ROASTING CONDITIONS AND QUALITY COFFEE: THE EMPIRICALLY OPTIMISED PROCESS

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Article history: Received 27 June 2023, Received in revised form 14 July 2023, Accepted 16 July 2023, Available online 18 July 2023.

This work was published free of charge as a publisher's support for Ukrainian authors struggling with wartime difficulties caused by Russian aggression against their country.

Highlight

Coffee roasting: the delicate balance between a skilled roaster's expertise and the science of optimising roasting conditions for the highest quality brew.

Abstract

The degree of roast, temperature and duration of the roasting phases of the coffee bean directly affect the sensory characteristics of the coffee cup. Therefore, to achieve the best roasting result, it is important to combine the human factor with special software products. To automate the roasting process, the Artisan roasting recording software was used. Automation of roasting allows better reproduction of the process conditions for different coffee samples. However, roasting is a rather complex and multi-stage process, and its automation does not guarantee the full reproduction and disclosure of the taste and aroma properties of the "perfect cup". Therefore, the qualifications, skills and experience of the roaster play a significant role in achieving and further reproducing the desired flavour profile.

Keywords

arabica coffee; robusta coffee; coffee beans; roasting process; temperature; sensory characteristics.

Introduction

Coffee is one of the most popular drinks among the population due to its taste and aroma. However, the reproducibility of the taste and aroma of coffee is a rather complex process, which depends not only on the variety and storage conditions of the beans, but also on the coffee roasting process. From a sensory point of view, roasting has a great influence on coffee quality and is thus an important aspect of product differentiation

https://doi.org/10.32933/ActaInnovations.49.3 • ISSN 2300-5599 •

has a great influence on coffee quality and is thus an important aspect of product differentiation in the market [1]. Although the roasting process has been studied in great detail [2,3], there are many factors that depend directly on the roaster and cannot always be clearly unified. For example, even when using special software, the roasting process often stops when the beans reach a certain colour. In addition, in some cases, it is the roaster who determines the first crack has happened. It is clear that experience, skills and the human factor can affect the result even when roasting according to a known temperature profile. Although there are attempts to fully automate the control of the end of the roasting process, they are either under development or too expensive for small roasting shops [4]. Technically, the complexity of roasting beans lies in the fact that each type of coffee has its own unique properties and requires a certain temperature regime.

Roasting process causes a change in the structural-mechanical, thermophysical and sensory properties of coffee beans, which together determine the consistency, colour, odour, taste, which characterise the degree of readiness of the product. During coffee beans roasting, a complex mixture of volatile aromatic compounds are formed [2,5–7]. The main processes that occur during roasting are the decomposition of sugars and chlorogenic acid [8]. Moreover, the destruction of chlorogenic acid is more complete, the longer the roasting process and the higher the temperature [9]. At destruction of chlorogenic acid caffeic and quinic acid are formed. All these acids give coffee bitterness and astringency. Under the influence of temperature in coffee beans, about 50% of trigonelline is decomposed with the formation of decomposition products containing pyridine, nicotinic acid derivatives and a number of other organic substances. Pyridine is one of the substances that give coffee a specific aroma. In the process of roasting coffee beans, in addition to chemical transformations, a significant loss of moisture occurs on average from 11% to 3% [10,11]. Colour is a suitable indicator of the degree of roast for a given raw material. Traditionally the colour of coffee has been used to determine the degree of roasts and to enhance consistency in the end product. Nowadays, roast temperatures are recorded to allow the reproduction of previous roasts. However, roast profiles vary widely across different conditions and roaster designs. The aim of the study was to compare the organoleptic characteristics of coffee brewed from two types of Arabica and Robusta coffee beans roasted under different conditions (temperature and time).

Methods

Sampling

Two species of green coffee beans Arabica (Brazil Santos) and Robusta (Vietnam) were purchased from a local shop (Chernivtsi, Ukraine). Therefore, in the manuscript, the acronyms A for Arabica and R for Robusta samples were used to designate samples. In accordance with Standards coffee from the Specialty Coffee Association [12], each batch of coffee must be tested in the laboratory for six indicators: sensory (bean colour, surface characteristics, aroma, flavour and absence of defective beans), caffeine content, amount of extracted substances, ash content and metal impurities. Before the roasting process gets started, all defective beans are taken out from the samples [13]. After that, 1 kg of beans was weighed for roasting. Analysis of sensory characteristics and the humidity and density data (Table 1) allows you to assert compliance with the standards.

Table 1. Some physico-chemical properties of green coffee beans. *Source: Authors.*

Parameter	**Arabica**	**Robusta**	**Standard magnitude**
Humidity, %	9.9 ± 0.2	8.6 ± 0.2	8.0-12.0 [14]
Density, g/mL	0.784 ± 0.025	0.692 ± 0.025	0.404-0.891 [13]

Roasting process conditions

Roasting of coffee samples was carried out using a coffee roasting machine shop type TKM-SX 1 (Toper, Izmir, Turkey). The mass of loaded samples was 1 kg. Roasting was carried out in a gas roaster at the following temperatures: 180°C, 200°C, and 220°C for 9 - 11.5 minutes. The choice of temperatures was not random. Several studies, for example [15], it is conducted at temperatures of 160-185°C for light roasting, however, other studies claim that the best conditions for flavour and aroma development of coffee are roasting temperatures of 220 - 230°C. This is because at lower temperatures, only a peanut-like note appears instead of the real coffee taste [16]. The samples roasted at the appropriate temperature were designated for the Robusta variety as R1, R2 and R3, and for Arabica varieties as A1, A2 and A3. The samples were roasted using a combination of visual and software control for light-medium roast. The process of samples roasting was stopped when the colour of the beans reached the desired level. For all samples, frying was stopped until the second crack. The coffee roasters record, analyse and control toast profiles was carried out using an open-source software Artisan

(Development team, Germany) [17]. The parameters of the process of roasting samples of coffee beans are presented in Table 2.

Table 2. Roasting conditions for all samples. *Source: Authors.*

Sample	Maximum roasting temperature, °C	Drying time, min	Time to first crack, min	Development time, min	Total roasting time, min	Roast colour, Tonino scale value
A1	180	5:08	8:21	3:38	11:59	108
A2	200	4:44	7:32	2:10	9:43	109
A3	220	4:05	6:03	2:36	8:49	112
R1	180	5:25	7:41	4:26	10:67	114
R2	200	4:10	7:10	4:24	11:34	116
R3	220	4:01	6:05	2:39	8:44	117

In general, the roasting process can be represented as three stages, each of which corresponds to the time presented in Table 2. At the first, preparatory stage, a heat exchange balance is achieved between the roaster and green coffee beans. The temperature set here is required for drying. The second stage is characterised by the occurrence of Maillard reactions at temperatures below the caramelization temperature of sugars [18]. At this stage, characteristics such as body and sweetness are formed. The less coffee present at this stage, the lower the complexity and the lighter the taste. The last stage, called caramelization, is very important and is characterised by a large number of chemical reactions occurring in parallel. The influence of the transformations of these substances on the sensory characteristics of coffee will be significant. The beginning of this stage is accompanied by the appearance of the first crack. If you heat coffee to the second cod or longer, there is a risk of setting it on fire. Then carbon and ash tones will appear in the taste, which will significantly worsen the quality of the finished drink. To achieve a dark roast coffee with a pronounced bitterness, the roasting process can last up to the second "crack" at a temperature of 250 - 260 °C. However, the risk of coffee burning is high, making it unfit for consumption [19]. After firing, all test samples were kept for degassing for 15 days. This process is very important for coffee quality. Degassing was performed at room temperature in open plastic containers. After completion of the degassing process, the density and moisture content of the beans were re-determined.

Physicochemical properties

The colour of the coffee was evaluated by a Tonino Color Meter for Roasted Coffee (Development team, Germany) [20]. This spectrophotometric method makes it possible to measure the colour of the roast on a special Tonino numeric scale independent of the production process. This scale ranges from 50 to 130, with a smaller number indicating darker roasts. Beans moisturiser before and after roasting were measured on a grain moisture tester PM-450 (Kett, CA, USA). The density of coffee samples was measured with a laboratory measuring cylinder according to standard methods [13]. The efficiency and quality of the extraction brewing was evaluated using the VST LAB Coffee III refractometer as an instrument for measuring the total dissolved solids percentage (% TDS) of coffee.

Sensory analysis

Specialty Coffee Association (SCA) based on the following ten indicators: Fragrance, Aroma, Flavour, Aftertaste, Acidity, Body, Uniformity, Balance, Clean cup, Sweetness, Overall [12]. The intensity of each sensory characteristic was recorded on a 10-point hedonic scale after 1 h orientation sessions. In this session the panellists had specified the terminology and anchor points on the scale. The sensory analysis and the "blind" tasting were conducted by ten trained coffee experts. The panellists stayed in the room with temperature 25 ± 2 ^{0}C and the relative humidity 55 ± 3%. The samples were prepared 1 h before the evaluation. Samples were kept in coded plates covered with aluminium foil. The coded samples were shown simultaneously and evaluated in random order. The roasted coffee samples for cupping were ground using a coffee grinder (grind size #12 - "coarse"). After that, 12 grams of coffee were weighed and poured into special cups for brewing. The water temperature used was 93°C. The water was poured in a way that created a funnel in the cup, which should lift all the coffee particles upward for proper extraction. After pouring the water, the coffee was allowed to steep for 4 minutes. A special spoon was used to break the crust that formed during brewing, and the aroma of the beverage was immediately evaluated. Then, using special spoon movements, the remaining crust and foam were removed from the surface of the drink. After 9 minutes from the start of brewing, the coffee was ready for taste evaluation. The beverage was "slurped" to distribute it across the entire oral cavity, reaching every taste receptor. After that, the drink was cooled to room temperature, and a re-evaluation of the taste was conducted. The coded samples were shown simultaneously and evaluated in random order.

Statistical and data analysis

For the statistical analysis a one-factor analysis (ANOVA) for a series of parallel measurements. Value of $p < 0.05$ was considered statistically significant. The Tukey-Kramer honestly significant test was used to determine significant differences between means. All data were expressed as average value ± standard deviation. Basic statistics and ANOVA were performed using the statistical software package Minitab ver. 18.1 (Minitab Inc., USA). Principal Components Analysis (PCA) was performed on the panel averaged data using the Minitab ver. 18.1 (Minitab Inc., USA). The data were scaled by centring and divided by their standard deviation.

Results and discussion

A general overview of the roasting process (Table 2) shows that the duration of the drying stage of the samples decreased with increasing of maximum roasting temperature. So, for all samples, the drying time, roasting time and total time decreased with roasting temperature increasing.

The moisture and density of the beans after roasting for all samples is very close ($p<0.05$), and amounted to 1.3 - 1.4 % and 0.362 - 0.369 g/cm^3 for R1 - R3 samples, and 1.0 - 1.2 % and 0.396 - 0.404 g/cm^3 for A1 - A3 samples, respectively. This indicates the uniformity of roasting and the correctness of the visual assessment of the time of completion of the roasting process. The specified values are within the limits defined by the standards for these values. The decrease in density is associated with an increase in the volume of coffee beans during roasting. However, their characteristics do not provide any information about coffee-drink sensory characteristics.

More informative are the colours of coffee and the content of extractives (Table 2). As follows from the data in Table 2, the samples are not too different in colour. For both varieties, an increase in roasting temperature caused an increase in colour intensity, which is consistent with the data of other authors [21,22]. It should be noted that the darker colour of Robusta samples compared to Arabica samples, indicates the difference in their chemical composition [23]. Based on research [3], our samples can be classified as light roasts. In general, the colour determines the degree of roasting. However, it is important to remember that loss of moisture, change in density and colour may not be sufficient criteria to determine the degree of roast. The frying temperature must also be considered (Franca et al., 2009). The time and temperature of the Maillard Phase and Final Phase will have a significant impact on the opening of the coffee body and its acidity. Artisan-software provides feedback on various phases of the roast, including the finishing phase, to help achieve desired flavour profiles. In our case, samples R1, R2 and A1 were marked as "Flat". The temperature gradient was insufficient and this warning indicates a possible sensory problem. The roaster must consider these guidelines to achieve the "perfect cup". This demonstrates the need for a combination of visual and hardware monitoring by roasting final point. The amount of extractives directly affects the taste of the drink. The content of extractive substances in espresso coffee is presented in Figure 1.

According to Coffee Standards by SCA [12] the content of extractives in roasted coffee (light and medium) should be 18 - 22 %. In our case, for samples R1 and A2 a significant excess of their content was obtained, which should have a negative effect on the taste of coffee drink. For the remaining samples, the content of extractives is near the upper limit of normal. On the contrary, if the coffee has a low amount of extractive substances, the drink may be weak, without sweet or aromatic nuances. The taste may not be rich enough. Capping was the most important step in this study. It is the taste and aroma of the finished drink, and not the colour of the beans or its physical and chemical properties, that are important for the end consumer. The reproducibility of the taste and aroma of coffee is a big problem. The results of capping all coffee samples are presented in Figure 2.

It can be seen from the petal diagrams (Figure 2) that the best taste and aroma properties are inherent in samples A3 and R2, and the worst in samples A1 and R1. Thus, the samples fried at low temperatures were not sufficiently balanced in acidity, their taste properties were also uncertain. Sample S1 was markedly bitter, and sample S2, with higher extractives, had an unpleasant tarry taste. The calculation of the total number of points for all samples testified to the best organoleptic indicators of samples R2 and A3, and the worst for samples R1 and A1. The last samples were roasted at a temperature of 180 ^{0}C, which is clearly not enough to fully reveal the taste and aroma properties of coffee in a drink. On the other hand, the coloration of these samples was the weakest, and the first crack appeared earlier than the rest of the samples. The taste of the samples turned out to be slurred with bitterness as a defect. The likely reason for this fact lies in the fact that coffee beans are more dried than roasted. This conclusion is consistent with the analysis of the study [16]. R3 and A3 samples lacked cup clarity and aftertaste. Due to the maximum roasting temperature, their colour was darker, and the content of extractives was relatively high. The resulting unpleasant aftertaste is probably associated with the formation of compounds that mask the characteristic taste and aroma of coffee [2]. It is important to note that the assessments of the experts coincided with the assessments of the Artisan-software. The relationships between serving temperature and the sensory attributes were evaluated in PCA with all sensory attributes included. A total of 95.5% of the variance was explained in the first two components (Figure 3). First principal component (87.2%) described the difference between the lower 180 °C versus the higher 220 °C maximum roasting temperatures. Second principal component (8.3%) mainly described the difference between two species of green coffee beans Arabica and Robusta. Correlation of samples with attribute loads showed a clear separation of samples, shifting from more “uniformity”, “Clean cup”, “acidity", "aftertaste" characteristics (A1 - A3) to more distinct "aroma", "flavour" characteristics (R1 - R3).

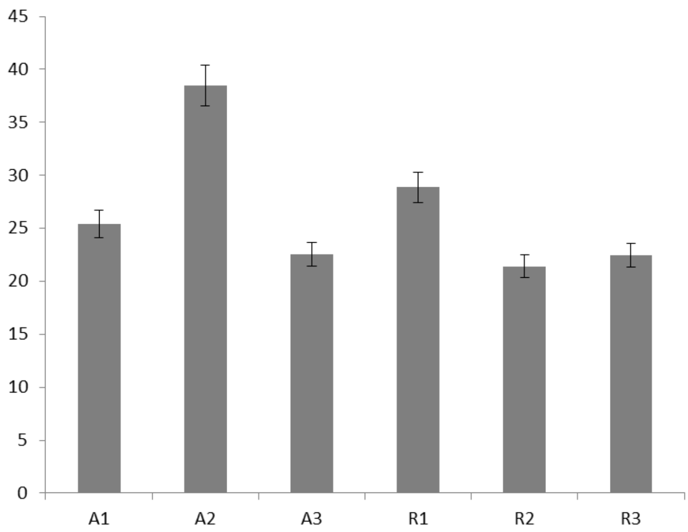

Figure 1. The content of extractives in espresso coffee made from samples. *Source: Authors.*

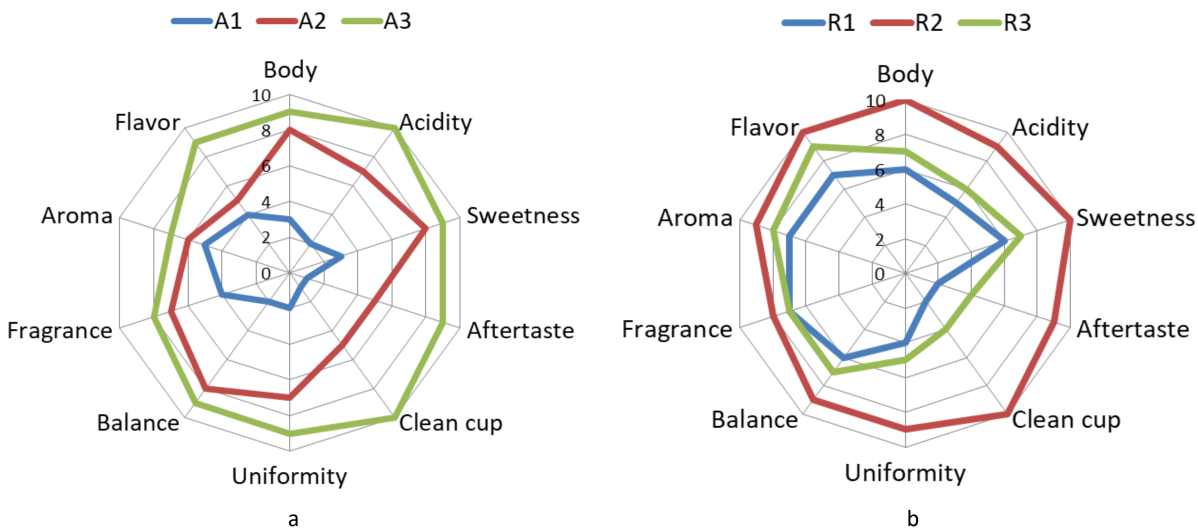

Figure 2. Spider plots showing consensus mean scores of espressos sensory evaluation (a) Arabica Santos and (b) Robusta Vietnam. *Source: Authors.*

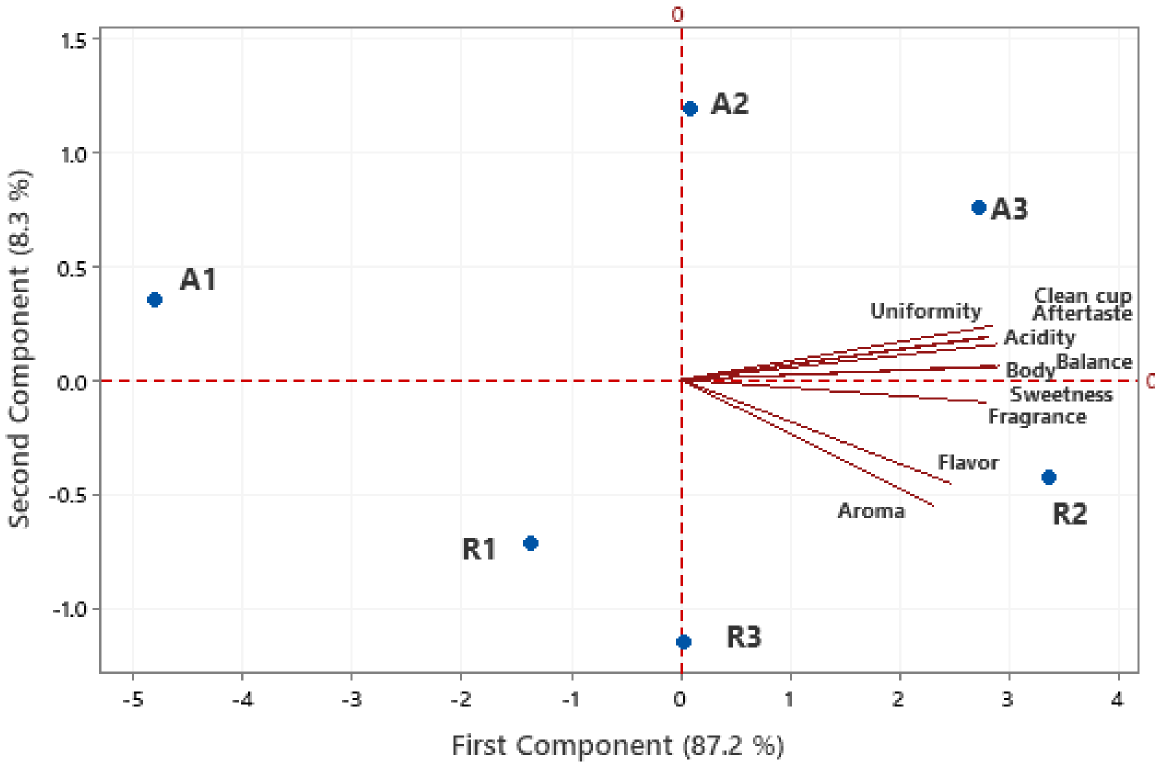

Figure 3. PCA bi-plot: loading of sensory characteristics of espresso coffee and scope of roasted coffee beans samples. *Source: Authors.*

None of the samples received the maximum score from the experts. For A3, the taste is shifted towards Acidity, and the palatability is not sufficiently developed and pronounced (Figure 3). For R2, we didn't reveal enough flavours. Thus, the best roasting conditions for Vietnam Robusta were the maximum roasting temperature of 200 ^{0}C and the time of coffee in the roaster of 11:34 min for sample R2. Arabica Santos, known as a mild coffee with a comparatively low caffeine content [24], required a higher temperature of 220 ^{0}C with a faster roast time of 8:09 min for sample A3. For both samples, the duration of the drying step was almost the same, but sample R2 needed a longer firing than sample A3. These conditions make it possible to obtain coffee with a rich colour, with the content of extractive substances corresponding to the standard [13] and a good balance of taste and aroma properties.

It should be noted that the empirical study made it possible to obtain results that are fair for the tested conditions, which determine their limitation. Similar judgments are also given by the authors of a multi-study empirical investigation [1]. The main aspect limiting the wide application of the results is the use of unwashed coffee beans roasted using a coffee roasting machine shop type TKM-SX 1 with a flame drum. This should be taken into account when generalizing these results to both other types of processed coffee and other roasters, especially if the scale of the process extends beyond the coffee house. The process of roasting coffee in the production workshops of enterprises and small coffee houses is fundamentally different. Full automation and unification, combined with optimization of the duration of processes as a systematic approach, are important in the enterprise, which will certainly affect the quality of the product. Smaller coffee shops are more focused on a specific segment, using more expensive coffees and a much more flexible empirical process with a combination of visual and hardware control at the final stage of roasting. Visual control allows you to observe the change in colour and appearance of the beans during roasting, and hardware control can provide accurate numerical data. However, even with the correct use of the software, there are many factors that directly affect the "final cup". These factors contribute to achieving the desired result in achieving optimal coffee taste and quality.

Impact

The implementation of the research results will improve the technology of roasted coffee beans to obtain a quality beverage. This will contribute to the solution of an important social task of improving the health of the population. On the one hand, coffee is one of the most popular beverages in the world, the consumption of which is growing significantly from year to year in many countries, including Ukraine. The main reason for this fact is the desire to satisfy the need, intensify activity or simply relax. These are important factors for creating an atmosphere of maximum effective work for members of a sustainable community. On the other hand, scientists argue that there are benefits from quality natural coffee. So for women, caffeine as a component of coffee speeds up metabolism, stimulates digestion and promotes weight loss. For men, natural coffee's health benefits lie in its aphrodisiac action, an important aspect of population demographics.

The shift in the consumer's focus towards the consumption of natural coffee from roasted coffee beans compared to instant coffee allows reducing additional and rather significant energy costs that occur at the freeze-drying stage. It is an important economic factor for coffee industry enterprises.

Conclusions

The overall aim of this investigation was to assess the relative importance of roasting temperatures on the sensory properties of coffee. It has been shown that roasting conditions (maximum temperature, duration of drying and roasting processes) significantly affect both the physicochemical and sensory characteristics of he finished drink. The results obtained indicate that roasting coffee at temperatures below 200 ºC does not allow for sufficiently revealing the taste and aroma during brewing: the drink is unsaturated and inexpressive. The combination of high temperatures (200 - 220 ºC) with moderate ageing in the roaster allows you to achieve good results. Even with the use of special software, the roaster's qualifications have a strong impact on the result. For example, they must understand the raw materials they are working with; conduct an auditory (crackle) and visual (bean colour) assessment of the process; understand the impact of roasting parameters (temperature, duration of stages, profiles) on the physical and chemical processes that occur in the beans; and systematically document the roasting process and its parameters to achieve the desired flavour profile.

Conflict of interest

There are no conflicts to declare.

Acknowledgments

This research has not been supported by any external funding. The authors express their gratitude to the management and employees of Bacara Coffee (Chernivtsi, Ukraine) for the provided samples, the possibility of using the equipment and performing sensory analysis.

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