied during storage, and the kaempferol content of CDC Pentium cultivar seed coats was reduced by almost half, whereas the kaempferol content of 1533–15 cultivar seed coats did not change significantly. This phenomenon might be attributed to hard-to-cook defect (Coelho et al., 2007; Jombo, Minnaar, & Taylor, 2017; Martin-Cabrejas et al., 1997).

Several theories have been proposed to explain the hard-to-cook phenomenon, including phytase–phytate–pectin theory, lignification theory, protein and starch interactions, and a multiple mechanism theory, but the “phytase–phytate–pectin” theory is the most widely accepted (Jombo et al., 2017). According to the “phytase–phytate–pectin” theory, water-soluble pectin permits water uptake by legume seeds. Both phytate and the carboxyl groups of soluble pectin can crosslink with calcium or magnesium ions, but phytate chelates preferentially with the above mentioned divalent cations. If the phytate is crosslinked with calcium or magnesium ions, legume seeds appear to be easy-to-cook. However, phytate may be hydrolyzed by phytase during storage so that the chelating potential of phytate vanishes, and then the calcium or magnesium ions will crosslink with the carboxyl groups of soluble pectin to form insoluble calcium and magnesium pectates, which are not dissolved readily when heated, thus restricting cell separation, inhibiting water uptake, and resulting in hard-to-cook defect (Figure 4). Paradoxically, other studies concluded that the TPAC of common beans dropped significantly after storage (Aparicio-Fernández, Manzo-Bonilla, & Loarca-Piña, 2005; Coelho et al., 2007), which might be attributed to the difference of cultivars. Beninger et al. (2005) reported a more specific conclusion that genotype had more effect on the TPC of common beans than the location.

Germination

The influence of germination on the TPC of edible seeds has been comprehensively summarized by our group (Gan et al., 2017). Contradictory findings have been published regarding the effects of germination on common bean cultivars (Table 3). For example, a study found that TPC in black bean sprouts decreased dramatically after germination (Guajardo-Flores, Serna-Saldivar, & Hosfield, 1999b; Valdés et al., 2011) on the polyphenols of common beans. Islam et al. (2003) reported that the TPC of common beans in Middle American gene pool was the highest, and that of the Andean gene pool was the lowest. These experiments also showed that both the location and genotype play an important role in the TPC of common beans. Espinosa-Alonso, Lygin, Widholm, Valverde, and Paredes-Lopéz (2006) also investigated the effect of genotype and location on the TPC of common beans and concluded that genotype had more effect on the TPC of common beans than the location.

Some studies have undertaken work to identify the flavonoid compounds in common beans and determined their contributions to seed coat color. Beninger, Hosfield, and Bassett (1999) analyzed the phytochemicals of three dry bean (*Phaseolus vulgaris* L.) genotypes differing in seed-coat color, mineral brown (*P. D. J G B v*), yellow brown (*P. D. J G b v*), and pale greenish yellow (*P. D. J g b v*) and found that astragalin existed in similar concentrations in pale greenish yellow and mineral brown genotypes but was significantly lower in yellow brown. This means that the G and B color genes may control the amount of astragalin present. In the same year, Beninger and Hosfield (1999b) isolated another 2 flavonol glycosides (‘3’, 4’, 5, 7-tetrahydroxyflavonol 3-O-β-D-glucopyranosyl (2→1) O-β-D-xyl-o-lyranoside and quercetin 3-O-β-D-glucopyranoside) from dark red kidney beans (*Phaseolus vulgaris* L.) and concluded that the change of the *Rk* allele to *rk* might allow the synthesis of flavonol glycosides in the presence of *čż*.

The influence of environmental conditions and genotype on proanthocyanidins has also been widely investigated. Barampama and Simard (1993) reported that proanthocyanidins were highly influenced by both environmental conditions and genetic factors. However, de Mejía et al. (2003) concluded that the TPAC of common beans was mainly influenced by genetic factors but not environmental conditions. Even though the conclusions drawn from these studies are slightly different, they both show that environmental conditions and genetic factors have an influence on the polyphenols of common beans.

![Figure 3–General trends of different processing methods on polyphenols in common beans.](Image)
Table 3—The effects of processing on common bean TPC, TFC, and TPAC (*Phaseolus vulgaris* L.).

<table>
<thead>
<tr>
<th>Processing methods</th>
<th>Bean sample</th>
<th>Before processing</th>
<th>After processing</th>
<th>Unit</th>
<th>References</th>
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<td><strong>TPC</strong></td>
<td></td>
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<tr>
<td><em>In vitro Gastrointestinal digestion</em></td>
<td>Black bean</td>
<td>0.85</td>
<td>0.20</td>
<td>mg GAE/g DW</td>
<td>(Sancho et al., 2015)</td>
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<tr>
<td></td>
<td>Regular darkening cranberry bean</td>
<td>2.60</td>
<td>0.21</td>
<td>mg GAE/g DW</td>
<td>(Chen et al., 2015b)</td>
</tr>
<tr>
<td></td>
<td>Non-darkening cranberry bean</td>
<td>0.60</td>
<td>0.06</td>
<td>mg GAE/g DW</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Small red bean</td>
<td>1.23</td>
<td>0.60</td>
<td>mg GAE/g DW</td>
<td>(Sancho et al., 2015)</td>
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<tr>
<td>Extrusion</td>
<td>Kidney bean</td>
<td>0.44</td>
<td>0.22</td>
<td>mg GAE/g DW</td>
<td>(Marzo, Alonso, Urdaneta, Arricibita, &amp; Ibanez, 2002)</td>
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<td><strong>Pressure cooking</strong></td>
<td>Kidney bean</td>
<td>2.07</td>
<td>1.12</td>
<td>mg TAE/g DW</td>
<td>(Rocha-Guzmán et al., 2007)</td>
</tr>
<tr>
<td></td>
<td>Common bean</td>
<td>44.0–96.0</td>
<td>12.0–27.0</td>
<td>mg CE/g DW</td>
<td>(Akillioglu &amp; Karakaya, 2010)</td>
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<td></td>
<td>Dry bean</td>
<td>5.48–5.62</td>
<td>1.56–1.66</td>
<td>mg CAE/g DW</td>
<td>(Nergiz &amp; Gökçöz, 2007)</td>
</tr>
<tr>
<td></td>
<td>Pinto bean</td>
<td>6.80</td>
<td>2.00</td>
<td>mg GAE/g DW</td>
<td>(Xu &amp; Chang, 2011)</td>
</tr>
<tr>
<td></td>
<td>Black bean</td>
<td>7.40</td>
<td>2.00</td>
<td>mg GAE/g DW</td>
<td></td>
</tr>
<tr>
<td>Traditional cooking</td>
<td>Common bean</td>
<td>2.36</td>
<td>8.58–11.8</td>
<td>mg GAE/g DW</td>
<td>(Valdés et al., 2011)</td>
</tr>
<tr>
<td></td>
<td>Common bean</td>
<td>3.50–5.00</td>
<td>2.10–2.50</td>
<td>mg GAE/g DW</td>
<td>(Nergiz &amp; Gökçöz, 2007)</td>
</tr>
<tr>
<td></td>
<td>Regular darkening cranberry bean</td>
<td>2.60</td>
<td>2.40</td>
<td>mg GAE/g DW</td>
<td>(Chen et al., 2015b)</td>
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<tr>
<td></td>
<td>Non-darkening cranberry bean</td>
<td>0.60</td>
<td>0.40</td>
<td>mg GAE/g DW</td>
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<tr>
<td>Soaking +cooking</td>
<td>Common bean</td>
<td>135–1292</td>
<td>126–688</td>
<td>mg GAE/g DW</td>
<td>(Ombra et al., 2016)</td>
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<td>Pinto bean</td>
<td>3.74</td>
<td>10.9–16.1</td>
<td>mg GAE/g DW</td>
<td>(Akillioglu &amp; Karakaya, 2010)</td>
</tr>
<tr>
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<td>Common bean</td>
<td>3.91–5.61</td>
<td>1.32–1.36</td>
<td>mg TAE/g DW</td>
<td>(Starzyńska-Janiszewska et al., 2015)</td>
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<tr>
<td></td>
<td>Common beans</td>
<td>8.80</td>
<td>3.00</td>
<td>mg GAE/g DW</td>
<td>(Hernández-Saavedra et al., 2013)</td>
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<tr>
<td></td>
<td>Var. Raba</td>
<td>1.06</td>
<td>0.55–0.94</td>
<td>mg CAE/g DW</td>
<td>(Piecyk, Wolosiak, Drożynska, &amp; Worobiej, 2012)</td>
</tr>
<tr>
<td>Soaking in hot/cold water +cooking with/without NaHCO₃</td>
<td>Pinto bean</td>
<td>3.74</td>
<td>12.4–16.1</td>
<td>mg GAE/g DW</td>
<td>(Valdés et al., 2011)</td>
</tr>
<tr>
<td></td>
<td>Common bean</td>
<td>3.50–5.00</td>
<td>1.71–2.74</td>
<td>mg GAE/g DW</td>
<td>(Hailélassie, Henry, &amp; Tyler, 2016)</td>
</tr>
<tr>
<td></td>
<td>Dry bean</td>
<td>5.48–5.62</td>
<td>1.12–1.32</td>
<td>mg GAE/g DW</td>
<td>(Nergiz &amp; Gökçöz, 2007)</td>
</tr>
<tr>
<td></td>
<td>Kidney bean</td>
<td>1.73</td>
<td>2.09–2.49</td>
<td>mg GAE/g DW</td>
<td>(Xu &amp; Chang, 2010)</td>
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<tr>
<td>Steamng</td>
<td>Common bean</td>
<td>0.94</td>
<td>0.43–0.77</td>
<td>mg GAE/g DW</td>
<td>(Sancho et al., 2015)</td>
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<tr>
<td></td>
<td>Pinto bean</td>
<td>≈6.80</td>
<td>≈1.70</td>
<td>mg GAE/g DW</td>
<td>(Xu &amp; Chang, 2011)</td>
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<tr>
<td></td>
<td>Black bean</td>
<td>≈7.40</td>
<td>≈2.00</td>
<td>mg GAE/g DW</td>
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<td></td>
<td>Black bean sprout</td>
<td>7.90</td>
<td>2.09–2.49</td>
<td>mg GAE/g DW</td>
<td>(Xu &amp; Chang, 2010)</td>
</tr>
<tr>
<td>Soaking</td>
<td>Common bean</td>
<td>3.90</td>
<td>4.00–4.50</td>
<td>mg GAE/g DW</td>
<td>(Aguilera et al., 2014)</td>
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<tr>
<td>Soaking (24h dark)</td>
<td>Kidney bean</td>
<td>3.90</td>
<td>1.30–1.70</td>
<td>mg GAE/g DW</td>
<td></td>
</tr>
<tr>
<td>Pressure steaming</td>
<td>Pinto bean</td>
<td>3.74</td>
<td>12.4–16.1</td>
<td>mg GAE/g DW</td>
<td>(Valdés et al., 2011)</td>
</tr>
<tr>
<td></td>
<td>Black bean</td>
<td>3.50–5.00</td>
<td>1.37–1.62</td>
<td>mg GAE/g DW</td>
<td>(Xu &amp; Chang, 2008)</td>
</tr>
<tr>
<td></td>
<td>Kidney bean</td>
<td>7.90</td>
<td>4.63–7.19</td>
<td>mg GAE/g DW</td>
<td>(Alonso et al., 2000)</td>
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<td></td>
<td>Red gram</td>
<td>2.07</td>
<td>1.64</td>
<td>mg TAE/g DW</td>
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<td>Steaming</td>
<td>Green gram</td>
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<td>3.43</td>
<td>mg GAE/g DW</td>
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<td>Pinto bean</td>
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<td>3.00</td>
<td>mg GAE/g DW</td>
<td>(Sancho et al., 2015)</td>
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<td>Black bean</td>
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<td>2.46–2.93</td>
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<td>Kidney bean</td>
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<td>4.00–4.50</td>
<td>mg GAE/g DW</td>
<td>(Aguilera et al., 2014)</td>
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<td>Thermal processing</td>
<td>Green bean</td>
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<td>0.50–0.58</td>
<td>mg GAE/g DW</td>
<td>(Jiratanan &amp; Liu, 2004)</td>
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<td>Germination (24h dark)</td>
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<td>1.30–1.70</td>
<td>mg GAE/g DW</td>
<td>(Aguilera et al., 2014)</td>
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<tr>
<td>Germination (12 h light/12 h dark)</td>
<td>Kidney bean</td>
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<td>1.30–1.70</td>
<td>mg GAE/g DW</td>
<td>(Aguilera et al., 2014)</td>
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<tr>
<td>Germination</td>
<td>Black bean</td>
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<td>6.74</td>
<td>mg GAE/g DW</td>
<td>(Xue et al., 2016)</td>
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<td>Black bean sprout</td>
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<td>mg GAE/g DW</td>
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<td>Black bean cotyledon</td>
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<td>0.30–2.10</td>
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<td>Black bean seed coat</td>
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<td>2.70–6.10</td>
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<td>Kidney bean</td>
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<td>0.97–1.40</td>
<td>mg TAE/g DW</td>
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<td>Fermentation</td>
<td>Dark common bean</td>
<td>3.91 – 5.61</td>
<td>1.39–1.76</td>
<td>mg TAE/g DW</td>
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<td><strong>TFC</strong></td>
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<td>6.80</td>
<td>1.70–2.00</td>
<td>mg GAE/g DW</td>
<td>(Akillioglu &amp; Karakaya, 2010)</td>
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<td><strong>TPAC</strong></td>
<td>Green bean</td>
<td>0.50</td>
<td>0.19–0.22</td>
<td>mg CE/g DW</td>
<td>(Jiratanan &amp; Liu, 2004)</td>
</tr>
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</table>

(Continued)
Table 3–Continued.

<table>
<thead>
<tr>
<th>Processing methods</th>
<th>Bean sample</th>
<th>Content</th>
<th>Unit</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td>Soaking in hot/cold water + cooking with/without NaHCO₃</td>
<td>Common bean</td>
<td>Before processing 0.29</td>
<td>After processing 0.27</td>
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<td>Tempe-type fermentation</td>
<td>Pinto bean</td>
<td>1.27</td>
<td>1.75–2.74</td>
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<td>Germination TPAC</td>
<td>Black bean</td>
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<td>After-darkening process</td>
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<td>Cooking</td>
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<td>Common bean</td>
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<td>Phaseolus vulgaris L.</td>
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<td>White kidney bean</td>
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<td>21.1</td>
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<td>Water soaking + cooking</td>
<td>Red kidney bean</td>
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<td>+ cooking</td>
<td>Kidney bean</td>
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<td>1.71</td>
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<td>Autoclaving</td>
<td>Kidney bean</td>
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<td>1.51</td>
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<td>White kidney bean</td>
<td>67.1</td>
<td>19.5</td>
<td>mg CE/g DW</td>
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<td>5.37</td>
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<td>Soaking (NaHCO₃) +</td>
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<td>Kidney bean</td>
<td>5.37</td>
<td>0.19–ND</td>
<td>mg CE/g DW</td>
</tr>
<tr>
<td>Soaking</td>
<td>Kidney bean</td>
<td>5.37</td>
<td>2.72</td>
<td>mg CE/g DW</td>
</tr>
<tr>
<td>Soaking (12 h in plain water)</td>
<td>Kidney bean</td>
<td>5.37</td>
<td>4.03</td>
<td>mg CE/g DW</td>
</tr>
<tr>
<td>Sodium bicarbonate soaking</td>
<td>Kidney bean</td>
<td>5.37</td>
<td>3.92</td>
<td>mg CE/g DW</td>
</tr>
<tr>
<td>(12 h)</td>
<td>Kidney bean</td>
<td>1.12</td>
<td>0.28</td>
<td>mg CE/g KDW</td>
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<tr>
<td>Extrusion</td>
<td>Kidney bean</td>
<td>3.59</td>
<td>0.58</td>
<td>mg CE/g KDW</td>
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<tr>
<td>Fermentation</td>
<td>Fresh common bean</td>
<td>0.90</td>
<td>0.70</td>
<td>mg CE/g FW</td>
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<tr>
<td></td>
<td>Hardened common bean</td>
<td>0.60</td>
<td>0.80</td>
<td>mg CE/g DW</td>
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<td></td>
<td>White kidney bean</td>
<td>67.1</td>
<td>33.5</td>
<td>mg CE/g DW</td>
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<td></td>
<td>Red kidney bean</td>
<td>26.7</td>
<td>4.22</td>
<td>mg CE/g DW</td>
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<td></td>
<td>Dark common bean</td>
<td>3.05</td>
<td>1.03</td>
<td>mg CE/g DW</td>
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<tr>
<td></td>
<td>Phaseolus vulgaris L.</td>
<td>4.06</td>
<td>0.30</td>
<td>mg CE/g DW</td>
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<tr>
<td></td>
<td>White kidney bean</td>
<td>67.1</td>
<td>21.1</td>
<td>mg CE/g DW</td>
</tr>
<tr>
<td>In vitro gastrointestinal</td>
<td>Black bean</td>
<td>760</td>
<td>60.4</td>
<td>mg CE/g DW</td>
</tr>
<tr>
<td>digestion</td>
<td>Regular darkening</td>
<td>≈2.20</td>
<td>≈1.40</td>
<td>mg PAC/g DW</td>
</tr>
<tr>
<td>cranberry bean</td>
<td>Small red bean</td>
<td>540</td>
<td>50.3</td>
<td>mg CE/g DW</td>
</tr>
<tr>
<td>Germination</td>
<td>Kidney bean</td>
<td>3.59</td>
<td>1.02–2.03</td>
<td>mg CE/g DW</td>
</tr>
<tr>
<td></td>
<td>Green gram</td>
<td>6.60</td>
<td>5.90</td>
<td>mg CE/g DW</td>
</tr>
<tr>
<td></td>
<td>Green gram</td>
<td>4.50</td>
<td>1.17–2.59</td>
<td>mg CE/g DW</td>
</tr>
<tr>
<td></td>
<td>Kidney bean</td>
<td>5.37</td>
<td>3.66–1.28</td>
<td>mg CE/g DW</td>
</tr>
<tr>
<td>Storage</td>
<td>Dry bean</td>
<td>ND–0.48</td>
<td>0.49–1.56</td>
<td>mg CE/g DW</td>
</tr>
<tr>
<td></td>
<td>Pinto bean of 1533-15</td>
<td>≈28.0</td>
<td>≈40.0</td>
<td>mg CE/g DW</td>
</tr>
<tr>
<td></td>
<td>Pinto bean of CDC pintium</td>
<td>≈128</td>
<td>≈158</td>
<td>mg CE/g DW</td>
</tr>
</tbody>
</table>

TPC, total phenolic content; TFC, total flavonoid content; TPCA, total proanthocyanidin content; GAE, gallic acid equivalent; CE, catechin equivalent; DW, dry weight; ND, not determined; FW, fresh weight; C3GE, cyanin 3-glucoside equivalent; RE, rutin equivalent; QE, quercetin equivalent; PAC, proanthocyanidin; TAE, tannic acid equivalent.
However, recently, Xue et al. (2016) found that germination can cause the accumulation of polyphenols in black bean sprouts, and bean sprouts have about 1.54 times more TPC than raw beans after sprouting for 6 days. This contradiction may be partly attributed to the way of calculating methods. The former only calculated the TPC of the sprouts without considering the TPC of seed coats, while the latter calculated the TPC of the whole beans.

Compared to TPC, there are fewer reports about the effect of germination on the TFC of common beans. Xue et al. (2016) showed that the TFC of black beans increased with the increase of germination time and reached the highest value on the 5th day.

Generally, germination can cause significant but varying degrees of TPAC reduction (Table 3). Alonso, Aguirre, and Marzo (2000) reported that the TPAC of kidney bean (*Phaseolus vulgaris* L.) decreased significantly after germination. Similar results were obtained by Ghavidel and Prakash (2007) and Hemalatha, Platel, and Srinivasan (2007), who reported that the TPAC of green gram (*Phaseolus aureus*) sprouts was much lower than that in the raw beans.

On the other hand, germination has a significant impact on the phenolic composition of common beans. For instance, five hydroxybenzoic compounds (gallic aldehyde, protocatechuic acid, protocatechuic aldehyde, *p*-hydroxybenzoic acid, and *p*-hydroxybenzoic aldehyde) were detected in the insoluble fractions of raw dark beans (*Phaseolus vulgaris* L.). However, no hydroxybenzoic compounds were detected in the insoluble fraction of the germinated beans. The same situation was observed in hydroxyxycinnamic compounds (*trans*-feruloyl aldaric acid and sinapoyl aldaric acid), which were detected in the insoluble fraction of raw dark beans but not in the insoluble fraction of germinated beans. The total content of hydroxybenzoic compounds in raw beans was much higher than that in germinated beans. By contrast, the total content of hydroxyxycinnamic compounds in raw beans was less than that in germinated beans (Duenas et al., 2016).

Based on the above discussion, germination shows a significant effect on the TPC, TFC, TPAC, and phenolic composition of common beans.

**Thermal processing**

Based on the majority of the articles reviewed, thermal processing has a significant effect on the phenolic content of common beans (Table 3). Xu and Chang (2009) reported that thermal processing methods caused a significant decrease in the TPC of both pinto and black beans. The similar conclusion was obtained in other studies. Hernández-Saavedra et al. (2013) concluded that the TPC of common beans decreased significantly after cooking, and Valdés et al. (2011) also reported that there was a loss of TPC in all cooked beans, while simple phenolics were only slightly decreased. However, Akillioglu and Karakaya (2010) found that common beans and pinto beans soaking in hot/cold water and cooking with/without NaHCO$_3$ had a significant increase in TPC, indicating that these methods may retain phenolic compounds during thermal processing.

In addition, contradictory findings have also appeared in the literature regarding the effect of thermal processing on the TFC of common beans. Jiratanan and Liu (2004) reported that thermal processing led to a significant reduction in the TFC of green beans (*Phaseolus vulgaris* L.). However, Akillioglu and Karakaya (2010) found that the TFC of beans (*Phaseolus vulgaris* L.) that were soaked in hot/cold water and cooked with/without NaHCO$_3$ increased. This explains to a certain extent that soaking and cooking with NaHCO$_3$ can largely retain the flavonoids in common beans.

Furthermore, Table 3 shows that thermal processing such as cooking, roasting, and autoclaving can significantly reduce the TPAC of common beans. For example, Helbig, do Oliveira, Queiroz, and Reis (2003) reported that nearly 90% proanthocyanidins in common beans were lost after cooking. This finding was further confirmed by other studies in Table 3.

Some studies have also been conducted to further investigate how the phenolic compositions in common beans are affected

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**Figure 4**—The proposed ‘phytase–phytate–pectin’ mechanism. Both phytate and the pectin can crosslink with calcium or magnesium ions, but phytate chelates preferentially with these divalent cations. If the phytate is crosslinked with calcium or magnesium ions, legume seeds appear to be easy-to-cook. However, phytate may be hydrolyzed by phytase during storage so that the chelating potential of phytate vanishes, and then the calcium or magnesium ions can crosslink with pectin to form insoluble calcium and magnesium pectates, which are not dissolved readily when heated, thus restricting cell separation, inhibiting water uptake, and resulting in hard-to-cook defect (Galiotou-Panayotou et al., 2008; Jombo et al., 2017).

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Common bean polyphenols... by thermal processing. Chen et al. (2015b) reported that cooking significantly increased the release of bound ferulic, sinapic acids, and flavanols. These results were consistent with a previous study, which reported that specific phenolic compounds, such as flavonols and free phenolic acids, were increased during thermal treatment (Ramilla et al., 2009). However, Xu and Chang (2009) reported that thermal processing methods significantly decreased the level of individual phenolic acids, anthocyanins, flavan-3-ols, and flavonoids. This disagreement may be attributed to the common bean varieties.

In conclusion, genotype, environment conditions, storage conditions, and thermal processing methods all strongly affect the phenolic compounds in common beans. In addition, other processing interventions, including in vitro gastrointestinal digestion, extrusion, soaking, and fermentation, also have effects on common bean polyphenols and antioxidant activity, which have been summarized in Figure 3.

**Extraction, Separation, and Identification Methods**

**Extraction**

Extraction procedure plays an important role in the recovery of polyphenols. Common bean polyphenols have been extracted from different matrices, including whole raw beans, seed coats, cotyledons, germinated common beans, fermented common beans, and thermally processed common beans. Generally, polyphenol extraction is a typical liquid–solid extraction procedure consisting of grinding, defatting, solvent extraction, centrifugation, filtration, evaporation, and drying (Figure 5). Extraction solvent is a key factor governing the efficiency of polyphenol extraction. Methanol/water/acidic systems are most commonly employed for the extraction of phenolic acids, while acetone/water/acidic systems are predominantly used for the extraction of proanthocyanidins (Table 1). The concentration of methanol or acetone used to extract polyphenols in common beans commonly ranges from 50 to 80%. Several studies also use pure water or methanol as the extraction solvent. However, the above-mentioned solvents are only suitable for the extraction of soluble phenolics. Bound phenolics need to be hydrolyzed with 2 mol/L NaOH and 12 mol/L HCl before further extraction (Aguilera et al., 2014; Ross, Beta, & Arrnfield, 2009; Treviño-Meja, Luna-Vital, Gaytán-Martínez, Mendoza, & Loarca-Piña, 2016). In addition, numerous studies have reported that the optimization of processing parameters plays a vital role in obtaining maximal polyphenols (Ghafoor, Choi, Jeon, & Jo, 2009; Jovanovic et al., 2017; Mourtzinos et al., 2016; Paleologou, Vasiliou, Grigoras, & Makris, 2016; Wong, Li, Li, Raznovski- Naumovski, & Chan, 2017; Zhang & Wang, 2016). However, few studies have systematically optimized the extraction conditions of common bean polyphenols. Owing to the lack of more data about the optimal extraction condition of common bean polyphenols, further studies are necessary to focus on this point.

In addition, extracting from isolated seed coats versus the whole beans using the same solvents makes a great difference in the outcome of analysis. Aquino-Bolaños et al. (2016) extracted flavonoids from the seed coats and whole seeds of Mexican common bean landraces with 70% methanol containing 5% acetic acid, and found that TFC in seed coats was much higher than that in the whole seeds. Similar conclusion was also obtained by Aparicio-Fernández, Yousef, Loarca-Piña, de Mejía, and Lila (2005) who extracted flavonoids from the whole seeds and seed coats of black Jamapa beans using 100% methanol, finding that TFC in seed coats was much higher than that in whole seeds. Besides, they also found that TPAC in seed coats was significantly higher than that in whole seeds. This trend also appears in other common bean varieties. Madhujith, Naczk, and Shahidi (2004) extracted proanthocyanidins with 80% acetone from the seed coat and whole seeds of 4 bean varieties with different seed coat colors (white, red, brown, and black), and also found that TPAC in seed coat was higher than that in whole seeds. In all studies, the seed coats are reported to contain higher levels of TFC and TPAC than whole seeds. However, there has been a disagreement concerning the TFC in seed coats and whole seeds. Madhujith et al. (2004) reported that TFC in seed coats was higher than that in whole seeds, while Ombral et al. (2016) reported that TPC in whole seeds was higher than that in seed coats of 11 common beans with different colors. This inconsistency may be due to different extraction conditions or common bean cultivars, and further studies are needed to clarify the potential reasons.

**Separation**

To obtain polyphenol-rich extracts, it is necessary to purify the sample by removing impurities with column chromatography (Nemitz et al., 2015). Different types of adsorbents, such as silica gel, macroporous resins, Sephadex LH-20, HW-F40 Toyopearl resin polymer, and silica gel type 60 have been used to purify common bean polyphenols.

Due to the polar nature of phenolics presented in common beans, HPLC has become the most commonly used analytical technique for the separation of these compounds. Almost all the chosen columns for phenolics were reverse phase type, with C18 as stationary phase, a 2 to 4.6 mm internal diameter, and a particle size between 3 and 10 μm (Beninger et al., 2005; Hu et al., 2006; Lin, Harrny, Pastor-Corràles, & Luthria, 2008). Apart from stationary phase, the mobile phase is usually made up of methanol or acetonitrile mixed isocratically or in a gradient with water. Usually, 0.1 to 10% acetic acid or formic acid is added to the solvents. For the separation of polyphenols, it is preferred that extraction solvents are mixtures of water/acetonitrile/acetic acid or water/methanol/acetic acid.

**Identification**

The most commonly used technology to characterize phenolic structure is mass spectrometry coupled to HPLC, such as ESI–MS. Lin et al. (2008) analyzed 24 common bean phenolic profiles via HPLC–DAD–ESI/MS. Kaempferol and astragalin were identified in red and pinto bean seed coats using HPLC–ESI/MS (Hu et al., 2006). HPLC–ESI/MS has also been applied to analyze the polyphenols in other common bean cultivars such as black Jamapa bean (Phaseolus vulgaris L.) (Aparicio–Fernández et al., 2005), Zolfino landraces (Phaseolus vulgaris L.) (Romani et al., 2004), cranberry beans (Phaseolus vulgaris L.) (Chen et al., 2015c), black beans (Phaseolus vulgaris L.) (Hart, Tako, Kochian, & Glahn, 2015), dark beans (Phaseolus vulgaris L.) (Duenas et al., 2016), white and red common beans (Phaseolus vulgaris L.) (García–Lafuente et al., 2014), processed common beans (Moreno–Jiménez et al., 2015), and 4 landraces (12 samples) of common beans (Phaseolus vulgaris L.) (Heimler, Vignolini, Dini, & Romani, 2005). In addition, de Lima et al. (2014) characterized isoflavonoids in Brazilian common bean germplasm (Phaseolus vulgaris L.) via LC–ESI–QTOF–MS. The phytochemical characterization of green bean (Phaseolus vulgaris L.) was also conducted by LC–ESI–TOF–MS. (Abu–Reidah, Arráez–Román, Lozano–Sánchez, Segura–Carretero, & Fernández–Gutiérrez, 2013). Furthermore, Tako et al. (2015) used UPLC–ESI–MS to characterize the phenolic...
Common bean polyphenols...

**Figure 5—General steps of extraction, purification, separation, and identification common beans phenolics.**

Compounds in cream seeded carioca bean seed (*Phaseolus vulgaris* L.) coat extracts.

Nuclear magnetic resonance (NMR) is also widely used for the identification of phenolic compounds in common beans. Beninger and Hosfield (2003) used $^1$H and $^{13}$C NMR spectroscopy to identify flavonoids and to characterize the flavonoid composition of three dry bean (*Phaseolus vulgaris* L.) genotypes. They used the same methodology to characterize the flavonol glycosides from Montcalm dark red kidney bean (*Phaseolus vulgaris* L.), and the seed coat of a new Manteca-type dry bean (*Phaseolus vulgaris* L.) (Beninger, Hosfield, & Nair, 1998). In addition, Yoshida et al. (1996) also used $^1$H and $^{13}$C NMR to analyze the structure of anthocyanins from the colored seed coat of *Phaseolus* legumes. Most of the time, it is combined with MS. For instance, Beninger et al. (2005) identified kaempferol, kaempferol 3-O-glucoside, and kaempferol 3-O-glucofuranose in pinto bean (*Phaseolus vulgaris* L.) using NMR and ESI–MS; Takeoka et al. (1997) also used NMR and ESI–MS to characterize black bean (*Phaseolus vulgaris* L.) anthocyanins; Choung, Choi, An, Chu, and Cho (2003) characterized the anthocyanin profile of Korean cultivated kidney bean (*Phaseolus vulgaris* L.) by UV-Vis, LC/ES–MS, and $^1$H and $^{13}$C NMR.

**Antioxidant Activity**

Numerous studies have demonstrated that common bean polyphenols exhibited manifold effects related to human health, such as anti-mutagenic, antimicrobial, anti-diabetic, and anti-inflammatory activities (Figure 6). These are strongly related to the antioxidant characteristics of the polyphenols. Therefore, we herein highlight the antioxidant effect in more detail. However, detailed review of the health benefits of polyphenols is beyond the scope of this review.
<table>
<thead>
<tr>
<th>Bean sample</th>
<th>Extracts</th>
<th>Antioxidant assay</th>
<th>Antioxidant effect</th>
<th>Unit</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dry bean</td>
<td>Methanol</td>
<td>TEAC</td>
<td>0.40–1.30</td>
<td>μmol TE/g DW</td>
<td>(Oomah et al., 2005)</td>
</tr>
<tr>
<td>Green bean</td>
<td>Methanol</td>
<td>TEAC</td>
<td>1.20–3.10</td>
<td>μmol TE/g DW</td>
<td>(Cardador-Martínez, Loarca-Piña, &amp; Oomah, 2002)</td>
</tr>
<tr>
<td>Kidney bean</td>
<td>Methanol</td>
<td>ARA</td>
<td>14.5–47.9</td>
<td>μmol TE/g DW</td>
<td>(Jiratanan &amp; Liu, 2004)</td>
</tr>
<tr>
<td>Common bean</td>
<td>Methanol</td>
<td>FRAP</td>
<td>2.81–14.6</td>
<td>μmol/g DW</td>
<td>(Aguilera et al., 2014)</td>
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<tr>
<td>Ft Nobre bean</td>
<td>Methanol</td>
<td>DPPH</td>
<td>381–603</td>
<td>μmol/g DW</td>
<td>(Redan, Vinson, &amp; Coco Jr 2013)</td>
</tr>
<tr>
<td>Jalo precoce bean</td>
<td>Methanol</td>
<td>DPPH</td>
<td>5.80</td>
<td>μmol/g DW</td>
<td>(Ranilla et al., 2009)</td>
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<tr>
<td>Black bean cotyledon</td>
<td>Methanol</td>
<td>ARAC</td>
<td>98.0</td>
<td>μmol TE/g DW</td>
<td>(Guajardo-Flores et al., 2013)</td>
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<td>Black bean seed coat</td>
<td>Methanol</td>
<td>ORAC</td>
<td>120</td>
<td>μmol TE/g DW</td>
<td>(Starzyńska-Janiszewska et al., 2015)</td>
</tr>
<tr>
<td>Common bean</td>
<td>Methanol</td>
<td>ABTS</td>
<td>39.6</td>
<td>μmol TE/g DW</td>
<td>(Chen et al., 2015c)</td>
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<td>Methanol</td>
<td>OH</td>
<td>2.51</td>
<td>IC50 (mg/mL)</td>
<td>(Romani et al., 2013)</td>
</tr>
<tr>
<td>Turkish white bean</td>
<td>Methanol</td>
<td>DPPH</td>
<td>0.80–10.7</td>
<td>μmol/g DW</td>
<td>(Vidal et al., 2011)</td>
</tr>
<tr>
<td>Red kidney bean seed coat</td>
<td>Methanol</td>
<td>FRAP</td>
<td>3.50–5.17</td>
<td>μmol Fe2+/g DW</td>
<td>(García-Lafuente et al., 2014)</td>
</tr>
<tr>
<td>Big speckled kidney bean seed coat</td>
<td>Methanol</td>
<td>FRAP</td>
<td>346</td>
<td>mmol Fe2+/g DW</td>
<td>(Hernández-Salazar et al., 2010)</td>
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<tr>
<td>Small speckled kidney bean (oval) seed coat</td>
<td>Methanol</td>
<td>ABTS</td>
<td>288</td>
<td>mmol Te/g DW</td>
<td>(Ranilla et al., 2007)</td>
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<tr>
<td>Violet red kidney bean seed coat</td>
<td>Methanol</td>
<td>ABTS</td>
<td>282</td>
<td>mmol Fe2+/g DW</td>
<td>(Hernández-Salazar et al., 2010)</td>
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<tr>
<td>Brown string bean seed coat</td>
<td>Methanol</td>
<td>FRAP</td>
<td>212</td>
<td>mmol Te/g DW</td>
<td>(Romani et al., 2013)</td>
</tr>
<tr>
<td>Black bean</td>
<td>Water</td>
<td>TEAC</td>
<td>13.2</td>
<td>μmol TE/g DW</td>
<td>(Moreno-Jiménez et al., 2015)</td>
</tr>
<tr>
<td>Phaseolus vulgaris L seed coat</td>
<td>Methanol</td>
<td>DPPH</td>
<td>1.05–518</td>
<td>mmol Te/g FW</td>
<td>(Moreno-Jiménez et al., 2015)</td>
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<tr>
<td>Phaseolus vulgaris L cotyledon</td>
<td>Methanol</td>
<td>DPPH</td>
<td>0.88–2.67</td>
<td>mmol TE/g FW</td>
<td>(Moreno-Jiménez et al., 2015)</td>
</tr>
<tr>
<td>Sarconi bean</td>
<td>Methanol</td>
<td>DPPH</td>
<td>2.78–16.9</td>
<td>EC50 (g/mg)</td>
<td>(Romani et al., 2013)</td>
</tr>
<tr>
<td>White kidney bean</td>
<td>Methanol</td>
<td>DPPH</td>
<td>0.05–0.09</td>
<td>EC50 (g/mg)</td>
<td>(Romani et al., 2013)</td>
</tr>
<tr>
<td>Round purple bean</td>
<td>Methanol</td>
<td>DPPH</td>
<td>109</td>
<td>1/EC50 (mg/g)</td>
<td>(Romani et al., 2013)</td>
</tr>
<tr>
<td>Common bean</td>
<td>Methanol</td>
<td>OH</td>
<td>2400–4700</td>
<td>IC50 (μg/mL)</td>
<td>(Romani et al., 2013)</td>
</tr>
<tr>
<td>Regular darkening cranberry bean</td>
<td>Methanol</td>
<td>DPPH, LPI</td>
<td>200–1800</td>
<td>IC50 (μg/mL)</td>
<td>(Romani et al., 2013)</td>
</tr>
<tr>
<td>Non-darkening cranberry bean</td>
<td>Methanol</td>
<td>ORAC</td>
<td>50.0</td>
<td>μmol TE/g DW</td>
<td>(Romani et al., 2013)</td>
</tr>
<tr>
<td>Common bean seed coat</td>
<td>Methanol</td>
<td>DPPH</td>
<td>1.57–55.2</td>
<td>EC50 (mg/mL)</td>
<td>(Romani et al., 2013)</td>
</tr>
<tr>
<td>Common bean whole flour</td>
<td>Methanol</td>
<td>DPPH</td>
<td>7.10–32.4</td>
<td>μmol TE/g DW</td>
<td>(Romani et al., 2013)</td>
</tr>
<tr>
<td>Black bean</td>
<td>Methanol</td>
<td>ABTS</td>
<td>170</td>
<td>μmol TE/g DW</td>
<td>(Sancho et al., 2015)</td>
</tr>
<tr>
<td>Small red bean</td>
<td>Methanol</td>
<td>ORAC</td>
<td>1241</td>
<td>μmol TE/g DW</td>
<td>(Sancho et al., 2015)</td>
</tr>
<tr>
<td>Common bean</td>
<td>Methanol</td>
<td>ORAC</td>
<td>211</td>
<td>μmol TE/g DW</td>
<td>(Sancho et al., 2015)</td>
</tr>
</tbody>
</table>

Abbreviations: TOSC, total oxyradical scavenging capacity; VCE, vitamin C equivalent; TEAC, Trolox equivalent antioxidant activity; ARA, Antiradical activity; TE, Trolox equivalent; ABTS, 2, 2′-azino-bis(3-ethylbenzothiazoline-6-sulfonic acid) free radical scavenging assay; DPPH, 1, 1-diphenyl-2-picrylhydrazyl free radical scavenging assay; FRAP, ferric reducing antioxidant potential assay; ORAC, oxygen radical absorbance capacity; LPI, lipid peroxidation inhibition; OH, hydroxyl free radical scavenging assay.
Oxidative stress is thought to be a biochemical imbalance caused by overproduction of reactive oxygen species or a reduction in the antioxidant systems. It is a negative effect produced by free radicals in the body and is considered an important factor leading to the aging and complications of many chronic conditions, such as Alzheimer’s disease, diabetes, and various types of cancer. Among the characteristics of polyphenols, their antioxidant activity and high potential for resistance to oxidative stress are emphasized (Nakatani & Kikuzaki, 1995). Table 4 summarizes the available antioxidant activity data of common beans measured by different in vitro assays, including oxygen radical absorbance capacity (ORAC), ferric reducing antioxidant potential assay (FRAP), 1,1-diphenyl-2-picrylhydrazyl free radical scavenging assay (DPPH), hydroxyl free radical scavenging assay (OH), 2, 2′-azino-bis(3-ethylbenzothiazoline-6-sulfonic acid) free radical scavenging assay (ABTS), total oxyradical scavenging capacity (TOSC), and Trolox equivalent antioxidant activity assay (TEAC). Basically, most common bean cultivars possess antioxidant activity, and colored ones show superior antioxidant activity compared to white beans. For example, Ombra et al. (2016) used the DPPH method to compare the antioxidant activity of colored and white common beans, and found that the antioxidant activity of colored ones was higher than that of non-pigmented common beans. Similar conclusion was also obtained by Madhusijith and Shahidi (2005), who evaluated the antioxidant activity of four common bean varieties (white kidney, red pinto, Swedish brown, and black kidney beans) using TEAC assay, and deduced that compared with white beans, colored beans had excellent antioxidant activity. In addition, Table 4 shows that most of the polyphenols are concentrated in the seed coats of common beans, especially for the colored common beans. Ranilla et al. (2007) found that the antioxidant activity of common bean seed coat was higher than that of its cotyledon. This finding was further confirmed by other studies (for example, Aquino-Bolaños et al., 2016; Guajardo-Flores et al., 2013). More importantly, several studies have concluded that the antioxidant activity of common beans was positively correlated with the TPC of common beans (Anton, Ross, Beta, Fulcher, & Arntfield, 2008; Elizabeth et al., 2007; Ranilla et al., 2007). Another noteworthy point is that according to FRAP and ABTS methods, the antioxidant activity of most pigmented bean coats is higher than most common fruits and vegetables (Gan et al., 2016). Furthermore, not only the in vitro studies but animal studies have also confirmed that common beans possess antioxidant activity, as measured in various biochemical parameters such as thiobarbituric acid reactive substances, hydroperoxides, glutathione, glutathione reductase, glutathione S-transferase, glutathione peroxidase, and catalase (Ganesan & Xu, 2017). Xu and Chang (2011) reported that raw pinto and black beans (Phaseolus vulgaris L.) exhibited cellular antioxidant activities in dose-dependent manners.

On the other hand, the antioxidant activity of common beans is significantly affected by processing methods such as thermal processing, fermentation, and germination. Table 5 shows the effect of processing methods on the antioxidant activity of common beans. Generally, thermal processing methods, such as cooking and steaming, cause a significant decrease in antioxidant activity (Table 5). For instance, Starzyńska-Janiszewska, Stodolak, and Wikiera (2015) reported that soaking and cooking significantly reduced the free radical scavenging activity and reducing power of
Table 5–Effect of processing methods on common bean antioxidant activities (all *Phaseolus vulgaris* L.).

<table>
<thead>
<tr>
<th>Processing methods</th>
<th>Bean sample</th>
<th>Soluble/bound extract</th>
<th>Analytic methods</th>
<th>Antioxidant activity</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Thermal processing</strong></td>
<td><strong>Pinto Saltillo</strong></td>
<td>Soluble</td>
<td>OH</td>
<td>≈2300 ≈2600</td>
<td>IC$_{50}$ (μg/mL)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Soluble</td>
<td>OH</td>
<td>≈2700 ≈2750</td>
<td>IC$_{50}$ (μg/mL)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Soluble</td>
<td>LPI</td>
<td>≈200 ≈700</td>
<td>IC$_{50}$ (μg/mL)</td>
</tr>
<tr>
<td></td>
<td><strong>Negro 8025</strong></td>
<td>Soluble</td>
<td>OH</td>
<td>≈2850 ≈2800</td>
<td>IC$_{50}$ (μg/mL)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Soluble</td>
<td>LPI</td>
<td>≈600 ≈900</td>
<td>IC$_{50}$ (μg/mL)</td>
</tr>
<tr>
<td></td>
<td><strong>Bayo Victoria</strong></td>
<td>Soluble</td>
<td>LPI</td>
<td>≈1800 ≈2400</td>
<td>IC$_{50}$ (μg/mL)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Soluble</td>
<td>LPI</td>
<td>≈600 ≈950</td>
<td>IC$_{50}$ (μg/mL)</td>
</tr>
<tr>
<td></td>
<td><strong>Pinto bean</strong></td>
<td>Soluble</td>
<td>DPPH</td>
<td>≈18.0 ≈6.00–9.00</td>
<td>μmol TE/g DW</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Soluble</td>
<td>FRAP</td>
<td>≈6.00 ≈1.50–2.80</td>
<td>μmol Fe$_{III}$/g DW</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Soluble</td>
<td>ORAC</td>
<td>≈58.0 ≈18.0–30.0</td>
<td>μmol TE/g DW</td>
</tr>
<tr>
<td></td>
<td><strong>Black bean</strong></td>
<td>Soluble</td>
<td>DPPH</td>
<td>≈19.0 ≈10.0–14.0</td>
<td>μmol TE/g DW</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Soluble</td>
<td>FRAP</td>
<td>≈9.80 ≈2.8–4.50</td>
<td>μmol Fe$_{III}$/g DW</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Soluble</td>
<td>ORAC</td>
<td>≈70.0 ≈12.0–38.0</td>
<td>μmol TE/g DW</td>
</tr>
<tr>
<td></td>
<td><strong>Green bean</strong></td>
<td>Total</td>
<td>TOSC</td>
<td>≈38.0 ≈32.0</td>
<td>μmol VC/g DW</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Ft nobre bean</td>
<td>DPPH</td>
<td>5.80 1.90–7.30</td>
<td>μmol TE/g DW</td>
</tr>
<tr>
<td></td>
<td><strong>Jalo precoce bean</strong></td>
<td>Soluble</td>
<td>DPPH</td>
<td>6.40 2.50–11.9</td>
<td>μmol TE/g DW</td>
</tr>
<tr>
<td></td>
<td><strong>Common bean</strong></td>
<td>Soluble</td>
<td>ABTS</td>
<td>39.6 10.9</td>
<td>μmol TE/g DW</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Soluble</td>
<td>DPPH</td>
<td>8.04 2.11</td>
<td>μmol TE/g DW</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Soluble</td>
<td>RP</td>
<td>23.0 63.5</td>
<td>R$_{DPPH}$/mg/mL</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Soluble</td>
<td>OH</td>
<td>2.51 16.8</td>
<td>IC$_{50}$/mg/mL</td>
</tr>
<tr>
<td></td>
<td><strong>Common bean</strong></td>
<td>Soluble</td>
<td>DPPH</td>
<td>0.05–0.09 0.07–0.24</td>
<td>μmol CE/g DW</td>
</tr>
<tr>
<td></td>
<td><strong>Regular darkening cranberry bean</strong></td>
<td>Soluble</td>
<td>ORAC</td>
<td>≈142 ≈128</td>
<td>μmol TE/g DW</td>
</tr>
<tr>
<td></td>
<td><strong>Non-darkening cranberry bean</strong></td>
<td>Soluble</td>
<td>ORAC</td>
<td>≈50.0 ≈40.0</td>
<td>μmol TE/g DW</td>
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<tr>
<td></td>
<td><strong>Common bean</strong></td>
<td>Soluble</td>
<td>DPPH</td>
<td>1.57–55.2 3.82–66.6</td>
<td>μmol CE/g DW</td>
</tr>
<tr>
<td></td>
<td><strong>Black bean</strong></td>
<td>Soluble</td>
<td>DPPH</td>
<td>19.0 10.7–15.6</td>
<td>μmol CE/g DW</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Soluble</td>
<td>ORAC</td>
<td>92.7 10.8–64.6</td>
<td>μmol TE/g DW</td>
</tr>
<tr>
<td></td>
<td><strong>Pinto bean</strong></td>
<td>Total</td>
<td>FRAP</td>
<td>572 378</td>
<td>μmol CE/g DW</td>
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<td></td>
<td><strong>Navy bean</strong></td>
<td>Total</td>
<td>FRAP</td>
<td>508 442</td>
<td>μmol CE/g DW</td>
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<td></td>
<td><strong>Black bean</strong></td>
<td>Total</td>
<td>FRAP</td>
<td>476 404</td>
<td>μmol CE/g DW</td>
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<td></td>
<td><strong>Light red kidney bean</strong></td>
<td>Total</td>
<td>FRAP</td>
<td>592 442</td>
<td>μmol CE/g DW</td>
</tr>
<tr>
<td></td>
<td><strong>Dark red kidney bean</strong></td>
<td>Total</td>
<td>FRAP</td>
<td>603 352</td>
<td>μmol CE/g DW</td>
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<tr>
<td></td>
<td><strong>Garbanzo bean</strong></td>
<td>Total</td>
<td>FRAP</td>
<td>479 408</td>
<td>μmol CE/g DW</td>
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<td></td>
<td><strong>Great northern bean</strong></td>
<td>Total</td>
<td>FRAP</td>
<td>489 371</td>
<td>μmol CE/g DW</td>
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<td></td>
<td><strong>Red bean</strong></td>
<td>Total</td>
<td>FRAP</td>
<td>463 431</td>
<td>μmol CE/g DW</td>
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<td></td>
<td><strong>Blackeye bean</strong></td>
<td>Total</td>
<td>FRAP</td>
<td>381 387</td>
<td>μmol CE/g DW</td>
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<tr>
<td><strong>Soaking + cooking</strong></td>
<td><strong>Common bean</strong></td>
<td>Soluble</td>
<td>DPPH</td>
<td>0.05–0.09 0.025–0.04</td>
<td>μmol CE/g DW</td>
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<tr>
<td></td>
<td><strong>Kidney bean</strong></td>
<td>Soluble</td>
<td>TEAC</td>
<td>4.50 3.20–9.50</td>
<td>mmol TE/g DW</td>
</tr>
<tr>
<td></td>
<td><strong>Green bean</strong></td>
<td>Soluble</td>
<td>TOSC</td>
<td>≈38.0 ≈30.0–33.0</td>
<td>μmol VC/g DW</td>
</tr>
<tr>
<td></td>
<td><strong>Common bean</strong></td>
<td>Soluble</td>
<td>FRAP</td>
<td>2.81–14.6 1.59–7.96</td>
<td>μmol CE/g DW</td>
</tr>
<tr>
<td></td>
<td><strong>Bound</strong></td>
<td>FRAP</td>
<td>381–603 352–442</td>
<td>μmol CE/g DW</td>
<td></td>
</tr>
<tr>
<td></td>
<td><strong>Common bean</strong></td>
<td>Soluble</td>
<td>OH</td>
<td>≈2.40–4.70 ≈2.05–2.80</td>
<td>IC$_{50}$/mg/mL</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Soluble</td>
<td>LPI</td>
<td>≈200–1800 ≈80.0–3300</td>
<td>μmol CE/mL</td>
</tr>
<tr>
<td></td>
<td><strong>Black bean</strong></td>
<td>Soluble</td>
<td>DPPH</td>
<td>19.0 12.1–13.6</td>
<td>μmol CE/g DW</td>
</tr>
<tr>
<td></td>
<td><strong>Black bean</strong></td>
<td>Soluble</td>
<td>ORAC</td>
<td>92.7 50.3–77.2</td>
<td>μmol CE/g DW</td>
</tr>
<tr>
<td><strong>Soaking</strong></td>
<td><strong>Common bean</strong></td>
<td>Soluble</td>
<td>DPPH</td>
<td>0.05–0.09 0.14–0.22</td>
<td>μmol CE/g DW</td>
</tr>
<tr>
<td></td>
<td><strong>Black bean</strong></td>
<td>Soluble</td>
<td>DPPH</td>
<td>19.0 17.4–17.8</td>
<td>μmol CE/g DW</td>
</tr>
<tr>
<td></td>
<td><strong>Black bean</strong></td>
<td>Soluble</td>
<td>ORAC</td>
<td>92.7 66.3–77.9</td>
<td>μmol CE/g DW</td>
</tr>
<tr>
<td><strong>Germination</strong></td>
<td><strong>Black bean sprout</strong></td>
<td>Soluble</td>
<td>ORAC</td>
<td>27.0 10.0</td>
<td>μmol TE/g DW</td>
</tr>
<tr>
<td></td>
<td><strong>Black bean cotyledon</strong></td>
<td>Soluble</td>
<td>ORAC</td>
<td>98.0 10.0</td>
<td>μmol TE/g DW</td>
</tr>
<tr>
<td></td>
<td><strong>Black bean seed coat</strong></td>
<td>Soluble</td>
<td>ORAC</td>
<td>120 590</td>
<td>μmol TE/g DW</td>
</tr>
<tr>
<td></td>
<td><strong>Kidney bean</strong></td>
<td>Soluble</td>
<td>ORAC</td>
<td>≈240 ≈12.0–46.0</td>
<td>μmol TE/g DW</td>
</tr>
<tr>
<td></td>
<td><strong>Common bean</strong></td>
<td>Soluble</td>
<td>ABTS</td>
<td>39.6 14.4</td>
<td>μmol TE/g DW</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Soluble</td>
<td>OH</td>
<td>2.51 9.30</td>
<td>IC$_{50}$/mg/mL</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Soluble</td>
<td>DPPH</td>
<td>8.04 3.82–66.6</td>
<td>μmol CE/g DW</td>
</tr>
</tbody>
</table>

Abbreviations: TOSC, total oxyradical scavenging capacity; VCE, vitamin C equivalent; TEAC, Trolox equivalent antioxidant activity; TE, Trolox equivalent; ABTS, 2, 2'-azino-bis(3-ethylbenzothiazoline-6-sulfonic acid) free radical scavenging assay; DPPH, 1, 1-diphenyl-2-picrylhydrazyl free radical scavenging assay; OH, hydroxyl radical absorbance capacity; ORAC, oxygen radical absorbance capacity; LPI, lipid peroxidation inhibition; OH, hydroxyl free radical scavenging assay; FRAP, ferric reducing antioxidant potential assay; RP, reducing power.
Common bean polyphenols... 

common beans. Chen et al. (2015b) also found similar phenomena and explained that the decline in antioxidant activity was related to the decrease in the content of phenolics and flavonoids. However, still several other studies have reported a fluctuation or an increase of antioxidant activity in cooked common beans. For example, Ranilla et al. (2009) reported that there was a fluctuation in antioxidant activity of thermal processed common beans, mainly associated with the bean cultivar and whether they retained soaking water during thermal processing. In addition, some researchers found that thermal processing promoted the release of bound phenolics and then caused an increase in antioxidant activity (Moreno-Jíménez et al., 2015; Rocha-Guzmán, Herzog, et al., 2007; Váldes et al., 2011). On the other hand, germination can significantly increase the antioxidant activity of common beans. Several studies concluded that germination led to increased antioxidant activity due to the increased TPC in germinated beans (Aguirera et al., 2014; Xu & Chang, 2011; Xue et al., 2016), and in order to highlight this phenomenon, our group gave a comprehensive review about antioxidant activity of germinated edible seeds and sprouts (Gan et al., 2017). However, Guajardo-Flores et al. (2013) found that germination resulted in reduced antioxidant activity of black bean sprouts and cotyledons but increased antioxidant activity of black bean seed coats. Other processing methods such as Nano-Gro, an organic biostimulant, and fermentation are also applied to improve the antioxidant activity of common beans. Kocira, Kocira, Zlotek, Kornas, and Swieca (2015) applied Nano-Gro to increase the antioxidant activity of common beans. They also reported that fermentation increased the antioxidant activity of common beans compared with cooked beans. Overall, processing methods have a significant effect on the antioxidant activity of common beans.

Perspectives and Conclusions

Common bean (Phaseolus vulgaris L.) is one of the most important pulses because of its nutritional value and beneficial effects. In this review, the content, composition, distribution, and related factors influencing polyphenols in common beans as well as their antioxidant activity are systemically summarized and discussed. However, the following aspects still need further research to make up gaps in knowledge.

For the extraction of polyphenols, the extraction solvent plays an important role in the extraction efficiency. Although acetone/water or methanol/water mixtures are most commonly used for the simultaneous extraction of polar and nonpolar polyphenols, there is no precise recommendation for extracting a particular sample with a specific solvent or solvent mixture. Mathematical modeling such as the artificial neural networks and response surface methodology, an ideal candidate for predicting the interactions between the target compound and solvent, has been successfully applied in the selection of a particular solvent for higher extraction yield of polyphenols in many plants. However, to date, no available study has applied these modeling methods to optimize the extraction conditions of common bean polyphenols. Therefore, further studies can apply these methods to minimize the effort required to select solvents for common bean polyphenols in different varieties.

In addition, the research on the chemical composition of common beans provides a solid theoretical basis for the development and utilization of common beans. To further develop these beans, it is necessary to find more bioactive compounds and investigate their health benefits or their biologically active metabolites. Thus, future research can focus on the extraction and purification of new active compounds from common beans, and clinical studies are also needed to verify the therapeutic benefits of common beans rich in polyphenols.

Besides, thermal processing can adversely affect polyphenols thereby reducing the antioxidant activity of processed common beans. However, in several studies, antioxidant activity increased after processing, which may be due to the inherent nature of some common bean cultivars. Thus, special attention should be paid to such common bean varieties because of their intrinsic textures and other parameters after thermal processing.

It is obvious that the antioxidant activity of common beans is mainly attributed to the complex mixture of phytochemicals rather than a single antioxidant in beans. Measuring the antioxidant activity of common beans based solely on the presence of any single antioxidant is biased because phytochemical complexes can exhibit synergistic effects. Therefore, the synergistic effect of common bean polyphenols and other bioactive compounds deserves further study.

Acknowledgments

This study was financially supported by the Shanghai Agricultural Culture and Science and Technology Key Program (18391900600), Shanghai Basic and Key Program (18JC1410800), the National Key R&D Program of China (2017YFC1600100), Shanghai Pujiang Talent Plan (18PJ1404600), and Shanghai Jiao Tong University Young Scholar Starting Funding.

Author Contributions

R.Y.G. and H.C. conceived the idea, Q.Q.Y. and R.Y.G. constructed the manuscript, R.Y.G., Y.Y.G., D.Z., and H.C. edited and revised the manuscript.

Conflict of Interest

The authors declare no conflict of interest.

Abbreviations

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>TPC</td>
<td>Total phenolic content</td>
</tr>
<tr>
<td>TFC</td>
<td>Total flavonoid content</td>
</tr>
<tr>
<td>TAC</td>
<td>Total proanthocyanidin content</td>
</tr>
<tr>
<td>ORAC</td>
<td>Oxygen radical absorbance capacity</td>
</tr>
<tr>
<td>FRAP</td>
<td>Ferric reducing antioxidant potential</td>
</tr>
<tr>
<td>DPPH</td>
<td>1,1-Diphenyl-2-picrylhydrazyl</td>
</tr>
<tr>
<td>OH</td>
<td>Hydroxyl free radical</td>
</tr>
<tr>
<td>ABTS</td>
<td>2, 2’-Azino-bis (3-ethylbenzothiazoline-6-sulfonic acid)</td>
</tr>
<tr>
<td>TOSC</td>
<td>Oxyradical scavenging capacity</td>
</tr>
<tr>
<td>TEAC</td>
<td>Trolox equivalent antioxidant activity assay</td>
</tr>
<tr>
<td>GAE</td>
<td>Gallic acid equivalent</td>
</tr>
<tr>
<td>CE</td>
<td>Catechin equivalent</td>
</tr>
</tbody>
</table>

References


Akillioglu, H. G., & Karakaya, S. (2010). Changes in total phenols, total flavonoids, and antioxidant activities of common beans and pinto beans after...
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