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Flavonoid content of selected foods – A comparison of four international composition tables

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A R T I C L E I N F O

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A B S T R A C T

The content of flavonoids, widely found in plant-based foods, might differ depending on which food composition table (FCT) is being used. In this study, we investigated the variation and comparability in the flavonoid content of selected foods across four international food composition tables. Flavonoid estimates were derived for all foods available in each table, and comparisons were carried out for foods common between tables. Bias percentage, 95 % limits of agreement, and intra-class correlation coefficients (ICCs; 95 % confidence intervals [95 %CI]) were estimated. Phenol-Explorer and Indian FCT showed moderate level of agreement for total flavonoid (ICC 0.50 and 0.57 respectively) when compared to the USDA table. eBASIS for total flavonoids and anthocyanidins (ICC 0.67 and 0.85, respectively), and Indian FCT for flavanols and flavanones (ICC 0.71 and ICC 0.85, respectively) showed moderate-to-good level of agreement, and low level of agreement for other subclasses when compared to Phenol Explorer. Several flavonoid subclasses showed low to moderate levels of agreement between FCTs, whilst others (including total flavonoid intake) had lower levels of agreement. Methodological approaches in the measurement of flavonoid content of foods across tables, and continued efforts to improve harmonization of these databases would contribute to improve quantification of flavonoid content.

1. Background

Flavonoids are a large class of bioactive compounds, polyphenolic, non-nutrients, and ubiquitously distributed plant secondary metabolites, with fruits and vegetables being their richest sources (Beecher, 2003; Corradini et al., 2011; Pérez-Jiménez et al., 2010). Extensive scientific evidence shows that flavonoids have been demonstrated to have multiple potentially beneficial effects against several chronic diseases due to their well described antioxidant (Durazzo et al., 2019; Kumar and Pandey, 2013; Yao et al., 2004), anti-inflammatory (Del Rio et al., 2013; Gonzalez et al., 2011) anti-mutagenic properties, as well as their role in modulating metabolic pathways (Cazarolli et al., 2008; Del Rio et al., 2013). Findings from epidemiological studies suggest that dietary intake of flavonoids or of their dietary sources, is associated with several important health outcomes including better quality of sleep (Godos et al., 2020), reduced inflammation in obese individuals (Callcott et al., 2019), better lung function (Garcia-Larsen et al., 2015; Garcia-Larsen et al., 2018), and lower risk of several non-communicable diseases such as autoimmune diseases (Lu et al., 2017), and chronic obstructive pulmonary disease (COPD) (Kaluza et al., 2018; Tabak et al., 2001).

Population-level estimates of flavonoid intake mostly rely on the use

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of food composition tables (FCTs) to derive their content. These tools allow quantifying the intake of a wide variety of nutrients and non-nutrient bio-compounds, providing reference values that are often calculated within the research facilities linked to the specific FCT or compiled through scientific literature searches (Kapsokefalou et al., 2019). As such, the flavonoid content reported in FCTs is likely to show variations, which might be influenced by the differences in the analytical methods used to estimate their content in food, by the chemical form (e.g. aglycones or glycosides), the completeness of flavonoid FCTs, and by other factors related to seasonality and harvest (Peterson et al., 2015). In addition to the specific methodological variations in the quantification of flavonoids, the epidemiological tools used to ascertain dietary intake (e.g. food frequency questionnaires (FFQ), 24-hour recall questionnaires) can also affect estimates (Jun et al., 2016). Furthermore, it is important to note that the flavonoid content reported is more likely to show variations in relation to natural and inherent differences. Scientific evidence increasingly shows that the evaluation of organically and conventionally grown fruit and vegetables, as well as different parts of plants, shows a difference in polyphenol content (Faller and Fialho, 2010).

These challenges highlight the need to improve our understanding of the comparability of FCTs that are currently available to derive estimates of flavonoids. We therefore investigated the variations in the content of flavonoids reported by four international FCTs commonly used in epidemiological studies. As part of the multinational Burden of Lung Disease (BOLD) survey (Buist et al., 2005), a standardized, and validated FFQ (Garcia-Larsen et al., 2011) was adapted to be used in six countries in Europe, Africa and Asia participating in BOLD I. The FFQ contains a wide range of plant-based foods commonly consumed across participant countries, as well as specific foods representative of each country's dietary habits. Their flavonoid content was examined using different food composition tables.

2. Methods

2.1. Selection of foods included for the determination of flavonoid content

The BOLD Survey was designed to describe the variations in the prevalence of COPD across the world, and to identify its risk factors across several regions in the world, mostly in low- and middle-income countries (Buist et al., 2005). The survey uses standardized and validated methods across all participant countries. The GA^{2}LEN food frequency questionnaire (FFQ) (Garcia-Larsen et al., 2011) is an internationally validated, semi-quantitative questionnaire that was used as a common, standardized tool to ascertain dietary intake across all research sites participating in the BOLD study. The FFQ has been further validated to show dietary intake of flavonoids was highly correlated with several novel potential markers of flavonoid intake in serum (Charles et al., 2021). The food group classification (n=32) was based on the European Food Consumption Survey Method (EFCOSUM) recommendations, facilitating international comparisons of dietary intake (Ireland et al., 2002). Six countries, namely Pakistan, Morocco, Albania, India, Kyrgyzstan and UK implemented the FFQ, and translated it to the local language. Frequency of food consumption was categorized as +4 per day, 2–3 per day, once per day, 5–6 per week, 2–4 per week, once per week, 1–3 times a month, and rarely or never.

2.2. Search strategy and identification of eligible FCTs with flavonoid content

An exhaustive search of FCTs with flavonoid data was carried out using website engines internationally recognized as a resource for food composition data, namely INFOODs/FAO (FAO/INFOODS, 2017; Murphy et al., 2016; Rand and Young, 1984), EuroFIR (European Food information Resource, 2019) and LANGUAL™ (Ireland and Moller, 2010). Country specific food composition tables were examined to identify if they included flavonoid data. Additional searches were carried out in PubMed Central, Scopus electronic databases and Google search engine to identify relevant literature on FCT with flavonoid content. FCTs were considered eligible if they included original flavonoid composition data. FCTs that compiled flavonoid data from pre-existing tables/databases were excluded.

We identified six potentially eligible FCTs with original estimates of flavonoid content: 1) The US Department of Agriculture (USDA) database describes flavonoid content in three separate datasets, (i) flavonoids (Haytowitz et al., 2018) (which contains five sub-classes: flavan-3-ols, flavanones, flavones, flavonols, and anthocyanidins), (ii) isoflavones (Department and Agriculture, 2015), and (iii) proanthocyanidins (Haytowitz et al., 2018). It contains worldwide food composition data on the seven main flavonoid classes (Haytowitz et al., 2018; Haytowitz et al., 2018; Department and Agriculture, 2015). 2) Phenol-Explorer is the second most commonly used database globally, but more frequently used in studies in Europe, which contains data on three additional flavonoid classes (chalcones, dihydrochalcones, and dihydroflavonols) with respect to USDA (French National Research Institute for Agriculture, 2015; Rothwell et al., 2013). 3) The Bioactive Substances in Food Information Systems (eBASIS) (EuroFIR, 2015; Plumb et al., 2017), an internet-deployed database with both compositional and biological activity data for bioactive substances. It contains flavonoid compositional data on seven subclasses. 4) The Indian Food Composition Table (IFCT) was built on the principle of 'key foods approach' to include those foods that contribute up to 75 % of the population's intake in India (Longvah et al., 2017). This compositional database comprises flavonoids data on five subclasses. These four FCTs were chosen for the comparison of flavonoid content. Another two identified databases, namely the EPIC FCT (Zamora-Ros et al., 2011) and FLAVIOLA (Vogiatzoglou et al., 2014) were excluded because their flavonoid data were obtained from Phenol Explorer and from the USDA flavonoid databases.

2.3. Matching of foods, data extraction and aggregation of flavonoid data

The foods that were used as a basis for the flavonoid content comparison were selected from the FFQ used in the BOLD Survey. The main version of the FFQ used in the BOLD survey contained 250 food items classified into 32 groups, which included separate sections to enquire consumption of fruits, vegetables, legumes, cereals, and other food groups, as per the EFCOSUM guidelines. Due to local adaptations to reflect consumption of traditional foods relevant to each country, the final list of foods was comprised of 396 items. Of these, 138 foods were recognized to have some flavonoid content and were therefore selected for this methodological study. A flavonoid-containing food included in the BOLD survey was matched to a food in a FCT if the name provided in the FCT clearly represented the food under consideration. This approach was used for the matching of all eligible foods, across all FCTs. Each FCT contained flavonoid estimates (per 100 g food) for each of the foods available in that table. In an effort to standardize the flavonoid content in each FCT, the raw (uncooked) form or the most generic form ('average') option was chosen for all foods. For example, for all fruits and vegetables, the reference food item used in each FCT was that reported for fresh (uncooked) fruit. The matching process review was routinely discussed within the research team to address queries and disagreements in the matching. For some traditional foods that did not have an obvious English translation, the Latin name was used to match it to its closest corresponding food in the FCTs. Subclasses of flavonoids were derived and aggregated to estimate the total flavonoid content of each food.

Data on flavonoid content in each of the four FCTs under comparison was harmonized to ensure that the content was expressed in mg/100 g foods. In eBASIS, content of flavonoid was expressed in mg/kg or μg/kg, therefore the flavonoid content was converted into the standard mg/100 g foods, using the conversion formula from FAO/INFOODS

Guideline (FAO/INFOODS, 2012b). Similarly, as the flavonoid content of some foods in Phenol Explorer was available as mg/100 ml, FAO/INFOODS Guideline (FAO/INFOODS, 2012b) and a density factor from FAO/INFOODS density database version 2 (FAO/INFOODS, 2012a) were used to standardize the content into mg/100 g of food. Foods that only reported flavonoid content as dry weight were excluded from comparisons.

In this study, the chemical form (whether glycoside and/or aglycone) was taken as reported in the selected FCTs without converting the reported values. The flavonoid content was reported as aglycones and/or glycosides in three of the four studied FCTs, namely Phenol Explorer (French National Research Institute for Agriculture, F. a. E., 2015; Rothwell et al., 2013), eBASIS (EuroFIR, 2015; Plumb et al., 2017), and IFCT (Longvah et al., 2017), whereas the USDA (Haytowitz et al., 2018; Haytowitz et al., 2018; Department and Agriculture, 2015) reported flavonoid content as aglycones only. In all FCTs, the catechin and epicatechin content was expressed as gallic acid esters i.e., as epicatechin gallate and epigallocatechin gallate, respectively (EuroFIR, 2015; French National Research Institute for Agriculture, 2015; Haytowitz et al., 2018; Haytowitz et al., 2018; Department and Agriculture, 2015; Plumb et al., 2017; Rothwell et al., 2013; Longvah et al., 2017).

2.4. Statistical Analyses

Levels of agreement in the content of total and subclass flavonoid of each table were used to compare flavonoid content (per 100 g of food) between FCTs. Comparisons were carried out across foods that were common (present) on all four tables, and between specific tables. For the latter, the USDA and the Phenol Explorer were used as reference tables for the US and Europe, respectively, and their flavonoid content was compared to that of each of the other three FCTs. Variations of flavonoid content were also investigated between the IFCT and eBASIS.

Bias percentage and a two-way mixed-effect model of intra-class correlation coefficients (ICCs; 95 % confidence intervals [95 %CI]) were calculated to quantify levels of agreement in the flavonoid content in each pair of FCTs under comparison. Bland-Altman plots were used to illustrate the magnitude of the mean differences between the FCTs (Bland and Altman, 1999), where %bias was calculated by dividing the

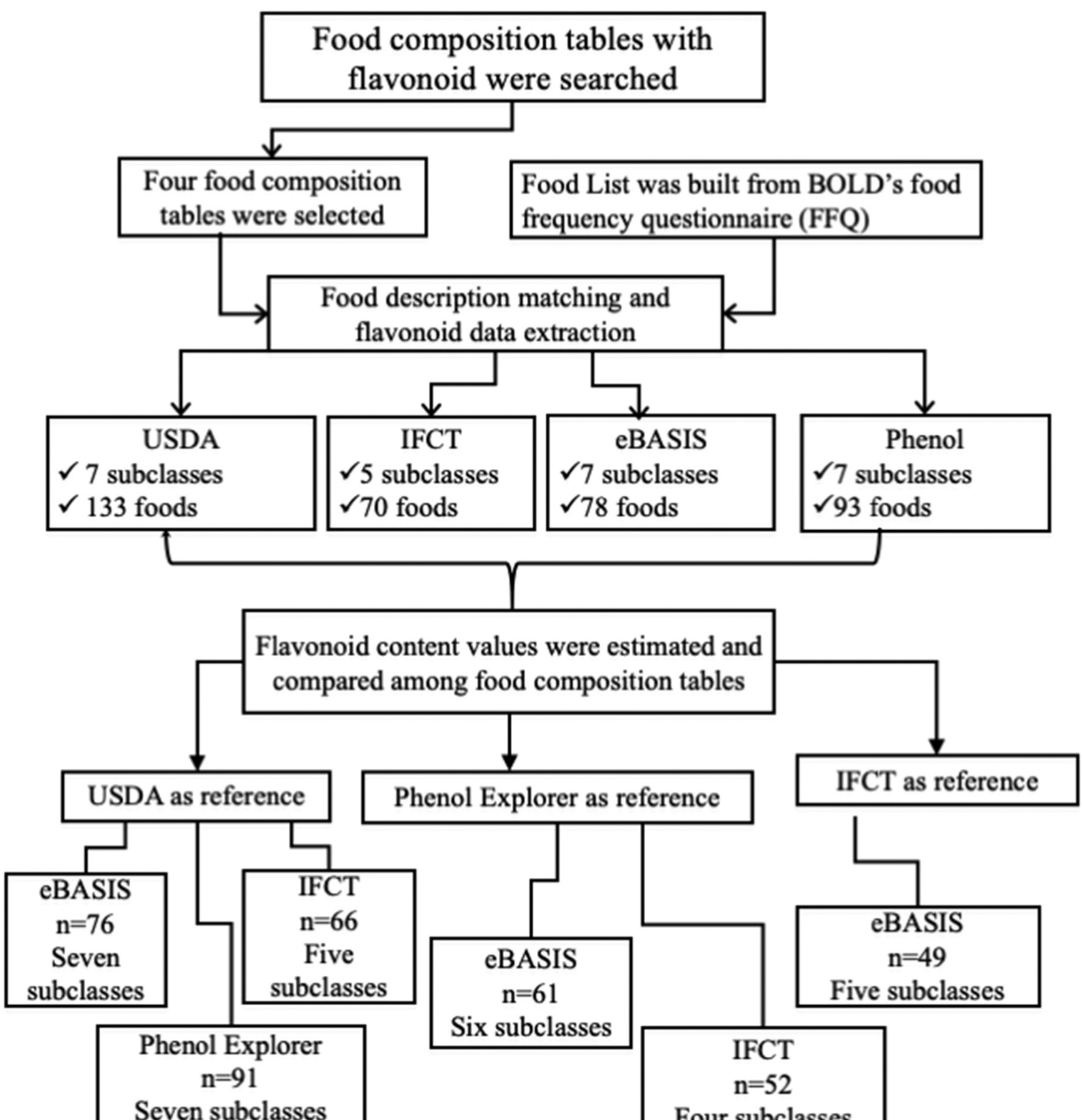

Fig. 1. Flowchart illustrating the comparison of flavonoid content for selected foods across the food composition tables under study.

estimated absolute difference in flavonoid content between FCTs by the mean of flavonoid estimates. ICC was categorized as indicating low (<0.5), moderate (0.50–0.75), good (0.76–0.90), or excellent (>0.90) level of agreement (Portney, 2020). The lower bound for 95 %CI of ICCs was truncated at zero value when the computed value was negative. The analyses were performed using Stata/IC 16.0.

3. Results

The general characteristics of the four FCTs included in this study namely USDA, Phenol-Explorer, eBASIS, and Indian Food Composition Table (IFCT), are described in Table 1. These databases have been set up with similar goals. USDA and IFCT present their polyphenol composition data as a single figure for each food item with a matched food description, allowing comparison with standard nutrient databases. However, Phenol Explorer and eBASIS provide the user with more detailed information on ranges, allowing a greater use for a variety of users. Phenol-Explorer includes useful summary statistics, whereas eBASIS covers raw data, enabling the user to choose their preferred methods of aggregation and statistical analysis of bioactive composition and bioeffects. With the exception of the IFCT, all tables used multinational data from peer-reviewed articles and from lab-confirmed estimates of flavonoid content to compile the datasets. The IFCT used national data from original lab-confirmed estimates (Table 1). The USDA table had flavonoid data available for most foods (n=133), whilst the IFCT had data available for the fewest (n=70) (Fig. 1).

Across tables, there were variations in the number of bio-compounds included in each subclass of flavonoids (Supplementary Table 1). The eBASIS and Phenol-Explorer tables included an extensive number of biocompounds within the anthocyanin and flavonol subclasses compared to the USDA table. The IFCT did not include anthocyanins.

There were 42 foods common to all four FCTs (Table2, Supplementary Table 2), with a variable number of foods available for the comparisons between two FCTs. The comparison of the flavonoid content of these 42 foods showed that the highest estimates of total flavonoid content was reported by eBASIS (934.33 mg/100 g) followed by Phenol Explorer (596.06 mg/100 g), IFCT (486.18 mg/100 g) and USDA (426.67 mg/100 g) (Table 2).

3.1. Comparison of Food Composition Tables for their flavonoid contents for selected foods

3.1.1. USDA as reference

The number of foods for total flavonoid content available for comparison with the USDA Table varied between 66 (IFCT) and 91 (Phenol-Explorer). All three tables showed low-to-moderate level of agreement for total flavonoid estimates when compared to the USDA tables (Table 3). Compared to USDA, Phenol-Explorer and IFCT table showed moderate-to-good level of agreement for flavanones, and low level of agreement for the flavonols (Table 3). eBASIS and IFCT tables showed a moderate level of agreement for isoflavones and low level of agreement for the flavones (Table 3).

Amongst flavonoid subclasses, the best level of agreement was observed with flavanones (Phenol-Explorer and IFCT), and with proanthocyanidins (Phenol-Explorer). Narrow confidence intervals for 95 % limit of agreement were reported in eBASIS, Phenol Explorer, and Indian FCT for isoflavones, flavones, and flavanols, respectively, when compared to the USDA table (Table 3, Figs. 2–4).

3.1.2. Phenol-Explorer table as reference

Compared to Phenol-Explorer, eBASIS and IFCT overestimated the content of most flavonoid subclasses (Table 4). The percentage bias for total flavonoids and for flavonoid subclasses of eBASIS and IFCT respect to Phenol Explorer varied from 10 % to 117 %. There was moderate-to-good level of agreement in the content of total flavonoids and anthocyanidins between Phenol-Explorer and eBASIS. IFCT showed moderate-to-good level of agreement for flavanols and flavanones, and low level of agreement for the other subclasses when compared to Phenol Explorer (Table 4). Flavanols in eBASIS and IFCT showed a narrow confidence interval for 95 % limit of agreement when compared to Phenol Explorer (Table 4, Figs. 5 and 6).

3.1.3. IFCT as reference, compared to eBASIS

Table 5 shows the comparison between IFCT and eBASIS. The level of

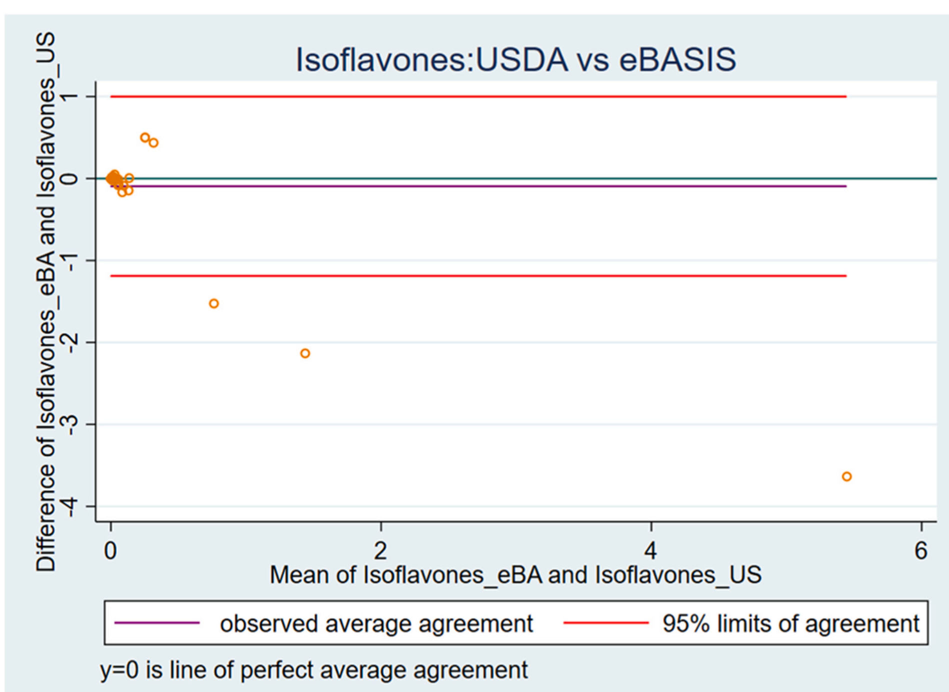

Fig. 2. Bland-Altman agreement between eBASIS and USDA for isoflavones content (mg) in 66 food items common for tables under study.

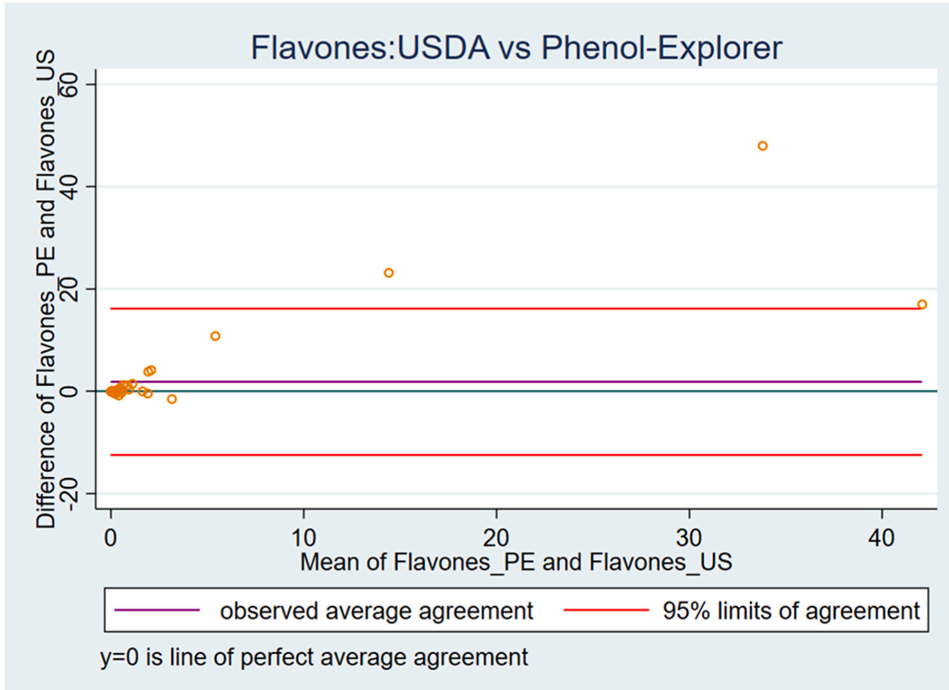

Fig. 3. Bland-Altman agreement between Phenol-Explorer and USDA for flavones content (mg) for 59 food items common for tables under study.

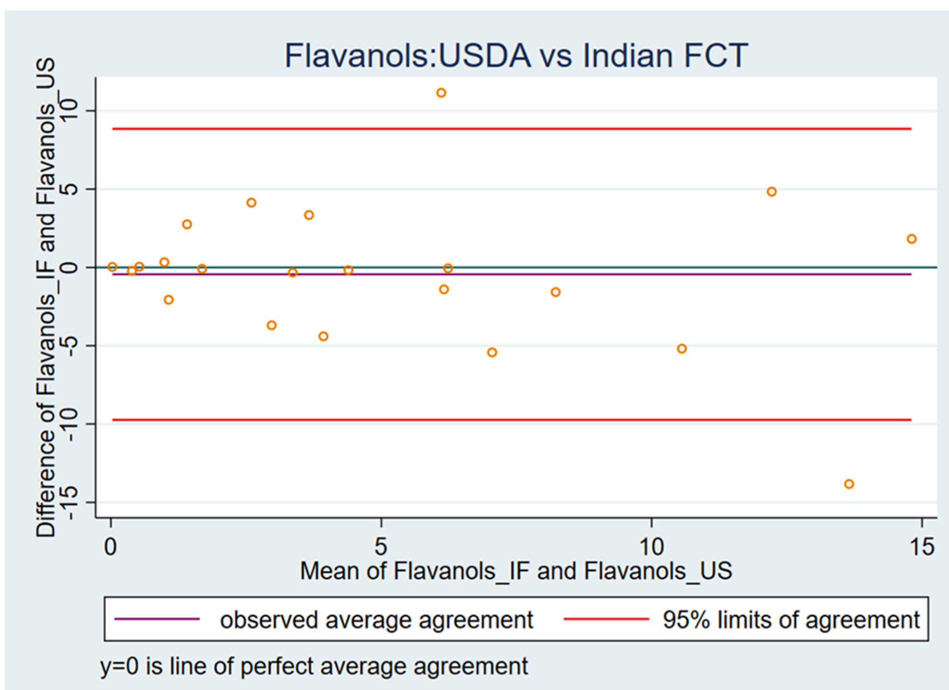

Fig. 4. Bland-Altman agreement between IFCT and USDA for flavanols content (mg) for 50 food items common for tables under study.

agreement for total flavonoid estimates between these two tables was poor, but eBASIS showed moderate-to-good level of agreement for flavanone and flavanol estimates. There was a low level of agreement for other flavonoid subclasses. Compared to the IFCT, flavonols and isoflavones were overestimated by nearly 28 % and 19 %, respectively, in eBASIS, whilst the content of flavones was underestimated by around 42 % (Table 5). For isoflavones, the Bland-Altman plots showed narrow confidence intervals for 95 % limit of agreement in eBASIS (Fig. 7).

4. Discussion

In this study, we investigated variations in the flavonoid estimates (mg/100 g edible food) in four international FCTs commonly used to derive intake of these bio-compounds in population-based surveys. We examined levels of agreement and variations in net content of total and subclasses of flavonoids from an extensive list of foods with known flavonoid content included in the BOLD FFQ. Our findings showed that there were variations in the content of flavonoids between tables.

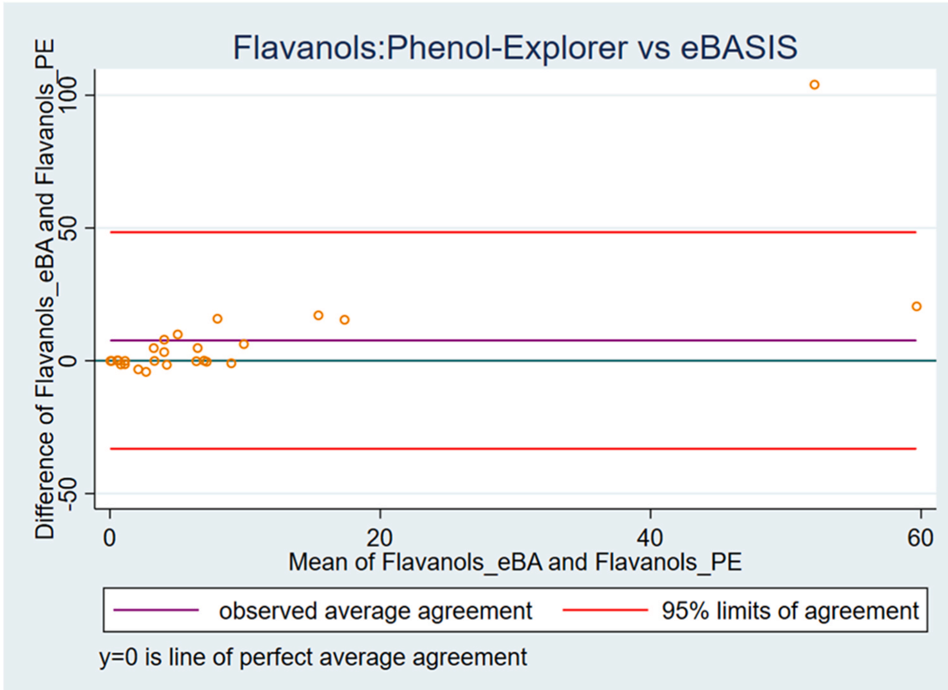

Fig. 5. Bland-Altman agreement between eBASIS and Phenol Explorer for flavonol content (mg) for 26 food items common for tables under study.

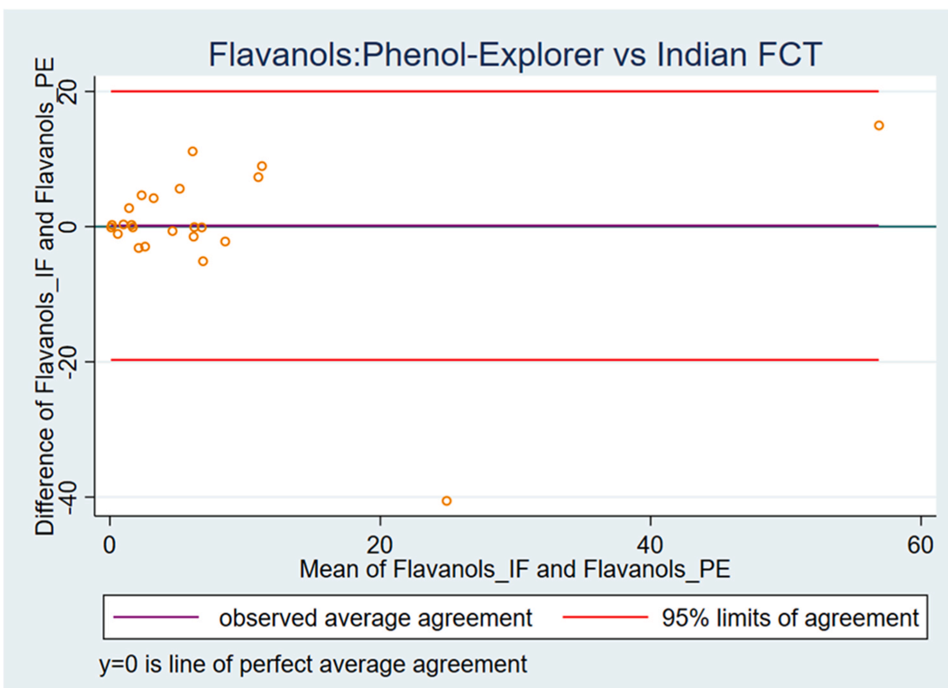

Fig. 6. Bland-Altman agreement between IFCT and Phenol Explorer for flavanols content (mg) for 23 food items common for tables under study.

Compared to the USDA table for example, the total and subclasses flavonoid content (mg/100 g edible food), varied between 4.43 % and 133.34 % in eBASIS, IFCT, and Phenol Explorer. In spite of the net differences in flavonoid content estimates, there was a low to moderate level of agreement between FCTs where most of the ICCs and 87.5 % of the comparisons had reported a low to moderate level of agreement; on the other hand, only 12.5 % of the comparisons had showed a good level of agreement.

There are several similarities in our findings and those from other studies. Ivey et al. (2016) reported a strong level of agreement between the USDA and Phenol Explorer for total flavonoid, flavanol, flavanone and anthocyanidin estimates in a study of elderly women. Another survey using dietary data estimated from adults (Anacleto et al., 2019) showed that the total flavonoid intake estimated by the USDA and Phenol-Explorer were similar (56.32 mg/day and 64.22 mg/day, respectively), whilst a study by Witkowska et al. (2015) reported that the flavonoid intake estimated using the USDA table was 30 % higher than the estimates generated with Phenol-Explorer. When comparing

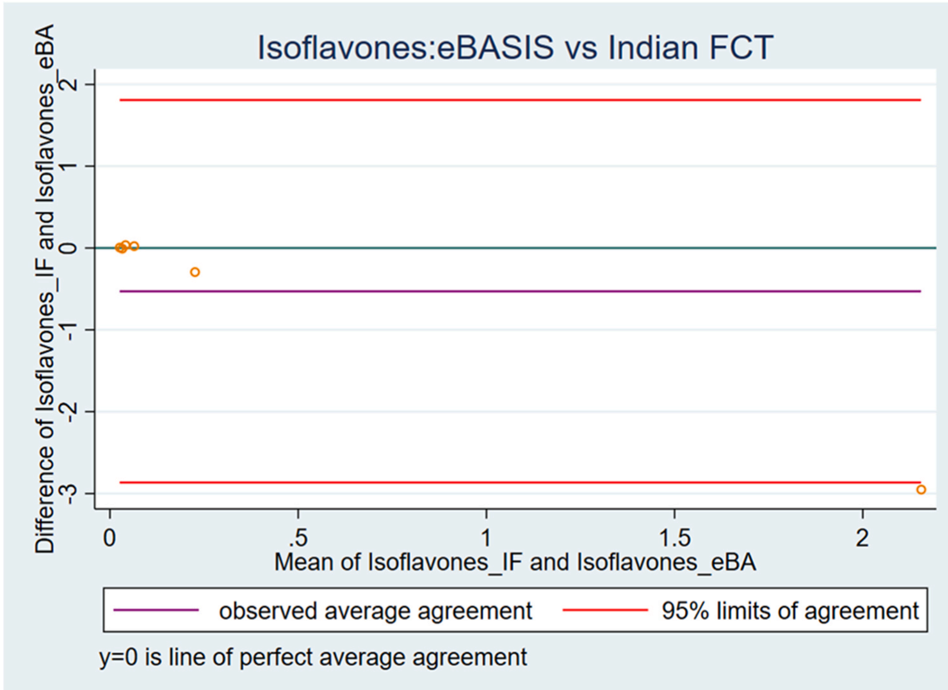

Fig. 7. Bland-Altman agreement between eBASIS and Indian IFCT for isoflavones content (mg) for 6 food items common for tables under study.

these two FCTs, we confirmed a moderate-to-good level of agreement for flavanone estimates, and found lower level of agreement for total flavonoids, flavanols and anthocyanidins.

Differences in the estimated flavonoid content of foods among surveys are likely to be influenced by several factors. These include the number and type of foods with flavonoid content included (Jun et al., 2016), differences in the versions used for the comparisons between FCT (e.g. older versions might have fewer estimates, and newer versions might include updated or more accurate estimates), analytical methods used to quantify content of flavonoids). In comparison to a study by Witkowska et al. (2015), our study included an extensive list of food items from an FFQ specifically designed to capture dietary intake of flavonoids. The larger number of foods we studied might have contributed to the greater differences observed in total flavonoid content.

Because of the wide range of potential benefits of some subclasses of flavonoids, researchers might be interested in specific flavonoid content of foods. Our study showed that FCTs had variations in the number of foods with flavonoid content, which is a relevant point to consider when deriving intake estimates in population-based surveys. There were only 42 food items with total flavonoid intake estimates common to all FCTs, and there were at least 66 foods available for comparison between FCTs. With the exception of the IFCT, all tables had data on anthocyanidins and proanthocyanidins.

Polyphenol content may vary due to natural and inherent differences due to the form of agriculture management (especially organic and conventional) (Faller and Fialho, 2010), and other factors include ripeness at harvest, environmental factors, processing and storage (Manach et al., 2004). The natural and inherent differences in content of polyphenol contents underscores that regional representativeness of flavonoid data might be important to consider when deriving flavonoid intake estimates in low-middle income countries. The IFCT is one of the few sources of flavonoid data outside high-income countries. The table, IFCT, showed relatively low levels of agreement in the estimates of flavone and flavonol content compared to the other three tables. These differences should be taken into consideration in studies ascertaining flavonoid intake in India, as the use of other tables might overestimate or underestimate the consumption of flavonoids in nutritional surveys in this country. The IFCT includes flavonoid content of foods representative of the country's usual diet.

Another methodological aspect that influences variations in the content of flavonoids in FCTs refers to the chemical form (aglycones or glycosides) included for flavonoids. Aglycone describes the core flavonoid, phenolic acid, lignan or stilbene, without the linked sugars or polyols. Although all four FCTs included flavonoid data in aglycone form, there were variations in the extent to which this information was available for all flavonoid subclasses across tables. In addition, some of the sources of flavonoid content were similar between tables, but they also used original or unpublished data. These factors might explain some of the higher-value biases we found in the reporting of proanthocyanidin content in eBASIS, flavones in IFCT when compared with their relative subclasses content in USDA.

FCTs of flavonoid content remain the main, and possibly one of the most helpful sources of information to estimate intake in population-based surveys. However, the limitations inherent to the variations in the methods and reporting of flavonoid data across FCTs, and those related to dietary instruments might reduce their level of agreement. To this end, new potential markers of flavonoid intake identified in urine and blood could contribute to improving the accuracy in the measurement of intake (Sandoval-Ramirez et al., 2020; Tahiri et al., 2020). Using the FFQ that is being administered in the BOLD study, we have identified several candidate markers of flavonoid and other polyphenolic compounds in sera, which can be used to calibrate the information provided in FCTs (Charles et al., 2021).

Flavonoid intakes vary greatly within and between populations (Peterson et al., 2015; Zamora-Ros et al., 2013), and improving our understanding on the variations between reference FCTs used to estimate flavonoid intake can contribute to reduce inconsistencies in the associations of flavonoids and health outcomes. Our study shows that there was a relatively low to moderate level of agreement across FCTs, but it also highlights the complexities associated with harmonizing data, and that content of flavonoid might differ across databases and specific foods (Peterson et al., 2015). It is, therefore, important to understand the particularities, advantages, and disadvantages of each database regarding the measurement of flavonoid content (Anacleto et al., 2019).

To our knowledge, this is the first study to compare the levels of agreement and variations in net estimates of flavonoids using four international FCTs. The findings from this study suggest that the choice of FCTs can influence the differences observed in the estimates of flavonoid content of foods. Our study has some limitations. Although we tried to harmonize the foods and flavonoids classes under comparison, unaccounted differences in data aggregation and comparability criteria within each table might have influenced some of the differences observed. Some of the aggregation of composition data might have resulted in over- or under- estimation. For example, the food item “apple” may have several composition variations due to its variety in pigments and species. In our study, the flavonoid estimate in different varieties of apples was aggregated into a single value, in order to give a generic estimate of this food item.

Due to the differences in reporting of flavonoid content (aglycones or glycosides), we were unable to consistently estimate content in one of the forms for all foods across all FCTs. International harmonization of chemical forms of flavonoids would facilitate comparisons that account for specific composition (Xiao, 2017).

5. Conclusions

In conclusion, our study found that several flavonoid subclasses showed low to moderate levels of agreement between FCTs, whilst very few (around five comparisons) had good levels of agreement. Methodological approaches in the measurement of flavonoid content of foods across tables, and continuous efforts to improve harmonization of these databases would contribute to improve quantification of flavonoid content.

6. List of abbreviations

BOLD – Burden of Obstructive Lung Disease
CARU – Comitato di Approvazione per la Ricerca sull’Uomo
CI – Confidence Intervals
COPD – Chronic Obstructive Pulmonary Disease
eBASIS – Bioactive Substances in Food Information Systems
EFCOSUM – European Food Consumption Survey Method
EPIC – The European Prospective Investigation into Cancer and Nutrition
EuroFIR – European Food Information Resource
F-PLUS – Flavonoids and Poor Lung function Study
FAO – Food and Agriculture Organization
FCT – Food Composition Table
FFQ – Food Frequency Questionnaires
GA^2LEN – Global Allergy and Asthma European Network
ICC – Intra-class correlation coefficients
IFCT – Indian Food Composition Tables
IFCT2017 – Indian Food Composition Table 2017 release
INFOODS – International Network of Food Data Systems
USDA – United State Department of Agriculture

Ethics approval and consent to participate

This methodological study, which did not include human subjects, or their data, is part of the Flavonoids and Poor Lung function Study (F-PLUS) project, for which ethical approval was obtained from the Review Board for Research involving Human Participants of the University of Verona (2019-UNVRCLE-0419163) (CARU - Comitato di Approvazione per la Ricerca sull’Uomo).

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CRediT authorship contribution statement

Maria Elisabetta Zanolin: Writing – review & editing, Supervision, Methodology, Investigation, Formal analysis, Conceptualization. **Mulubirhan Assrfa Alemayohu:** Writing – review & editing, Writing – original draft, Visualization, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Vanessa Garcia-Larsen:** Writing – review & editing, Supervision, Investigation, Data curation, Conceptualization. **Peter Burney:** Writing – review & editing, Investigation, Conceptualization. **Jenny Plumb:** Writing – review & editing, Visualization, Validation, Resources, Data curation. **K Bhaskarachary:** Writing – review & editing, Validation, Resources, Data curation. **Veronica Mattioli:** Writing – review & editing, Validation, Data curation. **Francisca Castro Mendes:** Writing – review & editing, Validation, Data curation. **Liliya Chamitava:** Writing – review & editing, Validation, Data curation. **Lucia Cazzoletti:** Writing – review & editing, Supervision, Methodology, Investigation, Formal analysis, Conceptualization.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper. The research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Data Availability

Data will be made available on request.

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Author contributions

V.G.L designed the study (project conception, development of overall research plan, and study oversight). M.A.A., M.E.Z and V.G.L, carried out research. M.A.A, L.C. and M.E.Z. analyzed data. J.P. and K.B. facilitated food composition datasets under study and contributed to their interpretation and analysis. M.AA wrote the first manuscript draft. L.C., M.E.Z., L.Ch., F.C.M., V.M., K.B. contributed to within and between dataset checking, and to the decisions on estimates used in each table. L. C., L.Ch., F.C.M., V.M., J.P., K. B. and P.G.J.B. contributed to the interpretation of results and discussion. V.G.L. has primary responsibility for the manuscript’s final content. All authors have read and approved the final manuscript.

Appendices

Table 1
Summary characteristics of included food composition tables (data extracted on 2020/21)

	Food composition table included in the study comparison			
	eBASIS	**IFCT**	**Phenol Explorer**	**USDA**
Tables and/or databases version	EuroFIR BASIS	2017 Updated version	version 3.6	Flav_R03–3; Isoflav_R2–1; PA02–1
Coverage	Multi-country	India	Multi-country	Multi-country
Data Source	Extracted from peer-reviewed publications	Survey and laboratory-based	Collected from scientific publications	Obtained from published and unpublished data
No of food items reported with measurable data	215	247	326	506; 560; 285
Unit of expression used to report values	mg/kg; μg/kg; mg/l; μg/l; μmole/kg[Π]; μmole/l;	mg/100 g	mg/100 g; mg/100 ml	mg/100 g
Value reported	Individual	Aggregated*	Aggregated*	Aggregated*
Quality evaluation[#]	A, B, C, U	na	Acceptable	A, B, C, D
Flavonoid reporting form				
Aglycon	✓	✓	✓	✓
Glycosylation	✓	✓	✓	×
Fresh weight	✓	✓	✓	✓
Dry weight	✓	×	×	×
Flavonoid subclasses (mg/100 g)				
Anthocyanins	✓	×	✓	✓
Flavanols	✓	✓	✓	✓
Flavonols	✓	✓	✓	✓
Flavanones	✓	✓	✓	✓
Flavones	✓	✓	✓	✓
Chalcones	×	×	✓	×
Dihydrochalcones	×	×	✓	×
Isoflavones	✓	✓	✓	✓
Dihydroflavonols	×	×	✓	×
Proanthocyanidins	✓	×	✓	✓

* Mean content values were reported by aggregating reported data for various foods with matched food descriptions. This reports a single value estimate for specific flavonoid compound of a given food.
[#] Flavonoid compositional data were evaluated for quality and were categorized based on the information retrieved from the primary data source. (1) **eBASIS**: 'A'-reliable and meet all five criteria being rated as acceptable, 'B'- study with some limitations, 'C' study with serious limitations, and 'U'-insufficient information; (2) **USDA**: the quality was rated and categorized based on quality index as 'A'- 75–100, 'B' 74–50, 'C' 49–25, and 'D' <25. (3) **Phenol Explorer**: The data filling specified minimal requirements set were considered as acceptable and selected for aggregation. In the case of **IFCT**, it is not applicable.
Π - In eBASIS for individual compounds a conversion is made from mole to mg to help the user

Table-2
Flavonoid content of common foods by food composition tables under study

	Total flavonoid content estimate of foods (mg)			
	eBASIS	**IFCT**	**Phenol Explorer**	**USDA**
Total Flavonoids (n=42)	934.33	486.18	596.06	426.67
Flavanols (n=17)	121.24	92.71	67.49	106.00
Flavanones (n=2)	173.35	94.53	75.95	50.08
Flavones (n=12)	223.53	33.03	56.65	39.80
Flavonols (n=28)	310.32	141.92	325.37	178.95
Isoflavones (n=6)	4.13	0.96	*	10.05

n -number of food items common for tables under comparison
*No isoflavones estimates available in Phenol-Explorer for the foods common to the other three tables

Table 3
Bias, Intra-class correlation coefficients and limits of agreement of flavonoid FCTs using USDA as reference

Flavonoids	n	%bias[Φ]	Intra-class correlation coefficients (95 %CI)	95 % Limits of Agreement
USDA and eBASIS				
Total Flavonoids*	76	-5.24	0.46 (0.32, 0.61)	-172.62–185.65
Anthocyanidins	22	56.59	0.33 (0.12, 0.55)	-202.13–262.57
Flavanols	27	24.68	0.02 (0.00[T], 0.20)	-35.49–45.42
Flavanones	7	32.22	0.27 (0.00[T], 0.59)	-78.60–115.78
Flavones	34	44.68	0.31(0.27, 0.35)	-51.56–63.00
Flavonols	50	47.03	0.004 (0.00[T], 0.08)	-116.02–142.50
Isoflavones	66	73.71	**0.72 (0.66, 0.77)**	-1.19–0.99
Proanthocyanidins	11	-133.34	0.02 (0.00[T], 0.010)	-193.57–70.17
USDA and Phenol Explorer				
Total Flavonoids*	91	-18.75	**0.50 (0.35, 0.63)**	-366.81–404.56

(continued on next page)

Table 3 (*continued*)

Flavonoids	n	%bias$^{\phi}$	Intra-class correlation coefficients (95 %CI)	95 % Limits of Agreement
USDA and eBASIS				
Anthocyanidins	18	27.39	0.14 (0.00^{T}, 0.61)	-233.77–259.22
Flavanols	57	-14.54	0.03 (0.00^{T}, 0.01)	-371.48–426.87
Flavanones	19	-23.55	**0.87 (0.77, 0.95)**	-14.15–19.21
Flavones	59	15.95	**0.57 (0.47, 0.67)**	-12.46–16.16
Flavonols	68	-12.64	0.21 (0.01,.40)	-41.43–49.85
Isoflavones	9	6.82	0.32 (0.00^{T}, 0.76)	-147.39–111.70
Proanthocyanidins	45	4.43	**0.89 (0.83, 0.95)**	-171.37–161.83
USDA and IFCT				
Total Flavonoids*	66	46.15	**0.57 (0.44, 0.70)**	-44.25–45.89
Flavanols	22	7.38	**0.55 (0.26, 0.85)**	-9.73–8.85
Flavanones	5	68.51	**0.73 (0.26, 0.98)**	-23.25–41.48
Flavones	31	106.73	0.38 (0.21, 0.54)	-9.32–10.42
Flavonols	50	38.77	0.47 (0.28, 0.66)	-16.5–15.28
Isoflavones	9	-47.11	**0.61 (0.48, 0.73)**	**-111.02–77.09**

$^{\phi}$ % bias- Flavonoid estimate absolute difference divided by the mean of estimate
n -number of food items common for tables under study and the Target in intraclass correlation coefficients estimation
* Total Flavonoids – Flavonoid estimated from 7 subclasses except for IFCT from 5 subclasses
In bold- moderate to excellent level of agreement
^{T} A common ad-hoc method of truncating at zero value was applied when the lower bound for 95 %CI of ICCs was computed as negative

Table 4
Bias, intra-class correlation coefficients and levels of agreement of flavonoid FCTs using Phenol Explorer as reference

Flavonoids	n	%bias$^{\phi}$	Intra-class correlation coefficients (95 %CI)	95 % Limits of Agreement
Phenol Explorer and eBASIS				
Total Flavonoids*	61	10.16	**0.67 (0.51, 0.79)**	-172.66–177.98
Anthocyanidins	10	55.29	**0.85 (0.51, 0.96)**	-164.78–204.61
Flavanols	26	31.66	0.30 (0.00^{T}, 0.60)	-33.16–48.41
Flavanones	6	11.11	0.35 (0.00^{T}, 0.88)	-98.33–118.18
Flavones	28	89.78	0.42 (0.06, 0.68)	-57.25–65.50
Flavonols	40	77.91	0.24 (0.00^{T}, 0.51)	-121.16–142.71
Isoflavones$^{\theta}$	1	-		-
Proanthocyanidins	9	-117.10	0.04 (0.00^{T}, 0.56)	-247.11–102
Phenol Explorer and IFCT				
Total Flavonoids*	52	50.15	0.38 (0.12, 0.59)	-55.92–51.52
Flavanols	23	17.39	**0.71 (0.42, 0.86)**	-19.70–20.01
Flavanones	4	14.18	**0.85 (0.00^{T}, 0.99)**	-29.12–38.20
Flavones	25	91.83	0.16 (0.00^{T}, 0.52)	-21.32–22.31
Flavonols	43	60.21	0.03 (0.00^{T}, 0.32)	-55.35–44.85
Isoflavones$^{\theta}$	1	-		-

$^{\phi}$ % bias- Flavonoid estimate absolute difference divided by the mean of estimate
n -number of food items common for tables under study and the Target in intra-class correlation coefficients estimation
* Total Flavonoids – Flavonoid estimated from 7 subclasses except for IFCT from 5 subclasses
$^{\theta}$ Isoflavones have not been estimated for insufficient data (food in common) for this comparison
In bold- moderate to excellent level of agreement
^{T} A common ad-hoc method of truncating at zero value was applied when the lower bound for 95 %CI of ICCs was computed as negative

Table 5
Bias, intra-class correlation coefficients and levels of agreement of flavonoid FCTs comparing IFCT and eBASIS

Flavonoids	n	%bias$^{\phi}$	Intra-class correlation coefficients (95 %CI)	95 % Limits of Agreement
Total Flavonoids*	49	-18.01	0.37 (0.11, 0.58)	-65.65–83.38
Flavanols	19	-6.38	**0.89 (0.73, 0.95)**	-12.8–16.01
Flavanones	2	-1.06	**0.67 (0.00^{T}, 0.99)**	-101.65–180.47
Flavones	17	-41.70	0.07 (0.00^{T}, 0.52)	-82.18–103.78
Flavonols	37	28.19	0.33 (0.03, 0.58)	-22.53–31.27
Isoflavones	6	18.66	0.34 (0.00^{T}, 0.86)	-1.80–2.86

$^{\phi}$ % bias- Flavonoid estimate absolute difference divided by the mean of estimate
n -number of food items common for tables under study and the Target in intra-class correlation coefficients estimation
* Total Flavonoids – Flavonoid estimated from 7 subclasses except for IFCT from 5 subclasses
In bold- moderate to excellent level of agreement
^{T} A common ad-hoc method of truncating at zero value was applied when the lower bound for 95 %CI of ICCs was computed as negative

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