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Development of a flavour wheel for *Coffea canephora* using rate-all-that-apply

Fabiana M. Carvalho[1]✉, **Enrique A. Alves**[2], **Mateus M. Artêncio**[3], **Alvaro L. L. Cassago**[4] & **Lucas L. Pereira**[5]

Improving *Coffea canephora* cup quality became a target for several coffee improvement programs, opening the possibility of sensory profile diversification and opportunities for the recognition of *C. canephora* by the specialty coffee market. Nonetheless, there is a lack of a defined descriptive tool for evaluating the sensory quality of *C. canephora*. The aim of this study was to identify the aroma/flavour descriptors of *C. canephora* samples from 13 different countries of origin and submitted to various postharvest processes (dry and wet processing), with different quality levels (specialty and non-specialty), and organize them in a aroma/flavour wheel for use as a descriptive tool in quality assessment. Altogether, 49 professional coffee graders in both exporting (Brazil) and importing (Switzerland) countries evaluated and described 67 samples in 3 cupping sessions. They used a Rate-All-That-Apply (RATA) list as well as the CQI standard cupping protocol for quality assessment of overall attributes (e.g., aroma, flavour, body, aftertaste) and the final quality score (0–100). A total of 103 descriptors were represented in the three-tiered wheel. 'Roasted' was the Tier 1 category with the highest average mean score, followed by 'sweet', 'fruity', 'cocoa', all the way to 'salty' (the Tier 1 category with the lowest average mean score). The differences between exporting and importing graders regarding (1) the use of descriptive terms, (2) the rated intensity/frequency of certain aroma/flavour categories, and (3) the final score given to both low-grade (i.e., commercial) and specialty coffee samples are discussed. The aroma/flavour wheel can be used as a tool to identify, understand, and map the sensory characteristics of *C. canephora* that are most important or valued in different markets. Standardizing the description of *C. canephora* aroma/flavours in a replicable way is important not only for the coffee industry but also for scientists working on quality improvement.

Keywords Coffee, Specialty coffee, Robusta, Flavour wheel, Rate-all-that-apply

Coffee is one of the most appreciated and consumed beverages in the world, and it is commercially produced in more than 50 countries. The revenue of the coffee market worldwide is estimated to amount USD 461.20 billion in 2024, and it is driven by increasing consumption, both at-home and out-of-home, especially in emerging markets like Asia Pacific[1]. Over 100 coffee species under the genus Coffea have been described by botanists since the sixteenth century, and the global production is based on four species: Arabica (*Coffea arabica* L), Robusta/Conilon (*C. canephora*), Liberica (*C. liberica*), and Excelsa (*C. dewevrei*). The two most important species of coffee in economic terms are *C. arabica* and *C. canephora*, which comprise ~ 55% and ~ 44% of the market, respectively[2].

The species *C. arabica* and *C. canephora* differ deeply in terms of genetics (polyploid for the former, diploid for the latter)[3], required edaphoclimatic conditions[4], as well as metabolic and biochemical processes of fruit development and ripening[5–7]. Therefore, differences regarding flavour precursors in the green beans of the two species will emerge, which in turn will impact the roasting chemistry and the sensory characteristics of the final beverage[8,9]. The necessity to develop resistant varieties to disease, such as Typica and Bourbon, has been the main

[1]Department of Food Science and Nutrition, Faculty of Food Engineering, State University of Campinas, UNICAMP-FEA, Rua Monteiro Lobato, 80, Cidade Universitária, Campinas, SP 13083-862, Brazil. [2]Rondônia Agroforestry Research Center, Brazilian Agricultural Research Corporation (EMBRAPA), Porto Velho, RO, Brazil. [3]Department of Business Administration, School of Economics, Business Administration and Accounting of Ribeirão Preto, University of São Paulo (USP), Ribeirão Preto, SP, Brazil. [4]Department of Pharmaceutical Sciences, School of Pharmaceutical Sciences of Ribeirão Preto, University of São Paulo (USP), Ribeirão Preto, SP, Brazil. [5]Federal Institute of Education Science and Technology of Espírito Santo (IFES), Venda Nova do Imigrante, ES, Brazil. ✉email: bibimesq@gmail.com

motivation behind breeding programs for *C. arabica*, whereas for *C. canephora* the strict self-incompatibility has been the main determinant for breading strategies (see[10,11] for reviews on Coffea genus genetic diversity). Despite being popularly referred to as 'robusta', the species *C. canephora* has two distinct botanical varieties—Conilon and Robusta—that are commercially cultivated and have different beverage quality traits[12,13].

The coffee commercial sector encompasses both commodity and specialty products. Commodity coffees dominates the market, with the global market size for specialty coffees being estimated to comprise ~10%[14]. Specialty coffee is defined as coffee grown in unique and ideal climates, with distinctive taste and flavor, and with little to no defects[15]. Nonetheless, when referring to high quality coffees, the terminology 'specialty' concerns specifically *C. arabica*, whereas the terminology 'fine' is applied to *C. canephora* to differentiate between 'specialty arabica' and 'fine robusta'[16]. In either case, the differentiation between low and high quality coffee is determined by strict criteria for physical quality and sensory characteristics as specified in grading and cupping protocols developed by the Specialty Coffee Association (for *C. arabica*[17,18]) and the Coffee Quality Institute (for *C. canephora*[19]).

According to Fonseca and collaborators[20], *C. canephora* has been historically less valued than *C. arabica* for being mistakenly considered to be a worse product in terms of quality, forcing it towards highly commoditized markets. This assumption of 'low quality' has deflected the capture of *C. canephora* by alternative supply chain mechanisms (e.g., fair trade, direct trade) and weakened the motivation for quality improvement, common in the market of specialty arabica coffee. Indeed, when discussing the potential for quality of *C. canephora*, it must be taken into account that its genome, chemical composition, as well as crop and postharvest practices have been far less studied compared to *C. arabica*, mainly regarding standard procedures and/or potential markers for cup quality[21–24]. Historically, for being stigmatized as a commodity coffee, *C. canephora* has been subjected to inappropriate postharvest processing practices, leading to defective beans and negative flavour attributes[25,26]. Only recently, improving *C. canephora* cup quality, alongside *C. arabica*, became a target for several coffee improvement programs[27]. Studies have shown that *C. canephora* grown in different terroirs[28,29] and subjected to controlled fermentative postharvest process[30,31] have improved the quality of the final beverage. These results open the possibility of sensory profile diversification and opportunities for the acceptance and recognition of *C. canephora* by the specialty coffee market (i.e., traders, roasters, and consumers) (e.g., Ref.[32]).

C. canephora production has increased significantly over the last three decades, rising from ~ 25% in the early 1990s to ~ 44% in 2023[33], with a striking 3.6% jump from 2019 to 2023[2]. In fact, a number of studies have suggested that *C. canephora*, a plant that is resistant to weather changes, high temperatures and dry seasons, may increasingly serve as an alternative to *C. arabica*, a plant that is sensitive to the changes of climate, not able to withstand high temperatures or extended periods of drought[34–36]. Recent climate change models predict that increasing temperature and rainfall variability will drastically reduce the bio-climatic suitable areas, growth and yield of *C. arabica*[37]. Thus, to support sustainable production for the global coffee industry, more in-depth research for *C. canephora* is required. As posited by the World Coffee Research, "with soaring demand at center stage, alongside the expected negative effects of climate change and limited historical investment in coffee agricultural innovation, an expanded role for robusta [*C. canephora*] in the global coffee market is both practical and necessary"[27].

Along with the current challenge faced by the producing countries to elevate *C. canephora* to its fine/specialty status, it is also crucial that its sensory evaluation is carried out according to standardized methods. As aforementioned, both *C. arabica* and *C. canephora* have their own cupping protocol for quality assessment, which will assign coffees to the categories 'specialty/fine' and 'commercial'. In the recent years, sensory standard procedures for *C. arabica* have improved, such as the new Coffee Value Assessment created by the Specialty Coffee Association[17]. In particular, a lexicon for brewed coffee was developed[38] and used to update the coffee flavour wheel[39], which has been the main tool for the coffee industry to conduct descriptive sensory evaluation to improve the understanding of coffee quality. The coffee lexicon was developed using 105 coffee samples divided into four sets: "The first set included 13 arabica samples from the region of Pitalito, Colombia. Set 2 included 45 commercial coffees (Arabica, robusta, and blends), set 3 included 27 speciality coffees samples (arabica) from different parts of the world, and set 4 included 20 arabica coffee samples from the San Adolfo, Colombia region." (Ref.[38], p.466). Both commercial and specialty coffees were included in the study in order to cover both positive and negative attributes of aroma, taste and mouthfeel of coffees. Nonetheless, it is important to note that only commercial robusta coffee samples were used to create the flavour wheel. Commercial coffees are low quality coffees and, as stated by Hetzel (Ref.[40], p.30), "the lower end of the [quality] scale (0.25 to 5.75) is applicable to commercial coffees, which are cupped primarily for the assessment of defect types and intensities". Thus, any positive aroma, taste, and mouthfeel attributes of robusta coffees have not been represented neither in the coffee lexicon nor in the most recent version of the coffee flavour wheel.

Recently, it has been observed that the industry-standard coffee flavour wheel (i.e., Ref.[39]) may not be suitable for coffee beverages produced from different *Coffea* species, such as *C. congensis*[41]. As an anecdotal observation, when graders are trying to describe the differences between the flavour characteristics of high quality *C. arabica* and *C. canephora* beverages, they commonly refer to the differences between white and red wines as an analogy, with *C. arabica* being perceived as 'more delicate' and *C. canephora* as 'deeper'. This has been demonstrated by Vezzulli and collaborators[9] who investigated the impact of different extraction methods on the sensory profile of beverages from *C. arabica* and *C. canephora*. When comparing the sensory descriptors for the espresso beverages, for example, they observed that the *C. arabica* espresso received higher scores for acidity, fruity, floral, and honey notes, whereas the *C. canephora* espresso was rated as being higher in overall aroma, positive aromas, aroma persistence as well as in bitter taste, nutty, dried fruits, vegetal/herbal, and cocoa notes. Another important difference is the anecdotal observation by coffee professionals of positive 'savoury' or 'umami' notes in *C. canephora* (e.g., shoyu, tomato)[42], which are not represented in the *C. arabica* flavour wheel.

Therefore, there is a lack of a defined descriptive tool for evaluating the sensory quality of *C. canephora*. As a practical visual tool for identifying and describing flavour characteristics of food products, the flavour wheel represents these characteristics of tested samples by collecting, classifying, summarizing, and sorting specific sensory attribute descriptors[84]. It is an important means of a common and appropriate vocabulary for descriptive analysis (e.g., identification and description of both positive and negative characteristics) and also a reliable basis for communication between producers, traders, and consumers[44]. In addition, despite the relatively recent standardization of the cupping protocol, coffee quality has historically been characterized by different grading systems established in countries of origin (i.e., exporting) and in importing countries[45]. Furthermore, it has been shown that cultural differences can impact the description of food products by trained panelists[46,47].

The present study aims to:

(i) Identify the aroma/flavour descriptors of *C. canephora* samples from 13 different countries of origin and submitted to various postharvest processes, with different quality levels, and organize them in an aroma/flavour wheel for use as a descriptive tool in quality assessment.
(ii) Investigate differences in description as well as quality scores attributed to the *C. canephora* samples by professional exporting and importing coffee graders.

We used a rate-all-that-apply (RATA) list of descriptors for selection and rating of intensity of aroma/flavour attributes applicable to the samples[48,49]. Finally, we used the *C. canephora* standard cupping protocol[19] for quality assessment of overall attributes (e.g., aroma, flavour, body, aftertaste) as well as the final quality score.

Materials and methods

Participants

A total of 49 professional coffee graders took part in the experiment (mean age = 32.7 ± 9.5; 24 female, 25 male) after their informed consent was obtained. The study was approved by the Research Ethics Committee at Plataforma Brasil and was performed in accordance with the Declaration of Helsinki. Forty graders were certified Q graders and/or R graders. A certified grader is a coffee professional skilled in sensory evaluation of coffee. Certified graders share a common knowledge in product quality, analysis of flavour profiles and consistency through evaluation. They are also trained in the use of a common language of quality, which facilitates communication between producers and buyers (for further information, please visit https://www.coffeeinstitute.org/certification). An individual who is credentialed by the Coffee Quality Institute (CQI) to grade and score coffees is able to utilize pre-defined standards for arabica (Q) and robusta/canephora (R). In this evaluation, grades on a hedonic/quality scale of zero to ten (Anchors: 5–5.75: Average; 6–6.75: Good; 7–7.75: Very good; 8–8.75: Excellent; 9–10: Outstanding) are awarded for the given attributes. Each attribute worth 10 points, so that evaluations are based on a 100-point scale (for more details on the cupping protocols for *C. arabica* and *C. canephora*, please see Ref.[16]). In addition, only professional graders (certified or not) who had been grading and tasting both *C. arabica* and *C. canephora* for at least 2 years were included in the study. The graders were recruited according to the type of coffee business they are involved with, namely, exporting or importing. A total of 31 graders, all from Brazil, have been working in coffee exporting in Brazil, and 18 graders, from various nationalities, have been working in coffee importing in European Union countries (graders from the EU: 5 from Switzerland, 3 from Italy, 3 from the Netherlands, 2 from Germany; graders from outside the EU (all working in Switzerland): 1 from Brazil, 2 from Colombia, 1 from Costa Rica, 1 from Guatemala) (Supplementary Table S1).

Coffee samples

A total of 67 *C. canephora* samples were evaluated in three separate cupping sessions. The samples used were sourced from 13 countries-of-origin (Brazil, Congo, Costa Rica, Cuba, Ecuador, Ghana, Guatemala, India, Indonesia, Mexico, Peru, Uganda, Vietnam) and were transported between countries as green (unroasted) coffee beans in vacuum packaging. To ensure that the samples would represent the wide range of flavour attributes found in *C. canephora*, coffees varying in (1) quality level (from low to high quality coffee samples), (2) postharvest processing method (dry and wet processing), and (3) producing sites on three continents (South and Central Americas, Africa, and Asia) were chosen for the study.

A set of 34 samples was assessed in the first cupping session by two different groups of graders in two different locations: Brazil (exporting graders) and Switzerland (importing graders) (see "Experimental procedure"). The samples were subjected to the roasting and sensory evaluation process according to the protocol developed by the Coffee Quality Institute (CQI) along with the Uganda Coffee Development Authority (UCDA)[16,19]. One noticeable difference between *C. arabica* and *C. canephora* cupping protocols is the evaluation of the attributes acidity and sweetness. For *C. canephora*, acidity and sweetness are evaluated in a relative balance against saltiness and bitterness, respectively (i.e., Acid/Salt ratio; Sweet/Bitter ratio) which does not apply to *C. arabica* (see Supplementary Fig. S1). In order to ensure sample consistency between locations, the coffees were roasted on a Probatino P5 roaster (Brazil) and Probat Sample roaster BRZ4 (Switzerland) (both from Probat Ltd., Emmerich, Germany) following the same roasting curve, generated at the roasting software Cropster (Cropster GmbH, Innsbruck, Austria), as a guidance to achieve the same coloration. The roasting point of the coffees was then visually determined at 58 point coloration in the Agtron scale (SCA/Agtron Roast Color Classification System). The coffees samples were prepared according to the pre-determined ratio of 8.75 g per 150 mL of water (92–94 °C). The water used in all cupping sessions was in accordance to the specifications by the SCA[18] (Supplementary Table S2).

A second set of 33 samples was assessed in the second cupping session by Brazilian (exporting) graders only. In addition to coffees that were roasted the day before the session (according to the CQI/UCDA protocol), this sample set also included coffees that were roasted either 3 months or 6 months prior to the sensory evaluation.

It has been shown that the coffee aroma/flavour starts deteriorating after roasting, and the purpose was to introduce aroma/flavour nuances that are result of oxidative degradation (e.g., stale, rancid) and are usually deemed as negative[50].

Elaboration of rate-all-that-apply (RATA) list

The RATA list used in the cupping sessions was constructed based on two sources of reference for the terms, namely, prior database and published research. The prior database included data from prior cupping sessions of 2300 coffee samples performed at the Federal Institute of Espirito Santo by a group of 15 certified graders, from 2019 to 2023. The database contained cupping scores as well as aroma and flavour descriptors resulted from the sensory evaluation of Brazilian *C. canephora* from both Espirito Santo (var. conilon) and Rondonia (var. robusta). The original database was split into two datasets according to the quality level assigned to the samples (Table 1). Samples scoring 85 + were grouped together in one dataset (n = 300) whereas samples scoring from 70 to 83 were grouped together in a separate dataset (n = 2000). According to the CQI/UCDA robusta cupping protocol, coffees graded as 85 + are classified as 'fine' and 'outstanding', whereas coffees ranging from 70 to 83 are classified within a wider spectrum going from 'average' to 'very good'[19]. Only descriptive terms related to coffee aroma and flavour were included in the analysis. In this way, terms related to mouthfeel (e.g., smooth, astringent) and to the overall impression of the coffee (e.g., clean, balanced) were filtered out. Frequency counts for both datasets were then performed, and the observed frequencies were normalized (i.e., expressed as percentage) for the sake of accurate comparison between datasets as well as between descriptors within the same dataset. The second source of RATA terms was the available research on the development of coffee lexicons and/or flavour wheel[38,39,51].

Guided by the aforementioned previous studies, the descriptors extracted from the prior database were then classified into a three-tiered hierarchy (Table 1). The first level constitutes the most more general aroma/flavour categories (i.e., sweet, fruity, roasted, cocoa, fermented, spices, vegetal, floral, woody, umami, animalic, mold/paper, burnt, and chemical) whereas the second level refers to more specific subcategories (e.g., fruity—citrus fruit; roasted—nutty). These categories and subcategories can be referred to as 'umbrella' terms[39]. The third level is composed by the specific descriptor. Examples of specific descriptors were also included for each aroma/flavour category and subcategory in the RATA list, as well as 'other' to make it explicit that the grader could add a descriptor absent from the list. The complete RATA list is depicted in Fig. 1B. A 7-point scale was used instead of a 3- or 5-point scale to allow more precise discrimination between samples with subtle differences[52,53].

Experimental procedure

Prior to the start of the cupping session, the graders received a 10 min briefing regarding the overall aim, procedure and flow of the experiment, followed by a 20 min familiarization session to acquaint the graders with the RATA protocol, the definitions of sensory terms and the use of the 7-point scale to rate the intensity of sensory terms. Before starting the actual cupping, they were asked if the procedure was clear and explained again if necessary.

The aim of the first cupping session was to obtain as many descriptors as possible from the heterogeneous sample set (34 coffee samples in total) evaluated by exporting graders in Brazil and importing graders in Switzerland. It is referred to as the elaboration or 'development' stage[38]. The session was divided into three sub-sessions in which 12, 11, and 11 samples were evaluated at a time, respectively.

The aim of the second cupping session was to validate the preliminary flavour wheel that resulted from the development stage. That is, the graders were asked to evaluate whether the descriptors raised in the development stage would be broad enough to encompass or explain the sensory characteristics of a second heterogeneous sample set containing 33 new coffee samples, all previously graded as specialty. This stage is referred to as the 'validation' stage[38]. The second cupping session was divided into three sub-sessions in which 11 samples were evaluated at a time, and it was carried out solely in Brazil. In all cupping sessions, there were 30-min intervals between sub sessions, and water and water crackers were available for palate cleansing.

The graders were instructed to grade each one of the samples according to CQI/UCDA protocol (see Fig. 1, top) in addition to using the RATA list to indicate the presence and intensity of aroma/flavour nuances or notes. The CQI/UCDA protocol is composed of nine attributes or characteristics, namely, 'Fragrance/Aroma', 'Flavour', 'Aftertaste', 'Salt/Acid aspect ratio', 'Bitter/Sweet aspect ratio', 'Mouthfeel', 'Balance', 'Uniformity', and 'Clean Cup' (i.e., absence of defects), ranging from 0 to 10. An 'Overall' rating (0–10) is then attributed to the sample by the grader based on their personal appraisal of the coffee quality. Coffee defects are further assessed and recorded on the cupping form. The defects are the negative tasting notes or off-flavours, and can be measured at two intensities or levels with the CQI/UCDA protocol. If the coffee sample presents a slight defect, which is called 'taint', two points are subtracted from each defective cup. In case of a serious defect, which is called 'fault', four points are subtracted from each defective cup. The Final Score, ranging from 0 to 100, is then calculated by summing up the ratings for each individual attribute as well as subtracting the rating corresponding to defects (if present).

The aromatic/olfactory aspects of the coffee samples were further evaluated using the RATA list (Fig. 1). The graders were asked to select and rate all aromatic descriptors perceived via both ortho- and retronasal olfactory pathways, that is, fragrance/aroma notes and flavour notes, respectively. Also according to the CQI/UCDA protocol, each coffee sample was evaluated at least 3 times corresponding to 3 different temperatures ranging from hot (~ 70 °C) to warm (~ 55 °C) and cold (room temperature). Specifically, the graders were instructed to use the RATA sheet following this scoring order: (1) Score broader/fragrance/aroma notes from more general categories (e.g., fruity) from 1 to 7; (2) Score fragrance/aroma nuances (e.g., citrus, berry, tropical) within that broad category from 1 to 7; (3) Indicate more specific flavor notes (e.g., lemon, orange, grapefruit) whenever possible; (4) Indicate, by writing down under 'other', any perceived fragrance/aroma nuances or notes not on the

Categories, subcategories and specific descriptors	Overall frequency (%)	Frequency within category (%)
Grading 85 + (300 samples)		
Sweet	23.2	
Caramel	13.1	47.2
Fudge (i.e., doce de leite)	6.4	23.1
Honey	3.3	11.9
Vanilla	1.9	6.8
Molasses	1.7	6.2
Brown sugar (i.e., rapadura)	1.2	4.4
Fruity	20.9	
Tropical fruit (e.g., mango, banana)	3.5	21.5
Citrus fruit (e.g., orange, lemon)	3.4	20.9
Berry (e.g., strawberry, blueberry)	2.4	14.6
Dried fruit (e.g., raisin, prune)	2.4	14.3
Undefined ('fruity')	1.9	11.3
Stone fruit (e.g., peach, cherry)	1.8	11.0
White fruit (e.g., melon, pear)	0.9	5.8
Roasted	13.9	
Nutty (e.g., almond, cashew nut)	6.0	42.9
Cereal (e.g., popcorn, malt)	4.8	34.4
Pipe tobacco	2.3	16.2
Cocoa	8.0	
Dark chocolate	3.1	38.2
Undefined ('chocolate')	2.4	29.8
Cocoa (nibs or powder)	1.9	23.0
Milk chocolate	0.9	10.7
Fermented	7.7	
Liqueur	2.8	35.7
Rum/Cognac	1.2	15.8
Undefined ('alcoholic/boozy')	1.1	14.0
Winey	1.0	13.5
Acetic/Pungent	0.3	4.1
Floral	5.2	
Blossom (e.g., jasmine, rose)	3.1	59.5
Tea (e.g., mate tea, black tea)	2.1	40.5
Spices	5.2	
Aromatic (e.g., rosemary, cardamom)	1.9	35.7
Undefined ('spices')	1.6	31.3
Brown (e.g., clove, cinnamon)	1.0	19.1
Pepper (e.g., black pepper)	0.9	16.5
Woody	4.2	
Aromatic (e.g., barrel, cedar)	4.2	97.9
Sawdust	0.1	2.1
Vegetal	2.9	
Herbal (e.g., mint, basil)	1.5	53.1
Vegetal (e.g., cucumber, garden peas)	1.4	46.9
Umami	2.8	
Undefined ('umami')	1.1	40.3
Shōyu	0.8	27.4
Tomato	0.5	16.1
Coconut water	0.4	14.5
Animalic	2.3	
Dairy (e.g., yoghurt, cream)	1.5	66.7
Leather/Meaty	0.7	29.4
Continued		

Categories, subcategories and specific descriptors	Overall frequency (%)	Frequency within category (%)
Mold/paper	2.1	
Moldy/Earthy/Dusty/Baggy	1.3	59.6
Cardboard/Stale	0.9	40.4
Burnt	0.7	
Chemical	0.6	
Grading 70 to 83 (2000 samples)		
Sweet	22.5	
Caramel	12.0	53.4
Undefined ('sweet')	7.1	31.4
Molasses	1.4	6.3
Brown sugar	0.8	3.7
Fudge (i.e., doce de leite)	0.7	3.0
Roasted	18.1	
Nutty (e.g., almond, cashew nut)	9.6	53.2
Cereal (e.g., popcorn, malt)	6.2	34.3
Undefined ('roasted')	2.1	11.7
Pipe tobacco	0.2	1.1
Fruity	16.9	
Undefined ('fruity')	13.8	75.8
Dried fruit	2.4	13.0
Citrus fruit	1.6	8.7
Mold/paper	10.1	
Moldy/Earthy/Dusty	4.7	46.1
Cardboard/Stale	3.8	37.4
Baggy/Husk	1.3	12.5
Vegetal	9.8	
Herbal (e.g., grass, coriander)	6.4	65.5
Vegetal (e.g., cucumber, potato)	3.0	30.2
Cocoa	8.2	
Undefined ('chocolate')	7.0	84.5
Cocoa (nibs or powder)	1.1	13.2
Woody	4.7	
Undefined ('woody')	2.4	51.5
Aromatic (e.g., barrel, cedar)	1.1	24.5
Sawdust	0.7	28.2
Fermented	2.3	
Undefined ('alcoholic/boozy')	1.7	76.8
Acetic/Pungent	0.2	9.0
Chemical	2.2	
Undefined ('chemical')	1.2	56.3
Medicinal	0.5	22.3
Iodine-like	0.2	10.1
Spices	2.0	
Undefined ('spices')	1.6	82.9
Brown (e.g., clove, cinnamon)	0.2	7.6
Aromatic (e.g., rosemary, cardamom)	0.1	6.0
Animalic	1.7	
Leather/Meaty	0.7	40.5
Floral	1.0	
Continued		

Categories, subcategories and specific descriptors	Overall frequency (%)	Frequency within category (%)
Undefined ('floral')	0.6	64.7
Tea (e.g., mate tea, black tea)	0.2	20.6
Salty	0.2	
Umami	0.2	
Burnt	0.2	

Table 1. Normalized frequency count of the descriptive terms for fragrance, aroma, and flavour of coffee samples from the prior cupping database used for the RATA list development.

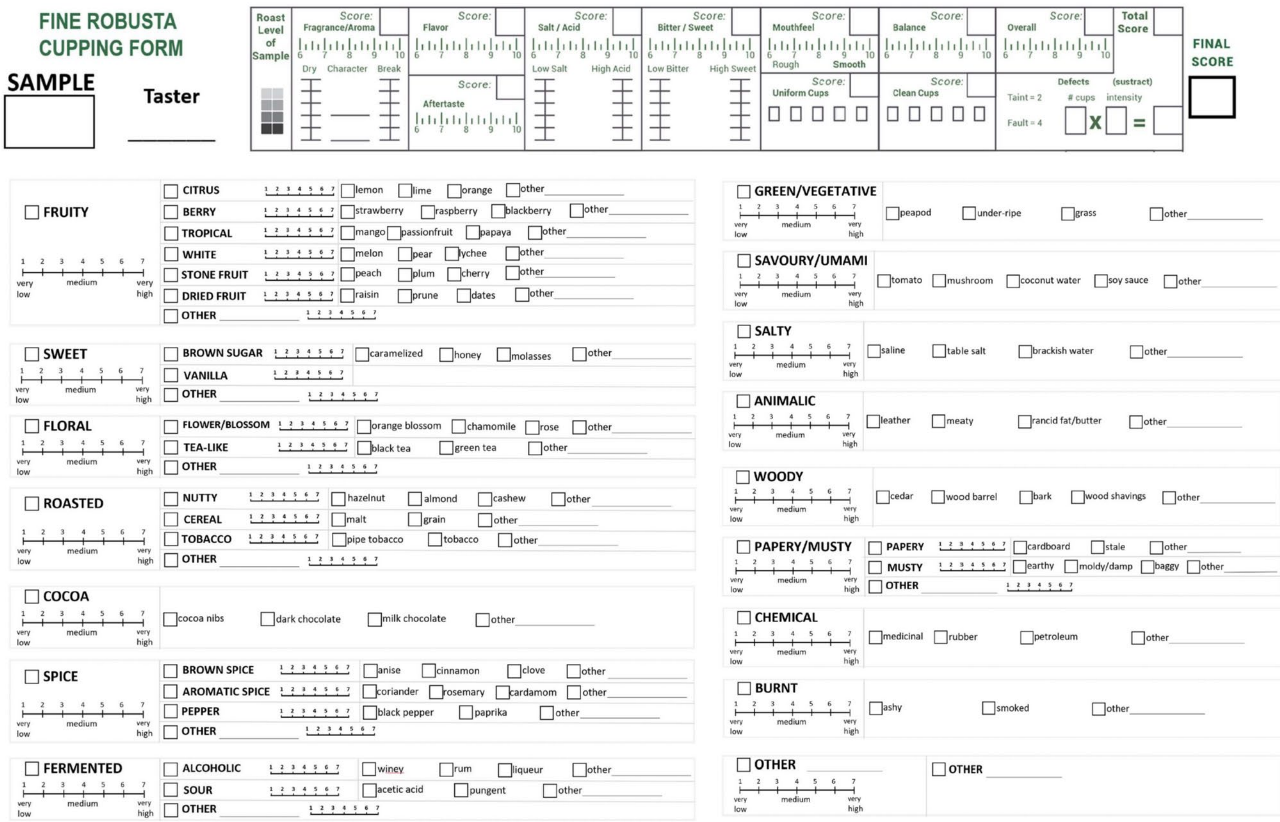

Fig. 1. Full scoring and descriptive form used in all cupping sessions. Upper panel: CQI/UCDA cupping protocol for robusta (canephora) coffees. Lower panel: Final Rate-All-That-Apply (RATA) list.

list. Then, graders were instructed to complete same steps 1 through 4 for each sample regarding flavor nuances or notes as well.

Cupping gradings and RATA scores data were collected on paper in university facilities: Federal Institute of Espirito Santo, Venda Nova do Imigrante, Brazil; Zurich University of Applied Sciences (ZHAW) Coffee Excellence Center, Zurich, Switzerland. All coffee samples were presented labelled with random 3-digit numbers starting with non-zero for identification. For the first cupping session, the exact same procedure was carried out both in Brazil and in Switzerland. One supervisor was present during the cupping sessions in order to provide guidance if needed.

Data analysis

Regarding the most suitable data analysis for RATA, contradictory results have been found. Meyners and collaborators[54] found similar discrimination ability results regardless of whether data were analyzed as binary or intensity data, whereas other studies showed that taking into account the intensity ratings can result in superior discrimination ability[52,53]. In the present study, we opted for incorporating the intensity rating (i.e., score) in the RATA analysis, instead of treating the data as binary.

In all three cupping sessions (i.e., development and validation stages), scores for each descriptive term were recorded on standardized paper forms, which were later digitized for analysis. Each grader's scores were treated independently to maintain objectivity. For each descriptive term, the mean score was calculated by averaging the scores given by all graders across all coffee samples. The formula used for calculating the mean score was:

$$\text{Mean score for attribute X} = \frac{\sum_{i=1}^{n} Xi}{n}$$

where X_i is the score given by taster *i* for attribute X, and *n* is the total number of tasters. This process was repeated for each attribute, resulting in an average mean score for each descriptive term that reflects the collective assessment of all tasters (i.e., an *index* that takes into account frequency and intensity). Subsequently, the average mean scores were used to construct a coffee flavor wheel utilizing Flourish Studio software (Canva UK Operations Ltd., UK). The hierarchical construction of the wheel followed the approach of the Coffee Taster's Flavor Wheel (Spencer et al., 2016) in which the terms were organized in a three-tiered radial hierarchy according to their level of description. The hierarchy goes from broader flavour terms, or categories (Tier 1, inner circle; e.g., 'fruity') to more detailed terms, or subcategories (Tier 2, middle circle; e.g., 'citrus fruit') to the most detailed terms, or specific descriptors (Tier 3, outer circle; e.g., 'lemon'). In addition, the position of the categories in the inner circle of the wheel was determined by the normalized average mean score (i.e., percentage) of each one of the categories, going from the lowest to the highest in a clockwise direction from 270 degrees. Descriptive terms with average mean score below 0.5 were not included in the graphic representation of the wheel to maintain the readability and clarity of the main descriptors. This approach, encompassing average mean score calculations and flavour wheel construction using Flourish Studio software, is in accordance with Artêncio and collaborators[55].

The RATA data from the first cupping session (i.e., development stage) carried out both in Brazil and in Switzerland were also used to explore whether exporting and importing graders would differ on sample description. Thus, the ratings for the broader flavour categories (i.e., Tier 1) were analysed by two-way analysis of variance (ANOVA) having the location/coffee business (i.e., Brazil/exporting; Switzerland/importing) as the between-group factor and the categories (i.e., fruity, roasted, sweet, cocoa, spices, papery/moldy, fermented, woody, floral, burnt, umami, animalic, green/vegetative, chemical, salty) as the dependent variables. Because of the unequal number of responses to these fifteen categories (since graders did not necessarily select and rate the same number of attributes across samples) and unequal group size, Levene's test was used to test for differences in the variances around the means between groups. For the categories in which the assumption of homogeneity of variances was violated (i.e., significant result of Levene's test), the analysis was carried out separately and the statistics associated with 'equal variance not assumed' was considered[56,57].

Finally, for the continuous data recorded on the CQI/UCDA form, a two-way MANOVA was conducted. Due to unequal group size, Levene's test was used to test for homogeneity. The location/coffee businesses (i.e., Brazil/exporting; Switzerland/importing) was the independent variable (between-group factor), and the continuous dependent variables (within-group factors) were aroma/fragrance, flavour, aftertaste, salt/acid ratio, bitter/sweet ratio, mouthfeel, and balance. For the dependent variable 'final score', the coffees were split into low grade (11 samples) and specialty (23 samples) (see Table 2) and a two-way ANOVA was carried out. Again, only the data from the first cupping session was included in the analysis since the second cupping was carried out solely in Brazil. All basic assumptions of the MANOVA test were checked beforehand and have been fulfilled. All post hoc comparisons were Bonferroni corrected and considered significant at $p < 0.05$ and the effects sizes (η^2_p) were reported. The statistical analyses were performed using the SPSS version 22.0 (SPSS Inc, Chicago, IL).

Results

Selection of the descriptive terms for the flavour wheel

The graders generated a total of 202 terms by either selecting the provided terms in the RATA list or by adding additional terms to the list during the sensory evaluation of the coffee samples. No new terms were generated by the second set of samples. Through term grouping, some terms were merged with similar terms. For example, the descriptors 'butterscotch', 'toffee', 'fudge', and '*doce de leite*' were merged into 'caramel'; the descriptors 'phenolic', 'iodoform', 'paracetamol', and 'rioysh/*rio*/*riado*' were all considered as 'medicinal' [for the sake of clarification, according to Brazilian Official Classification (COB), a coffee named *rioysh* (*riado* in Portuguese) has a slight taste similar to iodoform or phenic acid, and *rio* coffee has an unpleasant taste, very accentuated, which resembles even more iodoform or phenic acid[58]. Likewise, terms referring to specific fruit varieties were considered as the more general fruit name (e.g., '*laranja pêra*' and 'blood orange', as well as 'cantaloupe melon' and 'honeydew', were considered simply as 'orange' and 'melon', respectively).

The merging procedure resulted in a list of 170 descriptive terms (Table 3). As a second step, for the sake of readability, all descriptors with an average score below 0.5 were not included in the graphic representation of descriptors as a flavour wheel (Fig. 2). The average mean scores of the descriptors which were included in the wheel ranged from 0.5 ('Butyric acid', '*Cajá*', 'Charcoal', 'Cocoa butter', '*Cupuaçu*', and 'Fishy') to 21.4 ('Caramel') (Table 3; Fig. 2). Importantly, the position of the categories in the inner circle of the wheel was determined by the average mean score of each one of the categories, going from the lowest to the highest in a clockwise direction from 270 degrees (see Table 4; column 'All graders'). The total number of descriptors depicted in the flavour wheel is 103, a number that matches the total of 99 descriptors included in the most recent version of the coffee flavour wheel (mostly based on arabica coffees;[38,39]).

Rating of broader flavour categories

Levene's test showed that the assumption of homogeneity of variance holds for the flavour categories 'fruity', 'floral', 'sweet', 'spices', 'green/vegetative', 'salty', 'umami', 'papery/moldy', 'woody', 'animalic', and 'chemical', which were then analyzed as dependent variables in the same test. The between-group, two-way ANOVA revealed a

Country of origin	Region of origin	Number of samples	Quality grade (post-harvest process)	Cupping session
Brazil	Espirito Santo; Rondonia	3	2 Specialty (natural) 1 Low grade	1
Congo	Tshopo	3	2 Specialty (natural; honey) 1 Low grade	1
Ecuador	Orellana	3	2 Specialty (natural; washed) 1 Low grade	1
Ghana	Volta	4	3 Specialty (natural) 1 Low grade	1
Guatemala	Fraijanes; San Marcos	3	2 Specialty (honey; washed) 1 Low grade	1
India	Chickmangalur	3	2 Specialty (honey; washed) 1 Low grade	1
Indonesia	Java	3	2 Specialty (honey) 1 Low grade	1
Mexico	Chiapas; Veracruz	3	2 Specialty (natural; washed) 1 Low grade	1
Peru	Junin	3	2 Specialty (honey; washed) 1 Low grade	1
Uganda	Mubende	3	2 Specialty (natural; washed) 1 Low grade	1
Vietnam	Gia Lai; Lam Dong	3	2 Specialty (natural) 1 Low grade	1
Brazil	Espirito Santo; Rondonia	5	5 Specialty (natural)	2
Congo	South Kivu	2	2 Specialty (natural)*	2
Costa Rica	San Carlos	2	2 Specialty (natural)*	2
Cuba	Granma; Santiago	3	3 Specialty (natural; washed)	2
Guatemala	Santa Rosa	5	3 Specialty (natural; honey; washed)** 2 Specialty (natural)	2
India	Malabar	4	4 Specialty (natural; washed)	2
Indonesia	Sulawesi; Sumatra	3	3 Specialty (natural)	2
Mexico	Chiapas; Oaxaca; Veracruz	6	3 Specialty (natural; honey; washed) 3 Specialty (natural; washed)**	2
Vietnam	Dak Lak; Lam Dong	4	4 Specialty (natural; honey; washed)	2

Table 2. Country of origin, region of origin, post-harvest process and quality grade of the coffee samples used in the cupping sessions 1 and 2 for the creation of the canephora flavour wheel. *3 months roast; **6 months roast. Cupping session 1: Development stage; Cupping session 2: Validation stage.

significant effect of the location/coffee business (i.e., Brazil/exporting graders; Switzerland/importing graders) on graders' ratings of the categories 'fruity' [F(1,515) = 20.19, $p < 0.001$; importing: 5.68 ± 0.31, exporting: 3.84 ± 0.32], 'sweet' [F(1,760) = 17.46, $p < 0.001$; importing: 4.46 ± 0.21, exporting: 5.45 ± 0.25], 'spices' [F(1,400) = 18.14, $p < 0.001$; importing: 4.23 ± 0.45, exporting: 3.58 ± 0.41], 'green/vegetative' [F(1,295) = 38.23, $p < 0.001$; importing: 3.33 ± 0.39, exporting: 4.78 ± 0.37], 'papery/moldy' [F(1,284) = 8.90, $p < 0.010$; importing: 3.83 ± 0.27, exporting: 4.24 ± 0.42], 'woody' [F(1,438) = 19.06, $p < 0.001$; importing: 3.39 ± 0.31, exporting: 4.28 ± 0.22], and 'animalic' [F(1,123) = 8.89, $p < 0.01$; importing: 3.32 ± 0.37, exporting: 2.51 ± 0.32]. No effect was found for 'salty' ($p = 0.82$; importing: 3.08 ± 0.37, exporting: 3.03 ± 0.32), 'umami' ($p = 0.80$; importing: 3.21 ± 0.27, exporting: 3.25 ± 0.33), 'floral' ($p = 0.31$; importing: 3.58 ± 0.30, exporting: 3.45 ± 0.33), and 'chemical' ($p = 0.77$; importing: 3.14 ± 0.41, exporting: 3.21 ± 0.36) (Fig. 3).

For the flavour categories 'roasted', 'cocoa', 'fermented', and 'burnt', Levene's test for homogeneity of variance revealed significant differences between groups in the variance of ratings. These four categories were, therefore, analyzed together and the statistics associated with 'equal variance not assumed' was considered (Games–Howell test). It has been shown that violations of the homogeneity of variance assumption is mitigated if sample sizes of factors and levels are equal (Parra-Frutos, 2013; Sawyer, 2009). Thus, data was randomly deleted from the raw data matrix so the two groups would be matched in size (i.e., number of entries or data points). The between-group, two-way ANOVA revealed a significant effect of the location/coffee business (i.e., Brazil/exporting graders; Switzerland/importing graders) on graders' ratings of the categories 'roasted' [F(1,749) = 9.12, $p < 0.010$; importing: 4.79 ± 0.55, exporting: 5.26 ± 0.22] and 'fermented' [F(1,223) = 10.59, $p < 0.001$; importing: 3.40 ± 0.31, exporting: 4.07 ± 0.54]. No effect was found for 'cocoa' (p = 0.52; importing: 4.53 ± 0.63, exporting: 4.41 ± 0.31) and 'burnt' (p = 0.07; importing: 3.17 ± 0.72, exporting: 2.33 ± 0.41) (Fig. 3).

Cupping scores

The between-group, two-way MANOVA revealed a significant effect of the location/coffee business (i.e., Brazil/exporting; Switzerland/importing) on graders' ratings of evaluated coffee samples [F(1,636) = 28,607.24, $p < 0.001$, Wilks' lambda = 0.004, $\eta^2_p = 0.99$]. Follow-up univariate tests revealed that location/coffee business had a significant effect on ratings of fragrance/aroma [F(1,636) = 6.75, $p < 0.001$, $\eta^2_p = 0.74$] and aftertaste

Descriptors	Average mean score
Abil; *Açaí*; *Arnica*; Aspargus; Assam; Basil; *Biribá*; Calendula; Cashew (*caju*); Celery; Chickpea; Coca-cola; Eggplant; Eucalyptus; Fig; Garlic; Green apple; *Guaraná*; Hoppy; *Ingá*; Jasmine; *Jurubeba*; Leek; Lemon grass; Licorice; Oak; Oat; Pandan leaf; Pecan; Pequi; Pine; Pinenut; Pink peppercorn; *Pitanga*; Propolis; Quinoa; Rosehip; Scallion; *Seriguela*; Skunk; White chocolate	0.10
Acerola; Blueberry; *Buriti*; Coriander seed; Elderflower; Fennel; *Graviola*; *Jabuticaba*; Jackfruit; Jalapeño; Mustard; Nutmeg; Onion; Plastic; Red pepper; Sesame seed; Tangerine; Whiskey	0.20
Apricot; Brandy; Hay; Juniper; Macadamia	0.30
Chestnut; Grape; Grapefruit	0.40
Butyric acid; *Cajá*; Charcoal; Cocoa butter; *Cupuaçu*; Fishy	0.50
Jambo	0.60
Balsamic vinegar; Basmati rice; Coconut; Corn; Mint; Potato; Red apple	0.70
Camphor; Star fruit	0.80
Petroleum	0.88
Banana; Lychee; Pineapple	0.90
Rosemary	0.91
Papaya	0.92
Peach	0.95
Gorse	1.00
Cardamom	1.04
Herb-like	1.10
Pear; Pungent	1.17
Buttery	1.20
Meaty	1.21
Acetic Acid	1.22
Paprika	1.25
Baggy	1.26
Melon	1.30
Lime	1.37
Cherry	1.40
Mango; Stale	1.43
Date	1.45
Brackish water; Straw	1.50
Green tea	1.58
Coconut water	1.59
Shōyu	1.60
Plum	1.66
Raspberry	1.69
Strawberry; Walnut	1.70
Orange blossom	1.84
Tomato	1.88
Passion fruit	1.93
Liqueur	1.97
Blackberry	2.01
Clove	2.03
Cucumber; Peanut	2.10
Pipe tobacco	2.11
Anise	2.12
Prune	2.15
Toast	2.20
Raisin	2.25
Coriander	2.26
Chamomile	2.29
Mushroom	2.30
Rapadura	2.40
Cashew nut	2.45
Saline solution	2.53
Rose	2.67
Continued	

Descriptors	Average mean score
Rum	2.72
Lemon	2.85
Cinnamon	2.87
Barrel	2.90
Tobacco	2.98
Orange	3.00
Grass	3.19
Leather	3.21
Sawdust	3.26
Rancid fat	3.34
Ashy	3.39
Red wine	3.41
Black tea	3.51
Black pepper	3.53
Rubber	3.68
Smoky	4.06
Earthy	4.26
Underripe	4.57
Cardboard	4.94
Moldy/Dump	5.22
Tree bark	5.30
Cedar	5.37
Medicinal	5.47
Garden pea	6.06
Honey	6.27
Vanilla	6.34
Malt	6.38
Hazelnut	7.05
Molasses	7.40
Milk chocolate	7.78
Grain	8.08
Cocoa nibs	8.81
Almond	10.26
Dark chocolate	11.23
Caramel	21.40

Table 3. Final list of the 170 descriptive terms generated by the graders from all coffee samples, with the respective average mean scores. Terms in Brazilian Portuguese are shown in italic.

[$F(1,636) = 12.34$, $p < 0.001$, $\eta^2_p = 0.94$]. Post-hoc comparisons revealed that both the fragrance/aroma (importing: 7.9 ± 0.13, exporting: 7.6 ± 0.11) and the aftertaste (importing: 7.7 ± 0.16, exporting: 7.4 ± 0.12) were rated higher by the importing graders compared to the exporting graders, across all coffee samples (Fig. 4B).

To further explore the effect of location/coffee business on the variable 'final score' for coffees with different grades or quality levels (i.e., low grade vs. specialty), a between-group, two-way ANOVA was carried out. As expected, there was a significant main effect of coffee quality [$F(2,636) = 189.78$, $p < 0.001$, $\eta^2_p = 0.51$], meaning that the coffees already known to be of low grade in fact received lower ratings than coffees already known to be specialty. The test also revealed a significant main effect of location/coffee business (i.e., Brazil/exporting graders; Switzerland/importing graders) on graders' ratings of the final score [$F(2,636) = 38.12$, $p < 0.001$, $\eta^2_p = 0.21$]. Post-hoc comparisons revealed that both low grade (importing: 74.8 ± 3.8, exporting: 66.9 ± 1.6) and specialty (importing: 84.3 ± 1.8, exporting: 81.4 ± 1.9) coffees were rated higher by the importing graders compared to the exporting graders (Fig. 4A). A significant interaction was found between grader and coffee quality level [$F(2,636) = 15.46$, $p < 0.010$, $\eta 2_p = 0.08$] showing that the already observed main effect of location/coffee business was even more pronounced for low grade coffees. This means that importing graders rated low grade coffees higher than the exporting graders, and the difference was significantly higher than the difference also observed in the ratings for specialty coffees. Put simply, the importing graders punished less the coffees, particularly the ones considered of low grade, compared to the exporting graders.

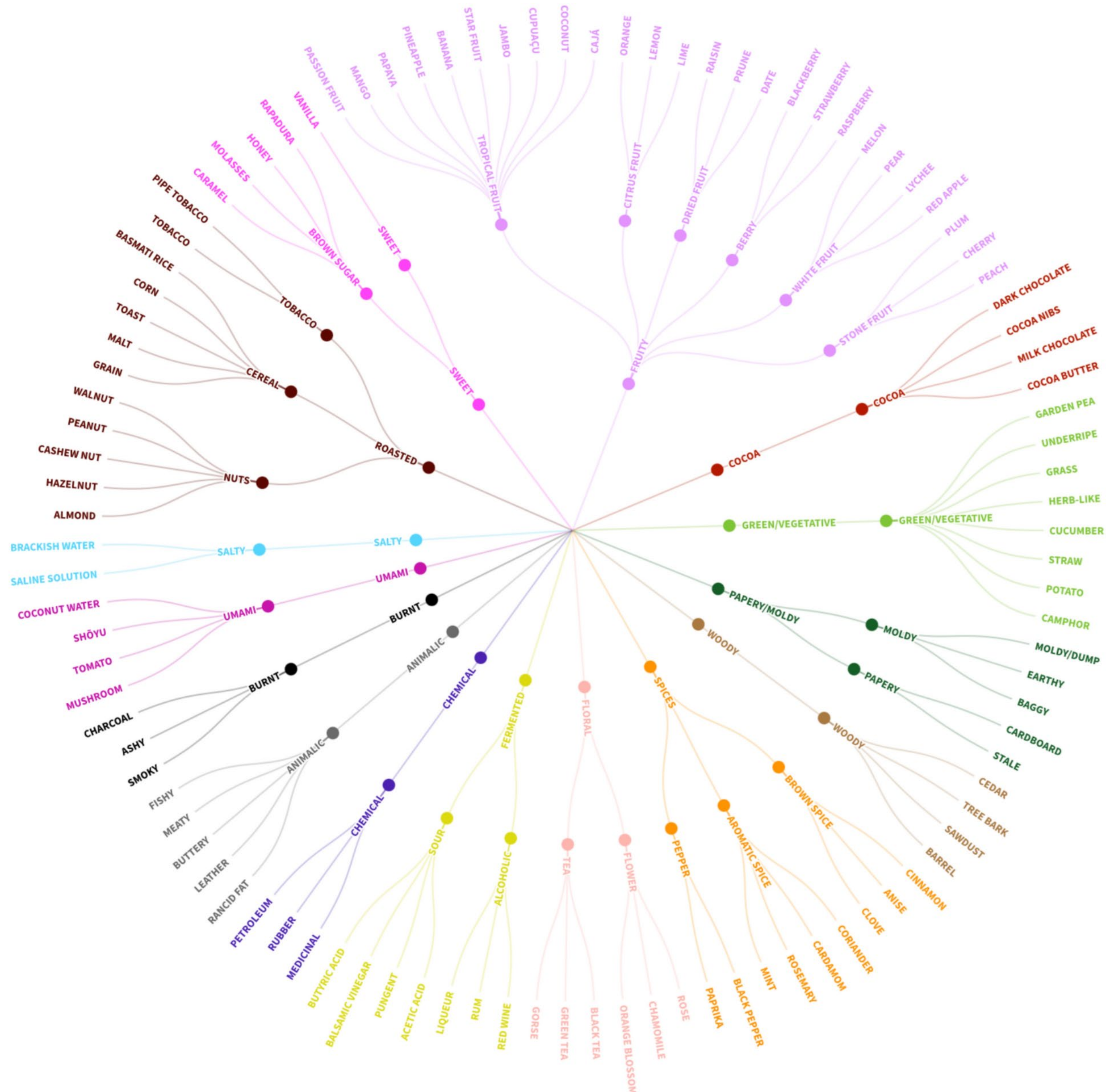

Fig. 2. The final *Coffea canephora* wheel. It includes all the 103 descriptive terms with an average mean score ≥ 0.5 (see Table 3). The wheel should be read clockwise from 270 degrees (i.e., from 'Roasted' to 'Salty'), where broader categories are listed in hierarchical order based on their average mean scores, i.e., from highest to lowest values (see Table 4).

Discussion

A total of 67 coffee samples from 13 countries of origin were tasted by professional graders to develop a flavour wheel for *C. canephora*. After term grouping, the number of descriptive terms was reduced to a list of 170, and 103 descriptors were included in the flavour wheel graphic representation. The descriptive terms were organized in different hierarchical categories according to the approach adopted for the development of the Coffee Taster's Flavor Wheel[39]. The hierarchy goes from broader flavour terms, or categories (Tier 1, inner circle; e.g., 'fruity') to more detailed terms, or subcategories (Tier 2, middle circle; e.g., 'citrus fruit') to the most detailed terms, or specific descriptors (Tier 3, outer circle; e.g., 'lemon').

The position of the Tier 1 categories (i.e., inner circle) in the wheel was determined by their average mean scores. They follow a sequential order from the lowest to the highest scores in a clockwise direction from 270 degrees. We found that 'roasted' was the category with the highest average mean score, followed by 'sweet', 'fruity', 'cocoa', all the way to 'salty', which was the category with the lowest average mean score. Saltiness (or salinity) in *C. canephora* is considered a negative attribute[20] and its intensity is evaluated in relation to the intensity of acidity of the sample. Acidity, on the other hand, is considered a positive attribute when present together with sweetness and fruity notes. *C. canephora*, as a coffee species, has traditionally been considered of lower sensory quality,

Categories (Tier 1)	All graders		Brazil (exporting graders)		Switzerland (importing graders)	
	AMS	AMS (%)	AMS	AMS (%)	AMS	AMS (%)
Roasted	**47.7**	**16.1**	43.4	15.8	31.4	14.6
Sweet	44.0	14.9	**45.8**	**16.7**	27.1	12.6
Fruity	36.6	12.4	23.9	8.7	**35.1**	**16.3**
Cocoa	28.3	9.6	30.0	10.9	22.1	10.3
Green/Vegetative	21.9	7.4	25.2	9.2	7.4	3.4
Paper/Moldy	17.1	5.8	18.9	6.9	12.6	5.9
Woody	16.8	5.7	21.4	7.8	9.5	4.4
Spices	16.7	5.6	14.6	5.3	15.8	7.3
Floral	12.9	4.4	10.4	3.8	8.2	3.8
Fermented	12.2	4.1	11.1	4.0	11.5	5.3
Chemical	10.7	3.6	9.2	3.4	7.2	3.4
Animalic	9.9	3.3	6.7	2.4	7.5	3.5
Burnt	8.1	2.7	**3.7**	**1.3**	8.1	3.7
Umami	7.5	2.5	4.2	1.5	8.0	3.7
Salty	**5.8**	**1.9**	6.3	2.3	**4.0**	**1.9**

Table 4. Average mean score (AMS) and normalized average mean score (AMS %) of each one of the categories in the inner circle of the wheel (Tier 1) for all graders, exporting graders, and importing graders. The highest and lowest values for each group are shown in bold.

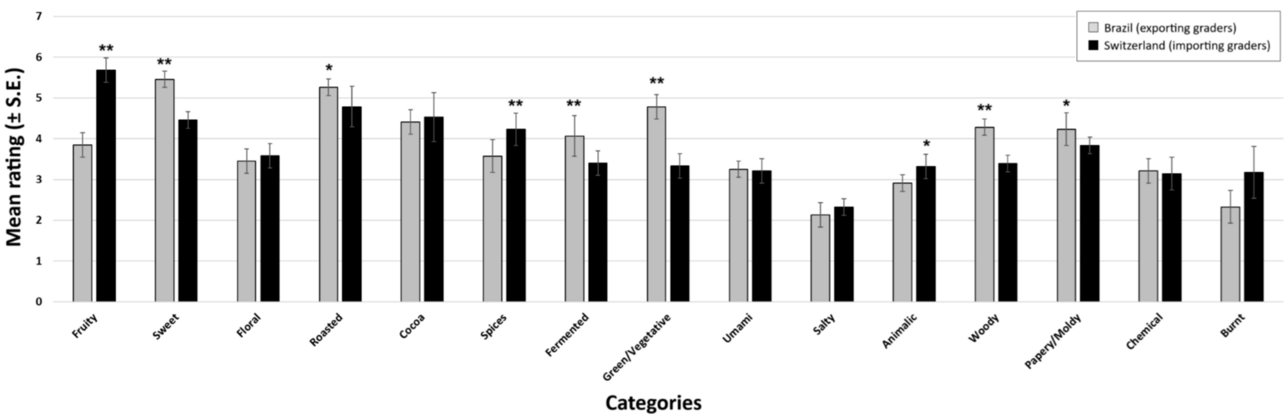

Fig. 3. Mean ratings (± SE) of the Tier 1 flavour categories ('fruity', 'sweet', 'floral', 'roasted', 'cocoa', 'spices', 'fermented', 'green/vegetative', 'umami', 'salty', 'animalic', 'woody', 'papery/moldy', 'chemical', 'burnt') given by exporting graders (Brazil; grey bars) and importing graders (Switzerland; black bars). The asterisks indicates statistical significance of ratings between the groups of graders $p < 0.01$ (*) or $p < 0.001$ (**) (Bonferroni corrected).

lacking notes related to sweetness and acidity, and possessing intense earthy and bitter aroma/flavour notes[59,60]. Our findings, however, contradict this traditional assumption by showing that the categories 'sweet' and 'fruity' received significantly high scores. In fact, more recent studies on *C. canephora* genotype, *terroir*, and postharvest methods have shown that high quality *C. canephora* samples are described as fruity, citrusy, and sweet[55,61]. For instance, certain genetic groups, such as the 'Lula' cultivar in Congo and the Amazon robusta in Brazil, as well as Ecuadorian *C. canephora* that has been wet-processed were associated with caramel, brown sugar, almond, fruity, smooth taste[21,26,62,63]. Our findings are in agreement with these observations and add further evidence that high quality *C. canephora* can present a wide range of sweet and fruity aroma/flavour notes, ranging from delicate honey to strong molasses, and from refreshing citrus to intense dried fruits.

We also observed differences between exporting and importing graders regarding (1) the use of descriptive terms, (2) the rated intensity/frequency of certain aroma/flavour categories, and (3) the final score given to both low-grade (i.e., commercial) and specialty coffee samples. The different use of aroma/flavour descriptive terms by the Brazilian graders when compared to graders working in Europe is likely to derive, firstly, from cultural differences rooted on attribute familiarity and, secondly, from the practice of using a vocabulary that is compatible with the market in which they are inserted[64]. For example, graders based in Europe used the term 'fudge' whereas Brazilian graders used the term '*doce de leite*' to describe the aroma/flavour of cooked sugar

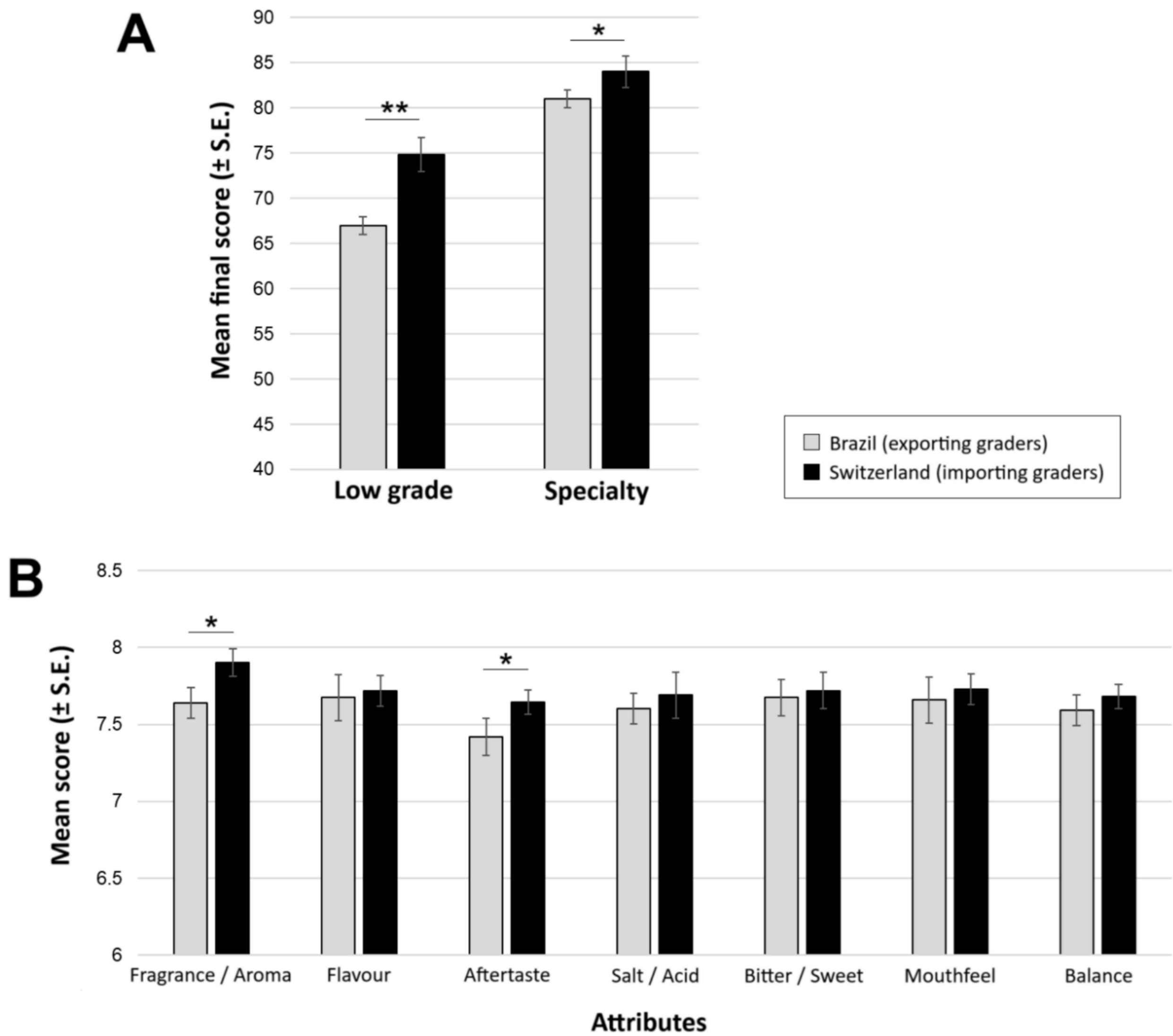

Fig. 4. (**A**) Mean final score (± SE) of the CQI/UCDA cupping form for low grade and specialty coffee samples; (**B**) Mean scores (± SE) of the CQI/UCDA cupping form attributes 'fragrance/aroma', 'flavour', 'aftertaste', 'salt/acid aspect ratio', 'bitter/sweet aspect ratio', 'mouthfeel', and 'balance'. Scores were given by exporting graders (Brazil; grey bars) and importing graders (Switzerland; black bars). The asterisks indicates statistical significance of ratings between the groups of graders $p < 0.01$ (*) or $p < 0.001$ (**) (Bonferroni corrected).

with milk or cream. The graders also differed regarding the rated intensity/frequency (i.e., average mean score) of the aroma/flavour categories: The 'fruity' category was the one with the highest average mean score for the import graders whereas for the exporting graders the 'sweet' category was the one with the highest average mean score (compared with all other categories). It has been reported by the coffee industry that the preference for fruity notes in specialty coffee is not necessarily shared amongst all specialty coffee consumers, and it seems to vary cross-culturally. For example, in Northern European countries, consumers have a preference for light-roast, fruitier, more floral, longer filter coffees[65], whereas in the Australian market, the land of the flat white, coffees that have low acidity and full-body are preferred in order to be paired with milk (i.e., used for milk-based coffee beverages)[66]. Thus, according to this observation, and considering that consumers' preferences influence perceived quality and value[67], it plausible to assume that fruity notes are going to be greatly valued by the European coffee market. This, in turn, may impact coffee evaluation and description by graders who import coffee to Europe – these graders are likely going to seek fruity aroma/flavour notes in coffee samples. On the other hand, Brazilian graders export coffee to several countries varying in preference and perceived value. Coffee natural sweetness is considered a key attribute of specialty coffees and is valued by consumers, roasters, and coffee farmers worldwide[68]. Hence, it is expected that exporting graders, who usually target multiple markets, are going to search for sweet aroma/flavour notes when performing coffee evaluation.

The third observed difference between the two groups of graders was regarding the final score given to both low-grade and specialty coffee samples. This may have happened either because the scoring of only one of the two groups was affected or there are factors affecting the scoring of both groups. There is evidence that suggests that the latter is the case, i.e., the importing graders scored higher and the exporting graders scored lower. First, the aforementioned finding that the 'fruity' category was the one with the highest average mean score for the importing graders may have positively impacted the samples' final scores. In a comprehensive study of Cup of Excellence (COE) auctions, the impact of material (e.g., sensory) and symbolic (e.g., origin, certifications) quality attributes on specialty coffee scores and prices was assessed. The COE is a program for coffee farmers that includes the most renowned coffee quality competition. The coffees with the highest scores can entry the COE auction in which the best coffees can reach astonishingly prices of hundreds of USD per pound (https://allianceforcoffeeexcellence.org/). The authors showed that the most common aroma/flavour are 'fruity', found in 95.7% of the COE coffees. This indicates that the coffee 'fruitiness' is a material attribute that yields high scores and premium prices.

Second, despite the recent movement towards the standardization of coffee grading system by the use of the SCA and CQI protocols, Brazilian coffee grading is still highly based on the Brazilian Official Classification for Coffee (COB). The COB protocol was consolidated in 1949 and it constitutes the main methodological basis for coffee classification in Brazil[20]. What is interesting is that the classification into the cup quality categories (namely, strictly soft, soft, softish, hard, and finally, riyosh and Rio) is outlined on the so-called sensory defects (i.e., negative attributes). For instance, for a coffee sample to be classified as 'soft', it must not present astringency (otherwise it goes a level down to 'hard'); then, for this sample to be classified as 'hard', it must not present 'medicinal' aroma/flavour notes (otherwise it goes a level down to 'riyosh')[69]. Due to the method's primary focus on negative attributes, Brazilian graders are extensively trained in detecting and naming coffee defective notes. Several studies on professional tasters have shown that preliminary perceptual, attentional, and semantic training hugely shapes the taster's capacity to perform olfactory discrimination and categorization[70–72]. In particular, attentional weighting may modify perceptual abilities, making relevant those attributes to which increased attention is paid to (e.g., by training and/or conditioning)[73]. In fact, selective attention to affective value of olfactory stimuli (i.e., pleasant versus unpleasant) engages brain systems different from when attention is directed to a simple physical properties of an odour, such as its intensity[74]. For instance, Tempere and collaborators[75] reported the impact of associative training between an odour and its affective value on shaping tasters' olfactory abilities. First, they assessed the individual rejection thresholds for geosmin of wine professionals and divided them into three groups. The control group was simply informed that their thresholds would be measured in two separate sessions. The second and third groups received geosmin samples and were asked to smell this odorant once daily for one month. In addition, the third group was also explicitly instructed to pay attention to its 'musty, earthy off-flavour'. After the training stage, wine rejection thresholds in the training groups were evaluated. A significant decrease in rejection threshold was found in the third group only. The simple fact that the geosmin was presented to the wine tasters in the third group as a defect was sufficient to focus their attention and enhance its perception and identification as an aversive signal (i.e., a defective note).

To the best of our knowledge, this is the first study to show that exporting coffee graders—at least Brazilian graders—who have been trained to focus specifically on certain aroma/flavour notes labelled as defects may be biased towards overweighting them. The a priori rule that the stimulus' relevant features are the defects results in attention amplification, which makes these features even more salient—just like holding a magnifying glass close to them[76]. Indeed, we reported that the average main score of all purely defective Tier 1 categories (i.e., green/vegetative, paper/moldy, chemical, salty) was higher for the exporting graders compared to the importing graders, except for the category 'burnt', which is not a green coffee defect (it is a roasting defect) and, thus, not included in the COB protocol. These results suggest that the Brazilian graders, who have been historically trained to identify certain negative attributes in coffee, are more tuned towards grading coffee based on defective notes. One way in which we could think about this finding is in terms of the stringent standards and regulations the producing countries have to comply in order to export agricultural products[77]. Being more rigorous on product description, specifically defects description, may be a way to ensure that the exporting grading requirements are fulfilled.

As expected, there is a considerable overlap between the descriptors reported in the present study and the descriptors represented in the *C. arabica* flavour wheel. However, there are also important differences that should be considered. We observed relevant contribution of positive woody (e.g., oak barrel, cedar), aromatic spices (e.g., cardamom, rosemary), and fermented alcoholic descriptors (e.g., rum, liqueur) that are absent from the *C. arabica* flavour wheel. Particularly, the descriptors tomato, fermented soy sauce (shoyu), coconut water, and mushroom were included under the category 'umami', and seems to be unique to *C. canephora*. At this point, it is important to note that further studies are necessary to shed light on the basis of the reported differences—given the intricate relationship between the aroma/flavour characteristics and the compounds that contribute to them[78]. Moreover, it should be especially noted that, although the same descriptors can be used for *C. arabica* and *C. canephora*, different standards can exist for the different types of coffee. At this point, it would be helpful to recur to an analogy with the use of descriptors in wine tasting. Caballero and Suárez-Toste[79] pointed out that certain descriptors appear to be more successfully applied to white wines than to red wines, particularly those terms used to describe the structural properties of wine. They further suggested that "white wines usually rely principally on acidity for structure, red wines aged in oak use tannin as the principal structural element" (pp. 250). This observation that the structural properties of wines differ and that it should be taken as the cornerstone upon which the descriptors are built is of great relevance for coffee tasting too. For example, oak barrel, cedar (i.e., aromatic woods), and pipe tobacco are commonly attributed to *C. canephora* as positive aroma/flavour characteristics[20]. On the other hand, the presence of such rich and deep aroma/flavour notes of aromatic woods and tobacco are usually deemed as negative/defective for *C. arabica* since they cause disharmony within the delicacy of arabica coffee beverage[80]. Still considering the wine/coffee analogy, it has been reported that the same volatile organic compound, dimethyl sulfide (DMS), can be evaluated as either positive or negative depending on the overall wine structure. The content of DMS increases with aging and is an important component of the truffle aroma that appears in late vintage, top quality wines[81]. However, its role is contradictory as its presence in young white wines is considered as negative[82].

In fact, for certain aroma categories, such as woody and spicy, it is crucial that the evaluation of whether the descriptor is beneficial or not is performed considering the 'context', that is, the overall characteristic of the beverage. Paradis[83] brings to our attention that red and white wines are mostly described through 'darkish' (e.g., blackberry, chocolate) and 'lightish' (e.g., honey, peach) objects, respectively. In addition, the author claims that some of the descriptors for reds and whites are the same, and spice is one of those. However, as it is amongst several other descriptors, the actual spice referred to differ. This highlights the importance of considering the context for spicy notes in the creation of meaning. An example of putting descriptors in context for sensory training is the creation of two separate aroma wheels, one for red and one white wines, by the German Wine Institute (https://winesofgermany.co.uk/educational-materials/). For the wheels' practical use, they write "the aroma wheels provide you with an appropriate vocabulary to describe the enormous sensory diversity of German white and red wines". It could be inferred that not all vocabulary is appropriate to both types of wine.

According to Lawless and Civille[84], when developing lexicons and flavour wheels for cross-cultural application, the involvement of panellists from all relevant cultures is desirable. This provides additional validation and allows the identification of potential drivers of product acceptance in different markets[64,85]. In the present study, we included graders from exporting and importing markets (i.e., Brazil and Europe, respectively) not only to investigate differences in grading between these two groups but also to facilitate communication between the players involved in coffee production and trading. Particularly, our goal was to widen our understanding of the concept of quality applied to *C. canephora* and promote opportunities for product improvement and value creation.

Having said that, it is also important for the coffee industry to reconsider the nomenclature associated to coffees of high quality. This is crucial in order to create opportunities for the acceptance and recognition of *C. canephora* by the specialty coffee market. We suggest that, independently of the coffee species, a high quality product should be graded as 'specialty'. The term speciality coffee was first used by the Norwegian Erna Knutsen back in 1970s, who defined speciality coffee as beans grown in special geographical microclimates[86]. Traore and collaborators[15] provide the historical context for the creation of the product category: "As a reaction to the decline in coffee quality, specialty coffee was born" (pp. 350). They define specialty coffee as coffees grown in special and ideal climates, with distinctive taste and flavour, and with little to no defects. Thus, the concept 'specialty' is appropriate and relevant to all coffees that fulfil the definition criteria and should not be exclusive to one coffee species only. In fact, it is already common to see high quality *C. canephora* being referred to (or defined) as specialty in academic research articles (e.g., Refs.[26,30,87]).

Conclusion and limitations

To the best of our knowledge, this is the first study to report the development of a flavor wheel for *C. canephora*. This aim of this project was to identify aroma/flavour descriptors and organize then in a graphical representation that simplifies and standardizes the descriptive assessment of *C. canephora* samples. The flavour wheel can be used as a tool to identify, understand, and map the sensory characteristics of *C. canephora* that are most important or valued in different markets. Standardizing the description of *C. canephora* aroma/flavours in a replicable way is important not only for the coffee industry but also for scientists working on quality improvement. This study was limited by the *C. canephora* samples that were used in the cupping sessions as well as by the vocabulary of the graders who assessed the samples.

Narrowing the gap between the industry standards and consumer demand for *C. canephora* coffees is utterly important. Future research is necessary on consumer testing to characterize the consumer's sensory vocabulary as well as understand acceptance and preference (e.g., Refs.[88,89]). Furthermore, a crucial step to highlighting C. canephora in the specialty coffee arena and leverage quality would be to showcase the innovations surrounding C. canephora at the World Coffee Championships (WCC) (https://wcc.coffee/).

Finally, it is important to note that the International Organization for Standardization (ISO), a worldwide federation of national standards bodies, has a standard for preparation of green coffee samples for use in sensory analysis (ISO 6668:2008[90]) as well as a standard for coffee sensory analysis vocabulary (ISO 18794:2018[91]). Nonetheless, there is no universally employed standard for cupping coffee, despite the existence of a commonly used methodology[92]. The SCA has a different (more detailed) standard procedure that is actively promoted through its programs and through the CQI. The SCA/CQI method does fall within the parameters of the ISO 6668:2008 and ISO 18794:2018. However, the SCA/CQI method can be seen as a version of the ISO standard targeted toward single-origin coffees as the cupping focuses on coffee's intrinsic characteristics (e.g., terroir, postharvest process) rather than on the brewing method[93]. Moreover, we recommend the implementation and/or development of aroma/flavour coffee wheels by the ISO as a descriptive tool for coffee sensory analysis.

Data availability

Data has been uploaded in Dryad, and will be made public after article peer review and publication. http://datadryad.org/share/8v9z3Pp0vPdZ8WzX8rvkL03YAx4Kz21YrLnH6lbWPg4.

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Author contributions
F.M.C.: Conceptualization, study design, data collection, formal analysis, writing (text, all tables, Figs. 1, 3, 4). E.A.A.: Conceptualization, data collection. M.M.A.: Study design, formal analysis, writing (material and methods) A.L.L.C.: Study design, formal analysis, writing (material and methods; Fig. 2). L.L.P.: Conceptualization, study design, data collection. All authors reviewed the manuscript.

Declarations

Competing interests
The authors declare no competing interests.

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Correspondence and requests for materials should be addressed to F.M.C.

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