Ildikó Bálint[1]

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Special designs of popularity tests, consumer preferences of coffee beverages

1. Summary

In my work, the balanced incomplete block (BIB) design, common in sensory analysis, but rarely used in product development or the design of experiments, is presented, with the examples of coffee beverages made of different coffee blends. It is a common feature of product development that a large number of consumer assessments (more than sixty assessments per target group, per cell) have to be performed simultaneously regarding many products (more than 6), however the limitations of this are discussed extensively in the literature. So, the reliability of the tests is significantly distorted by sensory fatigue, excessive mental strain and loss of motivation of the assessor, however, these factors can be avoided by developing the appropriate experimental design. One of the major advantages of the BIB design is that only a small portion of the samples (no more than six) are evaluated by the assessors, however, the nature of the result obtained after summarizing and analyzing the assessments is completely in line with the value which would have been obtained if every sample had been assessed by each assessor. Because of the complex nature of the coffee beverages and their fast-changing sensory characteristics, only a total of 4 samples of the 10 different coffee beverages involved in the test were evaluated by each assessor.

2. Introduction

2.1. Consumer sensory testing

According to their qualifications, sensory assessors can be divided into three categories: non-professional (naive) consumer assessors, trained assessors, and expert assessors. For different types of tasks, the application of assessors with different qualifications are required **[25], [27]**. It is characteristic of the attitudes of non-professional consumers that they experience their sensations, and not analyze them, they rely on their own experience during the assessment, and project their own tastes onto the products assessed. Therefore, questions posed to non-professional consumers are aimed at popularity, preference. During studies, that are called consumer tests in general, a query with a large number of people (at least 60 persons per target group, per cell) representing the basic population (in terms of gender, age, address, level of education, net salary, etc.) based on a sampling plan is performed. Assessors typically do not have prior knowledge of the product, only a few products are evaluated by them, with the help of simplified scales and easy-to-understand, short questionnaires. In this case, in reality, the personal, subjective taste is analyzed **[23], [38], [13]**.

Consumer sensory tests are useful in the field of plant breeding, because popularity analysis of the plant species and cultivars can provide valuable data for geneticists, when determining breeding directions. Examples of this are the performance evaluations of gene bank basil cultivars **[4], [5],** sweet corn cultivars **[16], [17]**, cherry tomato regional and commercial cultivars **[8], [9]**, thyme cultivars **[35], [37]**, sedum species **[46]**, champignons **[12]** and apple cultivars **[41]**.

The goal of food industry product optimization is the development of a product that, in addition to food safety and nutritional value aspects, can be preferred from an organoleptic point of view to satisfy consumer demands. For example, consumer preference

[1] Szent István University, Faculty of Food Science, Department of Postharvest

tests carried out in the case of pastas and breads made of aleurone-rich flours **[1], [2]**, different coffee blends **[48]**, flavored kefirs **[15]**, flavored bottled waters **[40]**, margarines **[21], [22]** mineral waters **[42]**, cola beverages **[47]**, frozen sweet corn products **[32]**, apple beverages **[30]**, tea beverages **[29]**.

Development of a product that satisfies consumer demands and one that is optimal from an organoleptic point of view poses challenges to stakeholders of the food industry. Identification of the most and least preferred products, and the determination of development directions can be aided efficiently by preference mapping. The essence of the preference method is the determination of a mathematical relationship between the popularity test performed for a given product group by a large group of non-professional consumers and an organoleptic test carried out by a small expert assessor group. Therefore, it is of utmost importance to follow the performance of expert assessors and assessor panels (consensus, differentiation ability, repeating ability, etc.) **[18], [20], [39], [43]**.

However, in industrial practice, market analysis and development regarding a given product are greatly influenced by time pressure and shrinking research resources. Large scale representative studies are being replaced more and more by small scale market research methods requiring fewer resources, that can be performed more quickly and economically. This trend is supported by the newly developed advanced statistical methods which compare the consumer popularities of products or prototypes **[45], [33]**.

In practice, during the organoleptic optimization of the products, an optimum scale (just-about-right, JAR) is used. The JAR scale is used in consumer research in order to determine the level of an organoleptic characteristic in a product (too high, too low, just right). When analyzing the relationship between JAR characteristics and overall popularity, penalty analysis has become the most widely used technique. Penalty analysis tells you which characteristics need to be changed, and to what extent, to achieve a higher consumer popularity. During development, it is an important issue to determine the priority of the characteristics, because the decision of the manufacturer whether it is worth developing a given property can be reasonably based on this. With the help of a new software method, available free of charge, these issues can be solved, based on the generalized pair correlation method (GPCM) **[19]**.

Food selection is a multi-complex process, influenced by several factors. There have been many international publications dealing with the psychological and/or economic factors that play significant roles in the decision-making. Both international and domestic research has been focusing more and more on subconscious research, such as the eye tracking analysis of eye movement and pupil dilation **[14], [28]**.

2.2. Balanced Incomplete Block Design, BIBD) and its fields of application

During sensory testing, it is important to follow standard organoleptic practice. By developing an appropriate experimental design, obtaining results that cannot be assessed and which are unreliable can be avoided. An important aspect of the experimental design is the order of the test samples to be evaluated by the assessors. In consumer studies, the testing of no more than 6 products is recommended at one time, in order to prevent sensory and mental fatigue **[31]**. It is also a rule that, in the case of sensory testing of more than one sample, samples should be presented in a random order, and assessors should receive the samples to be evaluated in different order, because this reduces taste carry-over and the order effect.

The experimental setup can be divided into subsets, so-called blocks. Blocks can be formed by samples, assessors, or other layout factors (e.g., management plan). For example, if the assessors are divided into subsets (blocks), then given block contains all the tests performed by the assessor. Two block layout types can be distinguished: the complete and the incomplete design. The complete block design can be considered ideal, because all of the samples are presented to each assessor during the test. In the case of the incomplete block design, either all the samples are presented during different sessions, or only a fraction of the total sample number is evaluated by a given assessor. With this design, the distorting effect of sensory fatigue can be avoided. It is important in both cases to present the samples to be evaluated in a random order, and for their order to be balanced. In the generally used complete balanced block design, the numbers of samples evaluated by the assessors are the same, each sample is presented, in combination with every other sample, to the assessor during a session the same number of times, and every sample is assessed the same number of times **[26]**.

Thus, the advantage of the incomplete balanced block design is that only a fraction of the total sample number is evaluated by the assessors, however, the nature of the result obtained after summarizing and analyzing the assessments is completely in line with the method where each sample is evaluated by every assessor. One of the disadvantages of the BIB design is that a total sample number and a sample number per assessor value are accompanied by a specific, predetermined number of assessments. The fewer the number of samples evaluated by an assessor according to the BIB design, the larger the number of assessors needed. When evaluating data of this type of structure, the application of advanced statistical methods is required. In the case of consumer sensory tests, results obtained according to the BIB design can be classified into two types: score or ranking **[24]**.

To evaluate score date in the case of the BIB design, application of the General Linear Model (*GLM*) or of the mixed model is necessary. The type of analysis of variance (ANOVA) used for the analysis of BIB data depends on how the design is determined. The BIB design has to be repeated *p* times, in order to reach the appropriate level of accuracy for the test. If the sample number is too large for each assessor to evaluate each sample, then each *p*b* assessor has to evaluate only one sample array (block) of *k* sample. The order of evaluation, within the block, in which the *k* samples are evaluated has to be selected in random. If the critical value of *F* is exceeded by the *F*-test performed with the degrees of freedom prescribed by the standard, then the null hypothesis of the same average values is rejected. If the *F*-test is significant, calculation of *L* with a multiple comparison method, such as the Fisher LSD, is necessary, to determine which samples are significantly different from the others. To evaluate ranking data, a Friedman-type statistics is required, described in detail by standard ISO 29842:2011 **[24]**.

2.3. The effects of coffee roasting

Thanks to its favorable organoleptic properties and to the stimulating effect of the caffeine found in it, coffee is an important product consumed all over the world, whose trade is growing year in, year out **[50]**. Coffee quality is affected by several factors. In addition to good quality raw material (coffee beans), one of the most important factors is roasting, which can influence the favorable organoleptic properties of coffee. Important variables of roasting include the temperature or the color or darkening of the coffee beans **[44]**. More than one thousand chemical reactions take place simultaneously during roasting. These include the Maillard reaction, the Strecker reaction, and decomposition reactions of polysaccharides, proteins, chlorogenic acids and trigonellines **[49]**.

Maximum chlorogenic acid content is genetically determined, however, its formation depends on several other factors, such as the ripeness of the crop, the agricultural methods used, the climate of the growing region and the composition of the soil. Chlorogenic acid content on a dry matter basis is between 5 and 6% for *Coffea arabica*, while between 7 and 12% for *Coffea caenophora*. In coffee beans, a chlorogenic acids form a complex with caffeine. Green (raw) coffee is one of the major sources of chlorogenic acids (CGA) in nature (5–12 g/100 g), the consumption of which can reduce the risk of cardiovascular diseases, type 2 diabetes and Alzheimer"s **[10]**, **[11]**.

During the roasting of coffee, chlorogenic acids participate in the development of color, flavor and aroma. During roasting their amount changes, they are transformed in the coffee beans. Due to intense roasting, because of their thermal instability, they almost completely decompose. Due to dark roasting, with each percent loss in dry matter content, a chlorogenic acid loss of 8 to 10% can be detected. The chlorogenic acid content of commercially available roasted coffees ranges from 0.5 to 7%, depending on the processing method, the roast intensity, the composition of the blend and the analytical method. Among people not consuming coffee, the daily intake of chlorogenic acid is around 100 mg, while for people consuming moderate to large amounts, the value is estimated between 0.1 and 2 g **[7]**.

While the amount of phenolic antioxidants (mainly chlorogenic acids) naturally occurring in coffee decreases during roasting, the total antioxidant content does not change, or it can even increase. This is due to the formation of compounds with antioxidant effects, especially the products of the Maillard reaction. The amounts of the reagents of the Maillard reaction depend on the coffee species and cultivar, resulting in different antioxidant activities during roasting **[36]**.

Green (raw) coffee is characterized by pea-like, potato-like aroma notes, caused by high levels of thermally stable 3-alkyl-2-methoxypyrazine and 3-isobutyl-2-methoxypyrazine compounds. Roasting produces intense odor substances, suppressing methoxypyrazines, which provide the characteristic notes of raw coffee **[3]**. Saccharides and trigonellines act as precursors of aromas, resulting in countless compounds which participate in the development of the aroma and flavor of the coffee beverage. The bitterness of the beverage is caused by the phenolic compounds that form during the thermal decomposition of chlorogenic acids. Non-volatile humic acids and melanoidins are the end products of the Maillard reaction between amino acids and monosaccharides, these are the compounds that give roasted coffee its characteristic brown color. Volatile coffee compounds form in extremely complex ways, often through interrelated reaction pathways **[6]**.

The characteristic flavor and aroma of coffee depends on several factors: the species, the cultivar, the growing region, the processing method, the roasting conditions, the method of preparation of the coffee beverage, etc. Non-volatile components of coffee determine its pungent and bitter nature, while the volatile components of the coffee beverage determine its characteristic coffee flavor. The composition of the volatile fraction of roasted coffee is very diverse. To date, more than 850 volatile components have been identified. The aroma profile of coffee, such as sweet/caramel-like, earthy, roasted, smoky/phenolic, fruity and spicy aromas, are presented in aroma wheels. Alkylpyrazines and phenols are contained in significantly higher concentrations by *Coffea robusta* coffees than by *Coffea arabica* coffee. Accordingly, more earthy and smoky, phenolic notes appear in the aroma profile more intensely. *Coffea arabica* coffee is usually richer in groups of sweet/caramel-like volatile components. Coffee aromas are not stable, fresh notes evaporate quickly.

The aroma profile changes, and mainly slowly evaporating furanones remain **[3]**.

3. Objective

In my work, the objective was to demonstrate, in practice, the sensory methodology of balanced incomplete block design by the optimization of the consumer popularity of the different roast intensities of beverages made from *Coffea arabica* green-roasted coffee, and *Coffea canephora (robusta)* green-roasted coffee blends. My research question is how well the more aroma poor nature of green coffee is obscured by more darkly roasted coffee mixed with green coffee. From a sensory point of view, another research question is how the sensory popularity (odor, flavor, color, texture, overall popularity) of coffee is influenced by blending ratios and roast degree. Based on the results, it can be determined whether it is the blending ratio or the roast degree that influences more strongly consumer preference. Another expected result is the determination of the ideal blending ratio (roasted: green, arabica: robusta), and of the ideal roast degree, favored most by consumers.

4. Materials and methods

In my work, green coffee beans of two species *(Coffea arabica, Coffea canophora (robusta))* and the beverages made from them were examined. The quality testing of green coffee bean raw materials was performed according to standard MSZ ISO 10470:2014. Samples were provided by Sara Lee Hungary Zrt. Roasting was carried out using a Hearthware i-Roast 1 roasting equipment. 100 grams each of the green coffee samples were roasted, using two different roasting programs. Parameters of the two roasting programs are presented in ***Table 1***.

Roasted and green coffee blends were weighed on a desktop balance, with 0.01 g accuracy. Blends with ratios of 1:3, 1:2 and 3:1 were prepared from the ground green (raw) and roasted varieties of the same coffee species (*arabica* or *robusta*). *Arabica* coffee was not mixed with *robusta*.

Coffee beverages were prepared using a piston-type (French press) UPPHETTA coffee machine, from non-carbonated mineral water with a neutral sensory profile, according to the same protocol. 25 grams of the ground coffee sample was measured into the French press coffee container. Subsequently, 0.5 liter of hot water (approx. 95 °C) was poured onto the ground coffee, and the lid of the container was placed on top, with the filter in the up position. The mixture was allowed to stand for 30 seconds, then it was stirred ten times with the help of a spoon, to promote more even dissolution. Following this, the ground coffee was allowed to soak in the covered container for 4 minutes, during which time the final aroma of the beverage develops. As a final step, the beverage was filtered using the filter of the coffee machine, and it was poured into glasses. As sensory analysis of coffee beverages, consumer popularity tests were performed on 10 different coffee blends.

Since the total number of brews is more than the six samples to be analyzed, proposed by the literature, therefore, to prevent sensory fatigue, the so-called balanced incomplete block design (BIB), a specific method recommended by the international standard, was used. Several plans are made available by the international standard in the case of 10 samples, from which I chose the one where the number of assessors in a block, and the number of samples evaluated by a single assessor are as small as possible. In the case of 10 samples tested, this means a block consisting of 10 assessors, where 4 samples are assessed by each assessor. In order to achieve adequate levels of precision for the testing, the total number of required evaluations is prescribed for 60 assessors by the standard. Accordingly, the operation in the block design was repeated four times **[24]**. BIB design of the consumer tests is presented in ***Table 2***. In the abbreviations, the first letter indicates the type of coffee used, the number indicates the roasting program, while the percentage is the amount of roasted coffee in the blend, in percent. For example, sample A1 25% is an Arabica coffee blend, with a roasted to green coffee ratio of 1:3, roasted by program 1.

Assessors were full-time undergraduate students of Szent István University. It was assumed that assessors participating in the experiment possessed average organoleptic sensitivity, modeling the average consumer. The consumer preference test was performed in the Sensory Qualification Laboratory of Szent István University. Since the laboratory meets international standards, assessment conditions can be considered constant (ISO 8589:2007) **[51]**. During the consumer preference test, coffee beverages had to be evaluated by assessors in a questionnaire form. When developing the consumer questionnaire, my goal was simplicity, because willingness to respond depends largely on the formulation of the questions. To characterize coffee beverages, a 9-point scale was used, from the least characteristic to the most characteristic category. Each category was identified by a symbol. In the first question, the overall popularity of the coffee beverages had to be assessed. This was followed by the evaluation, based on preference, of the different organoleptic properties – color, acidity, bitterness, flavor and smell. Finally, there was a ranking question, where 4 samples had to be ranked according to preference. The questionnaire was concluded by questions regarding general consumer habits, age and gender.

5. Results

The green coffee defect reference table, illustrating green coffee defects with pictures, is found in the annex of international standard MSZ ISO 10470:2004 **[34]**. With its help, defective beans were grouped, weight percentages of the defect groups were calculated (%), and then the given weight percentage was multiplied by the individual weight loss and sensory defect coefficients, giving the "*quality-affecting units*" of the given green coffee batch. Based on the results, the amount of defective coffee beans in the *Coffea robusta* and *Coffea arabica* green coffee batches tested by me was low, less than 5%.

The age of the consumers surveyed was between 19 and 25, the gender ratio was balanced. Nearly one half of the assessors (41%) consumed coffee-based beverages one or more times a day, almost one third (30%) one or more times a week, and almost another third of them (28.3%) rarely or not at all. In contrast, nearly half of the assessors (45%) consumed espresso coffee beverage (short coffee beverage without sugar and milk) only once a month, less frequently or not at all, almost one third (28.3%) once a day, and more than one quarter (26.6%) one or more times a week. Score averages of the coffee beverages made of the different blends are illustrated with their standard deviations, marking separately on the diagrams with letters the results of head-to-head comparisons. Higher roasted coffee contents were illustrated with darker colors in the diagrams, while type 1 and 2 roasting and the different coffee cultivars were also marked with different colors.

Overall popularity results of the coffee beverages are illustrated in ***Figure 1***. Based on the score averages of the answers given to the consumer questionnaire, the most preferred coffees in terms of overall preference are the more intensely roasted *arabica* with 50%, 25% and 0% green coffee content, and *robusta* coffee with 25% green coffee content.

5.1. Overall popularity of the coffee beverages tested

Based on overall popularity, the most preferred samples were coffee beverages made of type 2 roasted 25%, 50%, 75%, 100% arabica and 75% robusta ground coffees, and they did not differ significantly, according to the head-to-head difference calculations. In terms of overall popularity, the least preferred coffee beverage was the type 1 roasted 25% *arabica* coffee beverage. According to the Tukey HSD test, arabica and robusta blends from type 2 roast were significantly different from the type 1 roast 25% arabica blend in terms of overall popularity. Arabica and robusta beverages containing type 1 roast coffee can be considered similar in terms of overall popularity, in case of these samples.

5.2. Color popularity of the coffee beverages tested

Results regarding the color popularities of the coffee beverages are presented in ***Figure 2***. Based on the scores, type 2 roast 50%, 75% and 100% *arabica* and the 75% *robusta* coffee beverages were the most popular. According to the calculations of head-to-head differences, consumers could not differentiate between the colors of coffee beverages made from type 2 roast 25%, 50%, 75% and 100% arabica and the 75% robusta *ground* coffees. The color of the type 1 roast 25% arabica coffee was the least preferred. In terms of color, there was a significant difference between the type 1 roast 25% *arabica* coffee and type 1 roast 75% *arabica*.

5.3. Acidity popularity of the coffee beverages tested

Results regarding the acidity popularities are presented in ***Figure 3***. Based on the answers, the darkly roasted 75% *arabica* coffee beverage was the most popular. According to the calculations of head-to-head differences, the acidity of the type 2 roast 75% arabica coffee beverage differed significantly from that of the lightly roasted 25% and 100% *arabica* blends. Lightly roasted 25% *arabica* was the least preferred, not differing significantly from lightly roasted 50%, 75% and 100% *arabica* and the 75% *robusta* blends.

5.4. Bitterness popularity of the coffee beverages tested

Results regarding the bitterness popularities are presented in ***Figure 4***. Based on consumer evaluation, the darkly roasted 50% *arabica* coffee beverage was the most popular. Type 2 roast 50% arabica differs from type 1 roast 25% arabica and the 75% *robusta* coffee, and from the type 1 roast 50% *arabica* coffee. In terms of bitterness, the type 1 roast 25% *arabica* blend was least preferred by consumers. Based on the Tukey HSD test, there was no significant difference between the lightly roasted 25% *arabica* and the lightly roasted 75% *robusta*.

5.5. Smell popularity of the coffee beverages tested

Results regarding the smell popularities are presented in ***Figure 5***. According to consumer results, the type 2 roast 100% arabica coffee beverage was the most popular, while the type 1 roast 25% *arabica* the least popular. This sample, based on the head-to-head difference matrix, does not differ significantly from the type 1 roast 50%, 75% and 100% arabica blends.

5.6. Flavor popularity of the coffee beverages tested

Results regarding the flavor popularities are presented in ***Figure 6***. Based on head-to-head differences, the most popular one was the type 2 roast 75% arabica. According to consumer opinion, in terms of flavor, the type 1 roast 25% *arabica* coffee beverage was the least popular. This sample did not differ significantly from the type 1 roast 50%, 75% and 100% *arabica* and the 75% *robusta* coffee beverages in terms of flavor.

A popularity ranking was established by the consumers, based on the 4 samples tested by them. According to the international standard regarding the evaluation of the data (ISO 8587:2014) **[52]**, if there is no expected order, a Friedman test has to be performed to compare the products. When evaluating the data, guidelines of the standard were followed. A ranking can be considered significant at a given risk level, if the value of the calculated F-test exceeds the F-value corresponding to the given significance level.

According to the international standard (ISO 8587:2014) **[52]**, if the number of assessors exceeds 20, then the exact values of the distribution can be well approximated by the values of the χ^2 distribution. In my study, 60 assessors (4x15) participated. The number of products was 10, the degree of freedom n-1=9. The critical value corresponding to the degree of freedom of n-1, in the case of predetermined type I errors are 16.92 (α=0.05) and 21.67 (α=0.01). The value of the F_{test} calculated according to the formula of the Friedman test found in the standard is 80.7. Since 80.7 is greater than the 21.67, calculated with the p=10 value approximated with the χ^2 distribution value at a significance level of α=0.01, the conclusion can be drawn that, in the given test, the 10 samples differ from each other significantly, with a 1% risk of error.

Because there is a clear difference between the product rankings, according to the Friedman test, it was analyzed, with a risk selected after determination of the least significant difference (LSD) value, which products differ from each other significantly. Results are presented in ***Table 3***.

6. Conclusions

My studies proved that the BIB design can be used well and effectively for the consumer sensory preference testing of several products. Based on the results, the more aroma poor characteristic of green coffee can be obscured by more darkly roasted coffee, mixed with green coffee. It can be concluded that consumers did not experience a significant difference between blends with differing green coffee contents in terms of overall popularity, neither in the case of lighter, nor in the case of darker roasting. Based on the bitterness, acidity, smell and flavor test results it can be stated in summary that changes in the amount of green coffee could not be detected by consumers, i.e. non-professional assessors, below a green coffee content of 50%. Assessors preferred more darkly roasted coffee blends, reminding them more of the characteristics of the typical espresso coffee. Overall, it can be stated that the popularity of green-roasted coffees was influenced more by the degree of roasting than by the choice of green coffee content. Based on international publications, I consider it necessary to perform further studies on the subject, such as the determination of the active ingredient content of the blends, or the profiling of the aroma substances of the blends.

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