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Abstract: Polarized Sensory Positioning (PSP) is a relatively new methodology for sensory characterization, based on the comparison of samples to reference samples, usually called poles. The key step in the implementation of this methodology is the selection of the poles. In this context, the aim of the present work was to gain insights on the strategies used by consumers to complete this task and to study the influence of the number and characteristics of the poles on results from PSP. Three consumer studies were carried out, on three product categories: chocolate-flavoured milks, vanilla milk desserts and orange-flavoured powdered drinks. In each study, three groups of consumers (n=40) evaluated samples using one of three sets of two or three poles. After the PSP task consumers indicated how they evaluated the degree of difference between the samples and the poles, and listed the sensory characteristics of the poles they took into account for the evaluation. Consumers tended to evaluate the degree of difference between the samples and each of the poles by evaluating the intensity of one or two main sensory characteristics. Sample configurations obtained using two and three poles did not largely differ, especially when the poles clearly represented the sensory characteristics responsible for the main differences among samples. This work demonstrates that it is possible to unfold a multidimensional sensory space with the use of just two well-selected poles, and that the number of poles should be selected considering the main sensory characteristics that discriminate among samples, and not necessarily to the number of dimensions needed to represent samples in a low-dimensional space.

Cover Letter

May 6th, 2015

To the Editor of Food Quality and Preference,

I would like to submit manuscript entitled "*Pole selection in Polarized Sensory Positioning: Insights from the cognitive aspects behind the task*" by authors G. Ares, L. Antúnez, D. Oliveira, F. Alcaire, A. Giménez, I. Berget, T. Næs and P. Varela for its consideration and possible publication in Food Quality and Preference.

The manuscript aims at contributing to the development of best practices for the selection of poles for PSP studies, providing recommendations on how many poles are necessary for PSP studies and how these poles should be selected.

I look forward to hearing from you.

Yours sincerely,

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Research highlights

- The effect of the number and characteristics of the poles on results from PSP was studied.
- Consumers completed PSP tasks by focusing on specific sensory attributes.
- Sample configurations obtained using two and three poles were similar.
- Pole selection should depend on the characteristics that differentiate samples.

Pole selection in Polarized Sensory Positioning: Insights from the cognitive aspects behind the task

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Abstract

Polarized Sensory Positioning (PSP) is a relatively new methodology for sensory characterization, based on the comparison of samples to reference samples, usually called poles. The key step in the implementation of this methodology is the selection of the poles. In this context, the aim of the present work was to gain insights on the strategies used by consumers to complete this task and to study the influence of the number and characteristics of the poles on results from PSP. Three consumer studies were carried out, on three product categories: chocolate-flavoured milks, vanilla milk desserts and orange-flavoured powdered drinks. In each study, three groups of consumers (n=40) evaluated samples using one of three sets of two or three poles. After the PSP task consumers indicated how they evaluated the degree of difference between the samples and the poles, and listed the sensory characteristics of the poles they took into account for the evaluation. Consumers tended to evaluate the degree of difference between the samples and each of the poles by evaluating the intensity of one or two main sensory characteristics. Sample configurations obtained using two and three poles did not largely differ, especially when the poles clearly represented the sensory characteristics responsible for the main differences among samples. This work demonstrates that it is possible to unfold a multidimensional sensory space with the use of just two well-selected poles, and that the number of poles should be selected considering the main sensory characteristics that discriminate among samples, and not necessarily to the number of dimensions needed to represent samples in a low-dimensional space.

Keywords: *sensory characterization; PSP; reference-based methodologies; consumer*

1. Introduction

Polarized Sensory Positioning (PSP) is a reference-based methodology for sensory characterization with trained, semi-trained or untrained assessors (Varela & Ares, 2012). It is based on the comparison of samples with a set of fixed references, commonly referred to as poles (Teillet 2014). Comparison of samples with references allows comparing data collected in different sessions, which is the main advantage of the methodology. PSP is a good methodological choice for sensory characterization of sample sets that require multiple sessions to be evaluated due to their complexity or intense/persistent sensory characteristics (Ares & Varela, 2014). PSP was initially developed for sensory characterization of mineral waters, which can be regarded as challenging products due to the subtle differences usually found in their sensory profiles (Teillet, 2014). According to Teillet, Schlich, Urbano, Cordelle, & Guichard (2010) the best approach to evaluate the small differences that characterize samples of commercial mineral waters is comparison with references (Teillet, 2014). Initial explorations by Varela et al. (2014) with the use of a trained panel also suggested that PSP could be a good method when enhanced discrimination is sought.

The original application of PSP required assessors to quantify the overall degree of difference between each sample and each of the poles using unstructured scales, ranging from "exactly the same" to "totally different" (Teillet et al., 2010). No indication is given to assessors about the sensory attributes that should be considered in the evaluation of global similarities and differences between samples and the poles or their relative importance. PSP can be seen as a compromise between holistic methods, like projective mapping or sorting, and analytical methods, like flash profiling. In general, holistic methods can be regarded as more natural, less analytic and more representative of consumer evaluation of products than attribute-based methodologies (Ares & Varela, 2014). Thus, it could be expected that sensory characterizations obtained using PSP would better represent consumers' perceived similarities and differences among samples than those obtained using attribute-based techniques. The

potential disadvantage of PSP, as in any holistic methodology, is that assessors could use different criteria for sample evaluation, leading to more noisy data. However, heterogeneity could also be seen as an advantage as it allows considering different points of view, particularly when dealing with large groups of untrained assessors (Ares & Varela, 2014).

PSP has a great potential for sensory characterization with semi-trained or untrained assessors during new product development, due to its iterative nature (Costa & Jongen, 2006). In this process, prototypes are obtained in different moments in time and comparison of their sensory characteristics is usually necessary. PSP allows aggregating and comparing data collected in different sessions. However, published applications of PSP are limited to a few products, which include mineral water (Teillet et al., 2010), cosmetic creams (Chrea, Teillet, & Navarro, 2011), chocolate flavoured milk (Antúnez, Salvador, de Saldamando, Varela, Giménez, & Ares, 2015), cheese and meatballs (Varela, Svartebekk Myhrer, Næs, & Hersleth,2014), yogurt (Cadena et al., 2014), make-up foundations and orange flavoured powdered drinks (de Saldamando, Delgado, Herencia, Giménez, & Ares, 2013).

The selection of the poles is probably the most important step for the implementation of this methodology. In this sense, one of the first questions that arises when designing a PSP study is how many poles should be considered. Although it can be hypothesized that using more poles could enable to detect more detailed differences among samples, it should be taken into account that increasing the number of poles makes the task more difficult and tedious, increasing sensory fatigue and becoming more cognitively requiring.

The usual number of poles that has been used in PSP studies is three (Teillet, 2014). This number has been recommended, assuming that most information about the sensory characteristics of samples would be represented in a two-dimensional space, and considering that three poles would be needed to stabilize that space. According to this criterion, if more than two dimensions are expected to be necessary to represent

the similarities and differences among samples, the number of poles should be augmented. However, Teillet et al. (2010) has reported that a three-dimensional space was defined using a PSP task with three poles. This result suggests that the number of poles necessary for defining a sensory space would depend on the number of *sensory dimensions* responsible for the main similarities and differences among samples, rather than on the *spatial dimensions*. It could be hypothesized then, that if samples differ in two main sensory dimensions and the sensory space is simple enough, only two poles could be enough as long as the two sensory dimensions are adequately represented by the selected poles.

Therefore, how to select the poles is a relevant question that still needs to be answered. Published studies have selected poles that represent the main sensory characteristics responsible for the expected similarities and differences among samples. For example, according to Teillet et al. (2010) degree of mineralization was considered the main determinant of the sensory characteristics of mineral water. Waters with low mineralization are characterized by their metallic and bitter taste, waters with medium mineral content show neutral and fresh taste, while high mineralization provides salty taste. For this reason, the authors selected three poles with different degrees of mineralization (low, intermediate and high). Other research has shown that small changes in the set of poles do not lead to relevant changes in sample configurations, as long as the poles represent the main sensory characteristics responsible for similarities and differences among samples (de Saldamando et al., 2013, Teillet, 2014).

Understanding the cognitive strategies used by assessors to estimate the degree of difference between the samples and the poles could also contribute to generate recommendations on how to select the poles. That is, if assessors evaluate the differences thinking of one or two main sensory attributes, or if on the other hand, they assess the samples from a more holistic point of view. Those two cognitive paths could potentially require different points of reference or poles.

The present work aims at contributing to the development of best practices for the selection of poles for PSP studies. The following research questions were formulated: How does the number of poles affect sample configurations obtained using PSP? Do the sensory characteristics of the poles influence the number of poles needed in a PSP task? How do assessors evaluate the degree of difference between the samples and the poles? Results are expected to provide insights on how many poles are necessary for PSP studies and how these poles should be selected.

2. Materials and Methods

Across three consumer studies the influence of the number and characteristics of poles on results from PSP was studied using a between-subjects experimental design. In each study three groups of consumers used PSP for characterizing a sample set using different number of poles: one of the groups used 3 poles and the other two groups used 2 different sets of 2 poles. The rational of pole selection is explained in section 2.3. Consumers were asked to complete two open-ended questions about their strategy for evaluating the degree of difference between the samples and the poles and which sensory characteristics of the poles they took into account.

2.1. Consumers

One hundred and twenty consumers participated in each of the three studies, i.e. different consumers participated in each study. All of them were recruited from the consumer database of the Food Science and Technology Department of Universidad de la República (Uruguay), based on their consumption of the target product and their availability to participate. Participants ranged in age from 18 to 49 and were 60% female. They signed an informed consent form and received a small gift for their participation.

2.2. Samples

Three product categories were considered: chocolate-flavoured milk, vanilla milk desserts and orange-flavoured powdered drinks.

Study 1

Eight samples of chocolate flavoured milk were formulated in Study 1, varying the concentration of alkaline cocoa powder and sugar. Sample formulation, presented in Table 1, was determined by pilot testing with trained assessors in order to have samples with noticeable differences in two main sensory characteristics, sweetness and chocolate flavour. The rest of the formulation consisted of 0.08% carrageenan (Ticaloid® 780 Stabilizer, TIC GUMS, Philadelphia, USA) and pasteurized whole milk (up to 100%). Samples were prepared using a Thermomix TM 31 (Vorwerk Mexico S. de R.L. de C.V., Mexico D.F. Mexico). The solid ingredients were mixed with the milk, previously heated to 70°C for 3 min. The dispersion was mixed for 1 min under gentle agitation (100 rpm), heated to 70 °C for 4 min and cooled to 20 °C. Then, samples were placed in glass containers, closed, and maintained under refrigeration temperatures (4 °C ± 1°C). They were removed from the refrigerator as needed immediately prior to sensory evaluation, and dispensed into plastic serving cups.

Insert Table 1 around here

Study 2

Eight milk desserts were formulated by varying the concentration of modified starch (Purity HPC, National Starch and Chemical Company; Bridgewater, NJ, USA) and sugar. Sample formulations (Table 2) were selected based on previous studies to get a set of milk desserts with noticeable different sensory characteristics. Samples contained 12% powdered skimmed milk (Conaprole, Uruguay), 0.4% vanilla flavouring (0.4%), 0.1% sodium tripolyphosphate, 0.025% sucralose (0.025%), 0.02%

carrageenan (TIC PRETESTED® Colloid 710 H, TIC GUMS, Philadelphia, USA), 0.0025% egg yellow colouring, and water (up to 100%). Samples were prepared using a Thermomix TM 31 (Vorwerk Mexico S. de R.L. de C.V., México D.F., México). The solid ingredients were mixed with the water and heated to 90ºC for 5 minutes. Then, the colorant and vanilla flavour were added and the dispersion was mixed again for 1 minute under gentle agitation (100 rpm). The desserts were placed in glass containers and then stored refrigerated (4-7 ºC) for 24 h, prior to their evaluation.

Insert Table 2 around here

Study 3

Six samples of commercial orange-flavoured powdered drinks (samples A to F) were used in Study 3. All samples were available in the Uruguayan market and were purchased from local supermarkets in Montevideo (Uruguay). Two of the samples were selected as poles in the evaluation: pole P1 (sample E) and pole P2 (sample F). Pole P3 corresponded to a commercial sample that was not included in the sample set which, according to previous studies, had similar sensory characteristics to sample B (Ares, de Saldamando, Vidal, Antúnez, Giménez, & Varela, 2013). Samples were prepared following the recommendations provided by the manufacturer on the package. The powders were diluted in tap water and stored at 10°C until they were served to consumers in plastic containers, within 4 hours.

2.3. Experimental design

In each study consumers were randomly assigned to three groups (n=40), each of which evaluated samples using a different set of poles.

One of the groups evaluated samples using Set 1, which was composed of three poles (P1, P2, P3). The poles were selected to represent the main sensory

characteristics responsible for the similarities and differences among samples. The other two groups evaluated the samples using sets of two poles.

In Studies 1 and 2 pole selection was based on sample formulation. The three poles included in Set 1 (P1, P2 and P3) corresponded to extreme points of the experimental design (Figure 1). Set 2 comprised poles with the highest and lowest concentration of the two formulation variables, i.e. Poles P1 and P3. Finally, the third set included poles P1' and P2', which were formulated using the highest concentration of one of the variables and intermediate concentration of the other variable (Figure 1).

Meanwhile, pole selection in Study 3 was based on results from previous studies (Ares et al., 2013). Each of the three poles included in Set 1 represented one of the sensory characteristics responsible for the main differences among samples: sourness, sweetness and total flavour intensity. Sets 2 and 3 were created by selecting two of the poles included in Set 1. Poles P2 and P3 were considered in Set 2, whereas Poles P1 and P2 were included in Set 3.

A summary of the characteristics of the three sets of poles is shown in Table 3.

Insert Figure 1 around here

Insert Table 3 around here

2.4. Data collection

The procedure for data collection was identical in the three studies. Consumers received the three poles and the evaluated samples (coded with three-digit random numbers). The order in which participants received samples differed among participants, following a design balanced for order and carry-over effects (Williams' Latin Square). Consumers were asked to try the poles and to remember their sample characteristics. Then, they had to taste the samples and to rate the overall difference between each sample and each one of the poles using an unstructured scale anchored

from "exactly the same" to "totally different ". The poles were available for re-tasting during the whole evaluation. Consumers were told that they had to complete the task according to their own criteria, taking into account that there were no right or wrong answers. Still mineral water was available for mouth rinsing between samples.

After finishing the task consumers answered the following open-ended questions: “How did you evaluate the degree of difference between samples and the poles?” and “What sensory characteristics of each of the poles did you take into account in the evaluation?”.

Testing took place in a sensory laboratory in standard sensory booths designed in accordance with ISO 8589 (ISO, 2007), under artificial daylight and temperature control (22ºC). Data collection was carried out using *Compusense-at-hand* (Compusense Inc., Guelph, Canada).

2.5. Data analysis

Data from PSP were analysed using Multiple factor Analysis (MFA), considering data from each consumer as a separate group of variables. This approach preserves individual data and compensates for individual differences when scoring global differences between samples and poles (Teillet, 2014). Confidence ellipses were calculated using parametric bootstrapping (Dehlholm, Brockhoff, & Bredie, 2012).

The RV coefficient (Robert & Escoufier, 1976) was used to evaluate the agreement of sample configurations obtained from groups of consumers using different sets of poles. The significance of the RV coefficient was tested using a permutation test (Josse, Pagès, & Husson, 2008).

All statistical analyses were performed in R language (R Core Team, 2013) using FactoMineR (Lê, Josse, & Husson, 2008).

3. Results

3.1. Sample configurations

3.1. Study 1: Chocolate flavoured milks

When the set of three poles (Set 1) was considered in the PSP task the percentage of variance explained by the first and second dimensions of the MFA was 63.8%. As expected, samples were positioned in the bi-dimensional space according to their sugar and cacao concentration. The first dimension of the MFA was positively correlated with sugar content. Samples with the lowest sugar content (C and E) were located at negative values of the first dimension, while samples formulated with the highest sugar content (B and F) were located at the highest positive values of Dimension 1 (Figure 2a). Cacao content was correlated with both the first and second dimensions. Samples formulated with the highest cacao concentration (B and D) were located at positive values of the first and second dimensions, samples with the lowest cacao concentration (A and C) tended to be located at the opposite side of the sensory space, whereas samples with intermediate cacao concentration (E and F) were located between the other two groups. No overlapping in the confidence ellipses was observed, suggesting that the methodology significantly discriminated all samples.

Insert Figure 2 around here

When one of the poles was not included in the PSP task and consumers used only two poles (Set 2, poles P1 and P2) sample configurations were similar (Figure 2b). The percentage of explained variance and conclusions regarding similarities did not largely differ. The RV between samples configurations obtained using Set 1 and Set 2 was significant and close to 0.85 (Table 4). However, some differences between the configurations were identified. When consumers used Set 1, the first dimension of the

MFA was spanned by samples B and C (Figure 1a), whereas when Set 2 was considered these samples spanned the second dimension of the MFA (Figure 2b).

When consumers used Set 3, which also included 2 poles (c.f. Table 3), sample configurations were less similar (Figure 2c). Although samples were distributed along the first dimension according to their sugar content, the influence of cacao content was not very clear. Sample D was separated from the rest of the samples, which could be explained by its high cacao content. However, samples B and F were located very close to each other, as were samples C and E, even though they differed in their cacao content (c.f. Table 1 and Figure 2c). Despite these differences, the RV coefficient between sample configurations obtained using Set 1 and Set 3 was high (Table 4), which can be explained by the similarity between sample configurations in the first dimension of the MFA.

Insert Table 4 around here

3.2. Study 2: Milk desserts

When consumers completed the PSP task using three poles (Set 1), samples were distributed along the first dimension of the MFA according to their starch concentration. The thicker samples (B and D) were located at positive values of the first dimension, whereas samples A and F, formulated with the lowest starch concentration, were located at negative values of Dimension 1 (Figure 3). Sugar concentration was correlated to the second dimension. Samples formulated with low and intermediate sugar concentration (A, B, C and D) tended to be located at positive values of the second dimensions, whereas samples E and F (with the lowest sugar concentration) were located at negative values of the second dimension.

When consumers used Set 2 (which included poles P1 and P2), sample configuration was almost identical to the one obtained using Set 1 (c.f. Figures 3a and 3b), as denoted by the high RV coefficient (RV= 0.986, Table 4).

The sample configuration obtained using Set 3 showed some differences as compared to the configuration obtained with the other two set of poles (Figure 3). This can be visualized by comparing the RV coefficient between sample configurations obtained using the different set of poles (Table 4). In this study, sample discrimination was affected by changing the set of poles. When consumers used Set 3 samples A and F were located almost in the same place of the bi-dimensional space, while samples B and D were significantly discriminated. However, when Set 1 and Set 2 were considered the opposite trend was observed: the confidence ellipses of samples A and F did not overlap, whereas samples B and D were not significantly discriminated.

Insert Figure 3 around here

3.3. Study 3: Powdered orange juices

Four dimensions were necessary to explain the main sensory characteristics responsible for the similarities and differences among the orange-flavoured powdered drink samples considered in Study 3 (Figure 4). When consumers used three poles (Set 1) in the PSP task, three main groups of samples were identified in the first and second dimensions of the MFA (Figure 4a): sample E, a group composed of samples A, F and D, and another group composed of samples B and C. When the third and fourth dimensions of the MFA were considered sample D was located in a distinct position and samples B and C were significantly discriminated.

The sample configuration obtained using Set 2 (two poles) was almost identical to the one obtained using Set 1 in the four dimensions of the MFA (c.f. Figure 4a and b), showing RV coefficients higher than 0.96 (Table 4).

When Set 3 was considered sample configurations were less similar (Figure 4c, Table 4). Sample D was discriminated from samples A and F in the first two dimensions of the sensory space. Besides, consumers were not able to significantly discriminate between samples B and C in the first four dimensions of the MFA,

whereas samples A and F were located in clearly different positions in the third and fourth dimensions of the MFA (Figure 4c).

Insert Figure 4 around here

3.2. Open-ended questions

When consumers were asked about the cognitive strategies they used for evaluating the degree of difference between the samples and the poles, they referred to the evaluation of specific sensory characteristics. They stated that they first tasted the poles and tried to associate each of them with one or two sensory characteristics. Then, when they tasted the samples they evaluated the intensity of those sensory characteristics to evaluate the degree of difference between samples and the poles. Exemplar quotes of consumers' responses are included below:

> *"I tasted samples A2 and B2 and assigned characteristics to each of them. Then, I tried each of the samples looking for those characteristics"*
>
> *"I associated sample A2 with sweetness and sample B2 with bitterness. Then, I tried samples and evaluated those two characteristics to rate their similarity with samples A2 and B2"*
>
> *"I evaluated sweetness, sourness and total flavour intensity, which were the main characteristics of the three poles"*

These results suggest that consumers tend to evaluate the degree of difference between a sample and a pole as the intensity of a sensory characteristic or a group of similar characteristics. This was confirmed by consumers' responses to the open-ended question about the characteristics they took into account for evaluating the degree of difference between samples and each of the poles. As shown in Table 5, in Study 1 consumers mainly referred to sweetness, bitterness and chocolate flavour as the main sensory characteristics that were considered for estimating the degree of

difference between the samples and the poles. As expected, pole P1 was associated with sweetness, while pole P3 was mainly associated with bitterness and chocolate flavour. Pole P2 showed intermediate sensory characteristics, in agreement with its formulation (Table 1). Consumers stated that they took into account both chocolate flavour and sweetness for estimating the degree of difference between this pole and the samples. Pole P2' was expected to represent bitterness and chocolate flavour, as it was formulated with the maximum cacao concentration. It is interesting to note that the frequency of mention of the term bitter was lower than that of pole P3, which could be explained considering the difference in sugar concentration of both samples (Table 1).

In Study 2 results were similar. Consumers mainly took into account thickness and sweetness for estimating the degree of difference between the samples and the poles (Table 5).

In Study 3 the three poles considered in Set 1 represented three different sensory characteristics. Pole P1 was associated with sweetness and orange flavour, pole P2 with sourness and pole P3 with low total flavour intensity, being described as diluted (Table 5).

Insert Table 5 around here

4. Discussion

Selection of poles is a key step for the implementation of Polarized Sensory Positioning (PSP). Therefore, recommendations on how to select the poles are necessary for practitioners. The present work addressed this topic by studying how consumers evaluated the degree of differences between the poles and the samples, and by studying how sample configurations were affected by the number and characteristics of the poles.

4.1. Sensory characteristics of the poles

When completing PSP tasks consumers reported that they tried to identify the most relevant sensory characteristics that differentiated the poles. Then, they associated one or two sensory characteristics with each of the poles and evaluated the degree of difference between samples and each of the poles by measuring the intensity of those sensory characteristics. Therefore, degree of difference ratings are expected to be strongly correlated with the intensity of specific sensory characteristics. These results have several implications for the selection of the poles.

The poles should be perceivable different as they determine consumers' strategies for completing the PSP task. Consumers should be able to clearly identify differences among the poles and to associate these differences with specific sensory characteristics, which is the second implication of the cognitive strategy used by consumers for estimating the degree of difference between the poles and the samples. It is advisable that the poles clearly represent specific sensory characteristics. Sample discrimination in PSP tasks is expected to increase if consumers are able to easily identify the sensory characteristics that drive differences among the poles and to associate a few characteristics with each of the poles.

4.2. Degree of difference among the poles

Studies 1 and 2 provided an insight on the influence of the degree of difference among the poles on sample discrimination in PSP tasks. In both studies samples mainly differed in two sensory characteristics: sweetness and chocolate flavour/bitterness in Study 1, and sweetness and thickness in Study 2. The poles in Set 2 were selected based on their formulation to have high intensity of one sensory characteristic and low intensity of the other (c.f. Tables 1 and 2). Meanwhile, the poles in Set 3 were selected to have high intensity of one sensory characteristic and intermediate intensity of the other. Therefore, the degree of difference between the poles in Set 2 was larger than the difference among the poles in Set 3. When

consumers used Set 2 to complete the PSP task the position of samples along the first and second dimension of the MFA was clearly explained by their formulation (Figures 1 and 2). On the other hand, when consumers evaluated samples using Set 3, samples were not clearly sorted in the first two dimensions of the MFA according to their formulation. It can be hypothesized that when each pole is strongly associated with one sensory characteristic consumers are able to focus on that characteristic and more accurately evaluate the degree of difference between the samples and the poles.

4.3. Number of poles in PSP tasks

Another implication of how consumers complete the PSP task is related to the number of poles needed to obtain a bi-dimensional configuration. Difference ratings seem to be related to the intensity of specific sensory characteristics. Therefore, two poles can accurately represent a sensory space defined by two main groups of sensory characteristics. Samples would be located in the bi-dimensional space according to the intensity of those two groups of characteristics, measured as the degree of difference between samples and each of the poles. This was clearly observed in Studies 1 and 2. Removing one of the poles from Set 1 did not have a relevant effect on sample configurations, and therefore results obtained using two of the poles (Set 2) were almost identical (c.f. Figures 1 and 2, Table 4). Also, the percentage of explained variance did not largely vary when PSP was performed using 2 or 3 poles (Figures 1 and 2). In these studies pole P2 did not seem to add relevant information about similarities and differences among samples as it had intermediate sensory characteristics from poles P1 and P3 (c.f. Tables 1 and 2). However, it should be taken into account that the influence of the number of poles on results from PSP is expected to strongly depend on the sample set, as well as on the sensory characteristics of the poles.

Study 3 provided further insight on the influence of the number of poles in PSP studies. When consumers used three poles four dimensions were necessary to fully

visualize differences among samples, particularly for differentiating samples B and C and samples A and D (Figure 3a). Consumers referred to three main sensory characteristics as responsible for the differences between samples and the poles: sweetness, sourness and total flavour intensity (Table 5). However, it is important to note total flavour intensity can be considered as sweetness and sourness intensity. Sample configurations obtained with three poles (Set 1) and one of the subsets of two poles (Set 2) were almost identical, as shown in Figures 3 (a) and (b). It is interesting to note that the sample configurations obtained with 2 and 3 poles were similar in both the first two and the first four dimensions of the MFA (Table 4). This suggests that using two poles enabled to obtain a four-dimensional sensory space, which could be explained considering that consumers' heterogeneity was preserved by MFA. Some consumers might have taken into account different sensory characteristic for estimating the degree of difference between samples and the poles and their perception was kept in higher dimensions of the MFA. For example, in Study 3 some consumers referred to orange/citric flavour when asked about the sensory characteristics of the poles they relied on for estimating degree of difference, although the majority of the consumers referred to sweetness, sourness and total flavour intensity (Table 5). Similarly, in Study 1 the main sensory characteristics that characterized the poles were sweetness, bitterness and chocolate flavour. However, some consumers referred to roughness and total flavour intensity for describing the sensory characteristics of the poles.

4.4. Influence of the number of poles on sample discrimination in PSP tasks

When consumers used the other set of two poles (Set 3) sample configurations slightly differed from the one obtained using three poles (Set 1), as shown in Figure 3(c). When P1 and P2 were considered in the task, Sample D, which had intermediate sensory characteristics from the two poles was discriminated from samples A and F in the first dimension of the MFA (Figure 3). However, these samples were only discriminated in the third and fourth dimensions when consumers used three poles (Set

1) or when they used two poles that did not include a sweet sample (Tables 3 and 5). This suggests that discrimination according to sweetness and sourness was achieved considering two poles which differed in these specific characteristics. On the contrary, sample discrimination of diluted samples (B and C) was reduced when a pole representing this sensory characteristic was not included (Set 3). This result indicates that PSP can discriminate samples characterized by sensory attributes that are not represented by the poles, in agreement with results reported by Teillet et al. (2010). These authors reported that a water sample containing chlorine was identified in a PSP study performed using poles that did not represent this sensory attribute. However, it should be taken into account that discriminating ability might be compromised for samples with sensory characteristic that are not well-represented by the poles, as shown in Study 3 for samples B and C. In this sense, it is interesting to stress that sample discrimination did not seem to be affected by removing the pole that represented sweetness in Set 2, probably due to the fact that only one sample was clearly associated with this characteristic (sample E).

4.5. General recommendations, limitations and suggestions for further research

In the light of the obtained results, poles should reflect the main sensory dimensions as represented by the main specific sensory attributes, rather than just expanding the map dimensionality to cover a determined number of factors. This work demonstrates that it is possible to unfold a multidimensional sensory space with the use of two well selected poles. However, care must be taken, as the characteristics of the poles should really reflect the main characteristics that are drivers of the sensory space to being able to obtain reliable results with only two poles. It is also very important to think about the particular objectives of each product characterization study when deciding how to select the poles. In this regard, one can imagine situations in which some sensory dimensions could be more interesting than others (not necessarily the main sensory dimensions), so alternative poles could be selected to get increased

discrimination in those specific dimensions, or cases in which some attributes could be of interest in order to have a good discrimination. More research would be needed to generate recommendations on this aspects.

Further than this, more research would be needed to being able to generalize, but also better understand the limitations of the findings of this work, for example when more complex samples are under study. Sample complexity could be an issue when deciding the number of poles. If multiple texture and flavour characteristics were involved in sample description, or when it is not so easy to explicitly identify main sensory attributes, it would be very likely that the use of two poles would not be enough for characterizing the whole sensory space. Another point to consider in further research should be the degree of difference of the sample set to be characterized, it could be expected that when working with narrower sensory spaces, the use of a low number of poles could be problematic, as assessors might struggle to associate poles and samples with specific sensory attributes or group of attributes.

5. Conclusions

Results from the present work allowed a better understanding of pole selection in PSP Polarized Sensory Positioning studies. As general recommendation, poles should clearly represent the groups of main sensory characteristics responsible for the expected differences among samples. It is advisable to select poles that are perceived as clearly different and that each of the poles clearly represents one or two sensory characteristics.

The number of poles in a PSP task should be related to the number of groups of main sensory characteristics that are expected to discriminate among samples and not necessarily to the number of dimensions needed to represent samples in a low-dimensional space. Therefore, two well selected poles could potentially represent a sensory space defined by two main groups of sensory characteristics. Using two instead of three poles might make the task easier for untrained assessors, and reduce

sensory and cognitive fatigue, but care should be taken when selecting those two poles. PSP seems to be able to identify samples showing sensory characteristics not represented by the poles. However, it should be taken into account that the ability of the task to differentiate among these samples could be expected to be low. The present study did not aim to recommend the use of only two poles in PSP studies, but rather to highlight the potentials of unfolding sensory dimensions based on the diversity of consumers' perceptions.

Further research exploring the influence of the number and characteristics of the poles in studies involving more complex samples would be needed to better understand the implication of the potential unfolding (or not) of the sensory space. Also, the influence of the number of poles on the quality of sensory spaces constructed by aggregating PSP data collected in different sessions and/or with different panels deserves consideration.

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Figure captions

Figure 1. Graphical representation of the formulation of samples and poles in Study 1 (a) and Study 2 (b).

Figure 2. Sample configurations of chocolate flavoured milks in the first two dimensions of Multiple Factor Analysis performed on data from Polarized Sensory Positioning with different sets of poles: (a) Set 1, three poles (P1, P2 and P3), (b) Set 2, two poles (P1 and P3), (c) Set 3, two poles (P1' and P2').

Figure 3. Sample configurations of vanilla milk desserts in the first two dimensions of Multiple Factor Analysis performed on data from Polarized Sensory Positioning with different sets of poles: (a) Set 1, three poles (P1, P2 and P3), (b) Set 2, two poles (P1 and P3), (c) Set 3, two poles (P1' and P2').

Figure 4 Sample configurations of orange flavoured powdered drinks in the first four dimensions of Multiple Factor Analysis performed on data from Polarized Sensory Positioning with different sets of poles: (a) Set 1, three poles (P1, P2 and P3), (b) Set 2, two poles (P1 and P3), (c) Set 3, two poles (P1 and P2).

Tables

Table 1. Formulation of the chocolate flavoured milks used in Study 1. Samples P1, P2, P3, P1' and P2' correspond to poles in the Polarized Sensory Positioning task.

Sample	Sugar (%)	Cacao (%)
A	7.0	1.5
B, P2	9.0	3.5
C	5.0	1.5
D, P2'	7.0	3.5
E	5.0	2.5
F, P1'	9.0	2.5
P1	9.0	1.5
P3	5.0	3.5

Table 2. Formulation of the milk desserts used in Study 2. Samples P1, P2, P3, P1' and P2' correspond to poles in the Polarized Sensory Positioning task.

Sample	Sugar (%)	Starch (%)
A	6.0	3.4
B, P2	8.0	5.0
C, P2'	8.0	4.2
D, P1'	6.0	5.0
E	4.0	4.2
F	4.0	3.4
P1	4.0	5.0
P3	8.0	3.4

Table 3. Description of the three sets of poles used in the three Polarized Sensory Positioning studies.

Study	Set of poles	Pole P1	Pole P2	Pole P3	Pole P1'	Pole P2'
1	1	x	x	X		
	2	x		X		
	3				x	x
2	1	x	x	X		
	2	x		X		
	3				x	x
3	1	x	x	X		
	2		x	x		
	3	x	x			

Table 4. RV coefficients and p-value (between brackets) between sample configurations obtained using Polarized Sensory Positioning with different set of poles in the three consumer studies**.**

Study ID	Dimensions of the MFA	RV coefficient		
		Set 1 (P1, P2 and P3) and Set 2 (P1 and P3)	**Set 1 (P1, P2 and P3) and Set 3 (P1' and P2')**	**Set 2 (P1 and P3) and Set 3 (P1' and P2')**
1	1 and 2	0.865 (0.009)	0.850 (0.011)	0.774 (0.020)
2	1 and 2	0.986 (<0.001)	0.742 (0.030)	0.721 (0.025)
3	1 and 2	0.943 (0.004)	0.897 (0.007)	0.763 (0.023)
	1, 2, 3 and 4	0.968 (0.003)	0.870 (0.022)	0.829 (0.037)

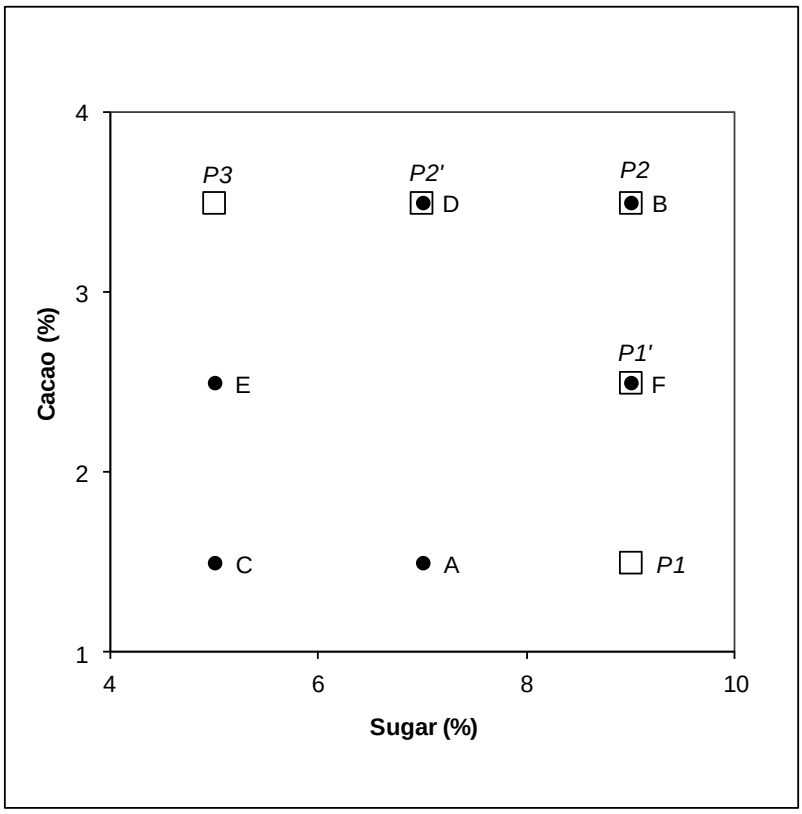
Table 5. Frequency of mention of the characteristics consumers stated to consider when estimating the degree of difference between the samples and the poles in the three studies.

Study	Set 1	Set 2	Set 3
1	*Pole P1* Sweet 88% *Pole P2* Sweet 50% Chocolate 60% *Pole P3* Bitter 65% Chocolate 30%	*Pole P1* Sweet 90% *Pole P3* Bitter 78% Chocolate 48% Not sweet 23%	*Pole P1'* Sweet 93% *Pole P2'* Bitter 43% Chocolate 53% Not sweet 43%
2	*Pole P1* Thick 58% Not very sweet 50% *Pole P2* Thick 73% Sweet 63% *Pole P3* Liquid 95% Sweet 43%	*Pole P1* Thick 88% Not very sweet 50% *Pole P3* Liquid 88% Sweet 83%	*Pole P1'* Thick 63% Sweet 50% *Pole P2'* Sweet 70% Liquid 55%
3	*Pole P1* Sweet 70% Orange flavour 23% *Pole P2* Sour 73% Not sweet 25% *Pole P3* Diluted 63% Sweet 38%	*Pole P2* Sour 75% Not sweet 38% *Pole P3* Diluted 73% Sweet 38%	*Pole P1* Sweet 83% *Pole P2* Sour 78%

Note: For simplicity, only the most frequently mentioned characteristics are included.

Figure 1.

(a)


4
3
2
1
Cacao (%)
P3
P2'
D
P2
B
P1'
E
F
C
A
P1
4
6
8
10
Sugar (%)

(b)

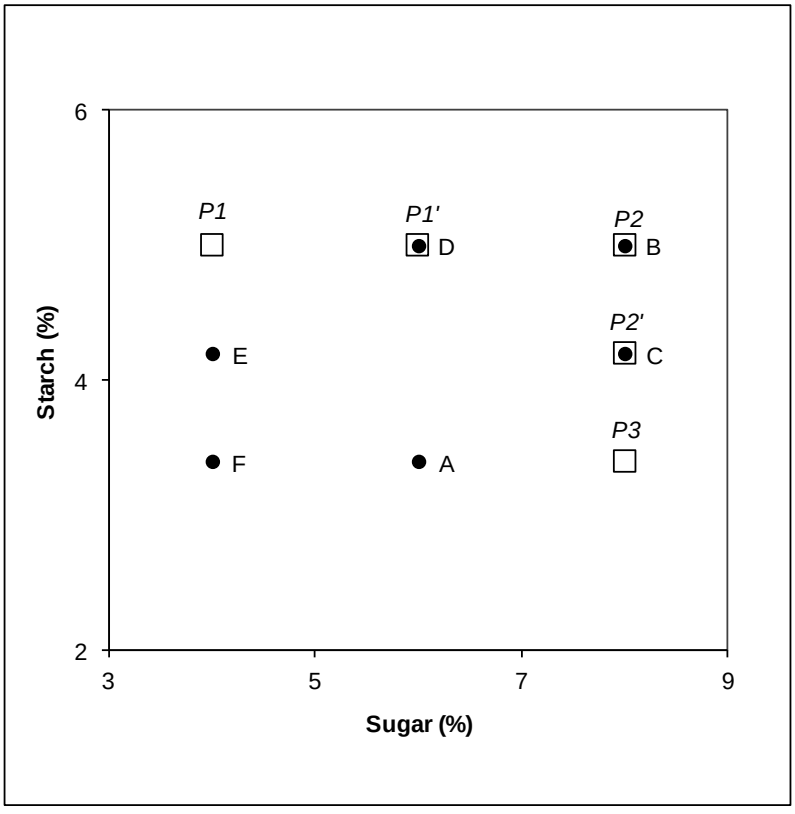

6
4
2
Starch (%)
P1
P1'
D
P2
B
P2'
E
C
P3
F
A
3
5
7
9
Sugar (%)

Figure 2.

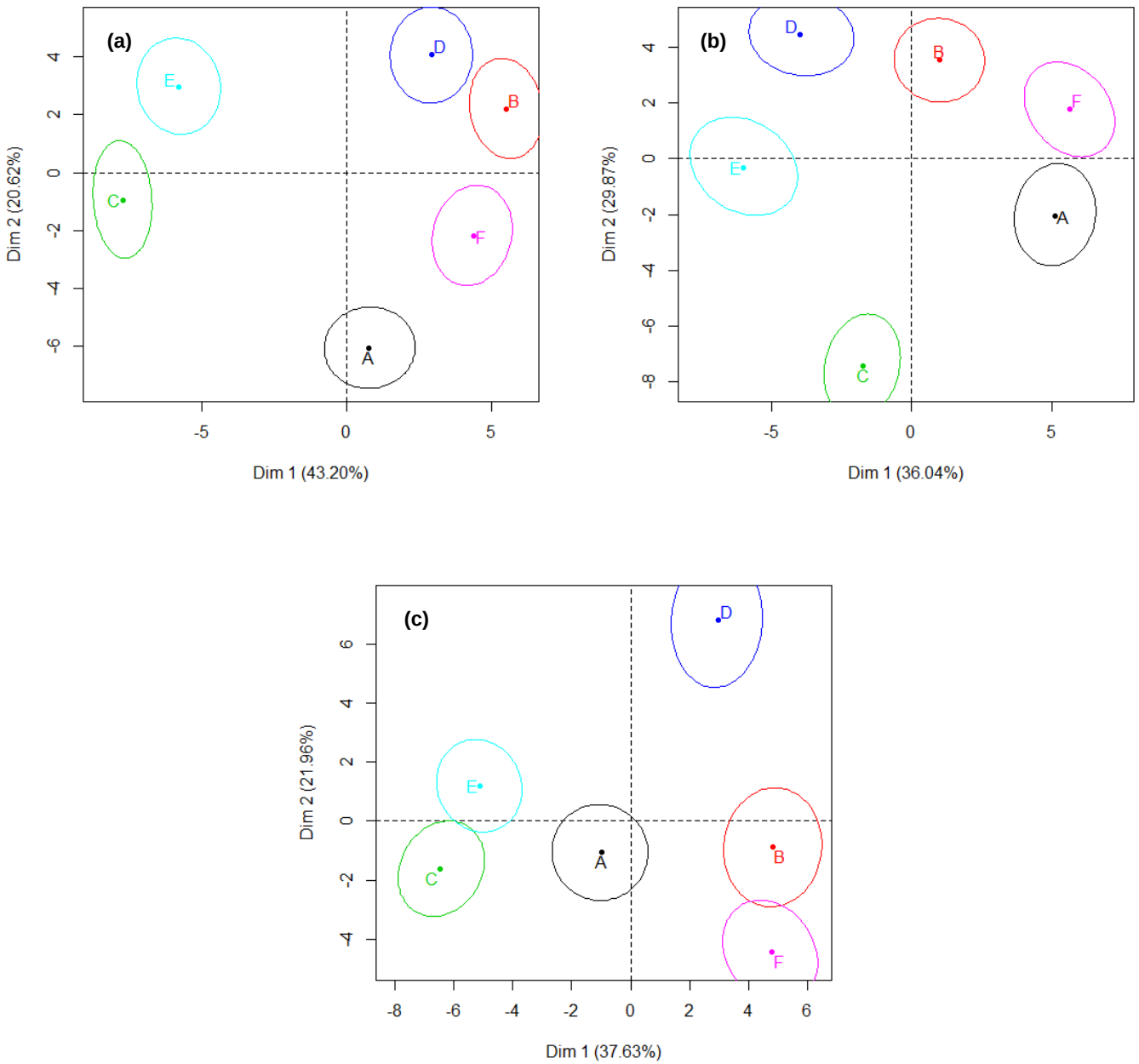

(a)
D
E
B
C
F
A
Dim 2 (20.62%)
Dim 1 (43.20%)
(b)
D
B
F
E
A
C
Dim 2 (29.87%)
Dim 1 (36.04%)
(c)
D
E
A
B
C
F
Dim 2 (21.96%)
Dim 1 (37.63%)

Figure 3.

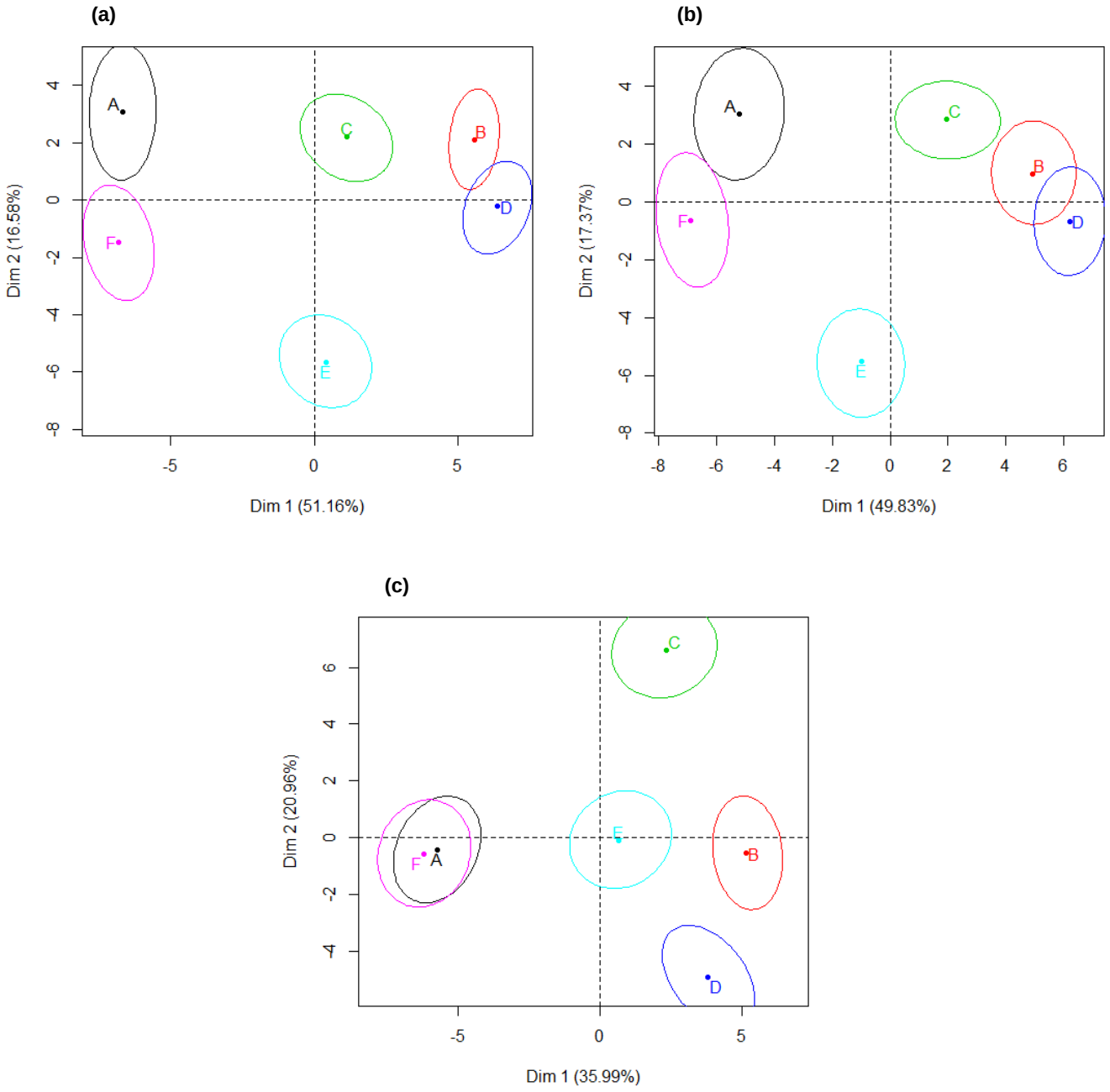
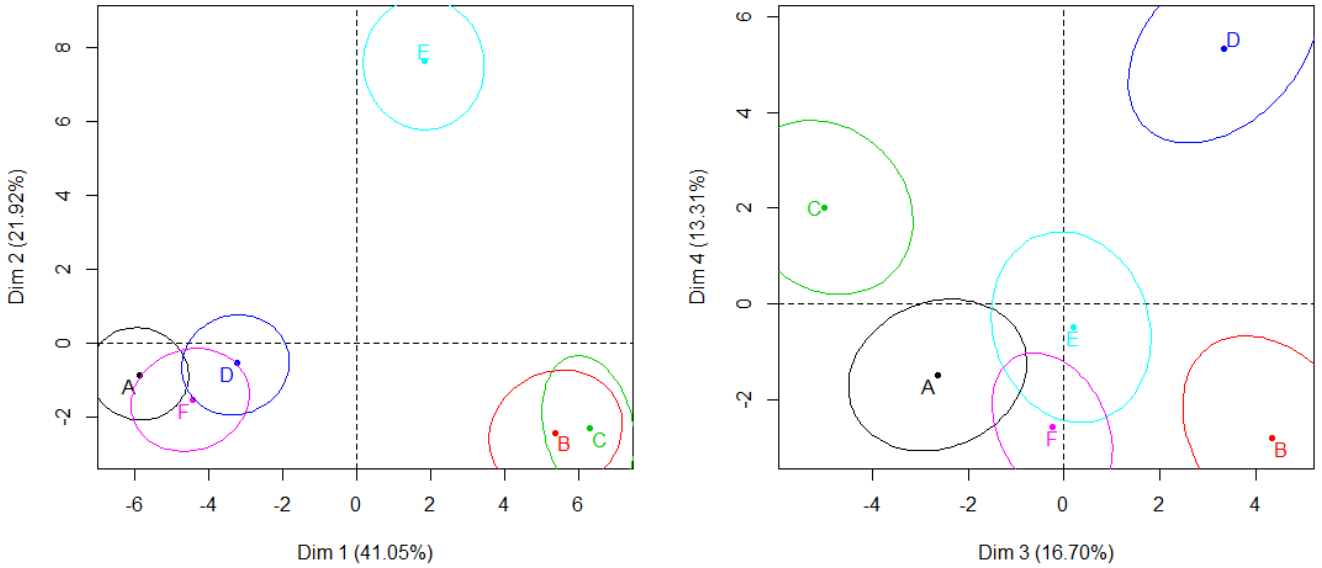
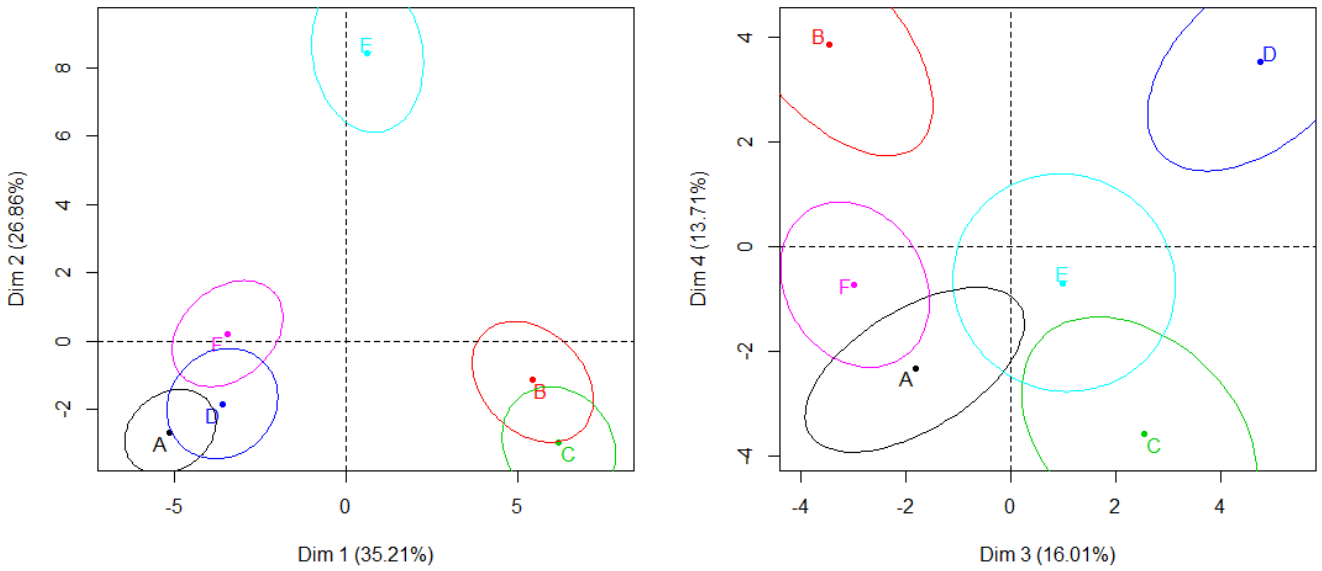

(a)
A
B
C
D
E
F
Dim 2 (16.58%)
Dim 1 (51.16%)
(b)
A
B
C
D
E
F
Dim 2 (17.37%)
Dim 1 (49.83%)
(c)
A
B
C
D
E
F
Dim 2 (20.96%)
Dim 1 (35.99%)

Figure 4.

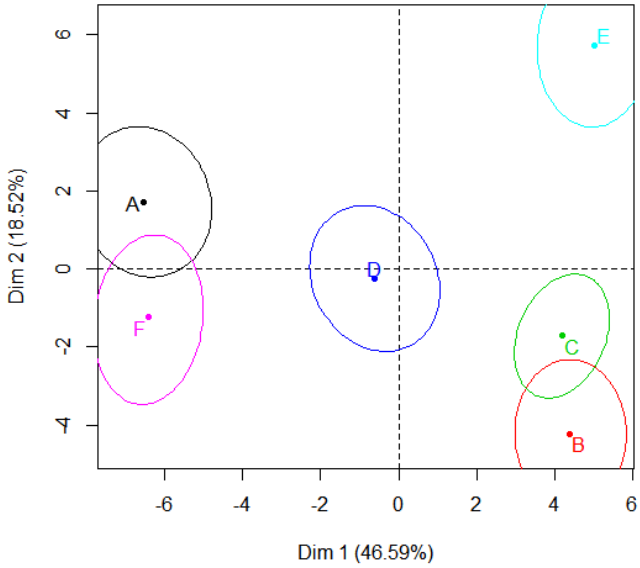
(a)

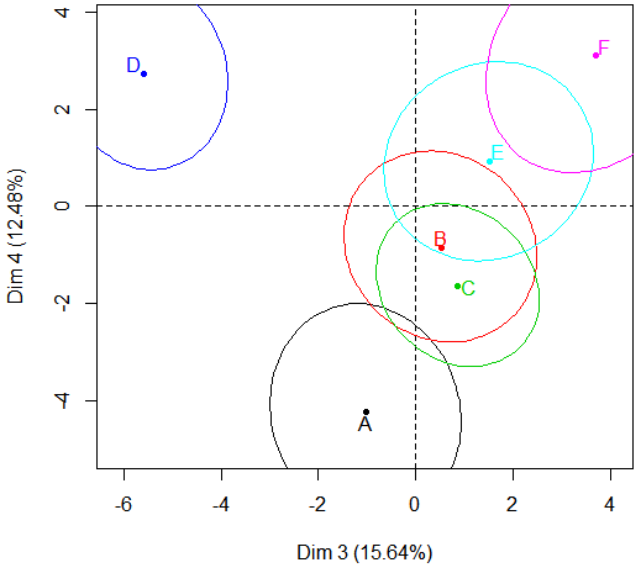

Dim 2 (21.92%)
Dim 1 (41.05%)
Dim 4 (13.31%)
Dim 3 (16.70%)
A
B
C
D
E
F

(b)


Dim 2 (26.86%)
Dim 1 (35.21%)
Dim 4 (13.71%)
Dim 3 (16.01%)
A
B
C
D
E
F

(c)


E
A
D
F
C
B
6
4
2
0
-2
-4
-6
-4
-2
0
2
4
6
Dim 2 (18.52%)
Dim 1 (46.59%)


D
F
E
B
C
A
4
2
0
-2
-4
-6
-4
-2
0
2
4
Dim 4 (12.48%)
Dim 3 (15.64%)