Interval-Valued Sensory Evaluation for Customized Beverage Product Formulation and Continuous Manufacturing

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***Abstract*—Understanding of consumer preferences and perceptions is a vital challenge for the food and beverage industry. Food and beverage product development is a very complex process that deals with highly uncertain factors, including consumer perceptions and manufacturing complexity. Sensory evaluation is widely used in the food industry for product design and defining market segments. Here, we develop a two-step approach to minimize uncertainty in the food and beverage product development, including consumers as co-creators. First, we develop interval-valued questionnaires to capture sensory perceptions of consumers for the corresponding sensory attributes. The data captured is modelled with fuzzy sets in order to then facilitate the design of new consumer-tailored products. Then, we demonstrate the real-world manufacture of a personalized beverage product with a continuous food formulation system. Finally, we highlight consumers` perceptions for the corresponding sensory attributes and their fuzzy set generated agreement models to capture product acceptance for the formulated and commercial orange juice drinks, and consequently to establish that continuous beverage formulator is capable of making similar commercial products for individuals.**

I. INTRODUCTION

The food and beverage industry is under constant pressure to develop products that meet specific customer requirements in the shortest time and at the lowest cost possible. The industry is faced with two main challenges; first, how to identify consumer needs and second, how to re-configure manufacturing lines to quickly respond to such changing consumer demands [1] [2]. Companies are increasingly looking at the consumer as a key driver for overcoming those challenges in order to design winning products. This has led to new challenges; sensory analysis, product formulation and make-to-order manufacturing. Today`s methods of collecting high quality sensory evaluations are faced with higher uncertainty than ever been, primarily due to short product cycles and constantly changing consumer demand.

Specifically, there is a great deal of uncertainty and risk surrounding the level of success of newly developed products, due to limited access to customers with current market research techniques. Understanding consumers' perceptions as individuals is not easy, and requires a novel and simple sensory evaluation tool. Fuzzy sets have been successfully used in the literature to capture uncertain or imprecise opinions and perceptions of large group of people [3] [4]. In this paper, survey responses that capture crowd agreement are modelled with fuzzy sets (FSs) using the Interval Agreement Approach (IAA) [5] [6] [7].

In tandem with dynamically and continuously capturing consumer preferences, in order to manufacture personalized products such as beverages, future food manufacturing systems should be adaptable to enable quick response to changing production requirements; i.e., they should be capable of a quick changeover with minimum product and time loss. Here, novel oscillatory flow mixing technology used in continuous flow reactor provides great opportunities for make-to-order production [7] [8].

In this paper, we first develop an interval-valued sensory evaluation tool to capture fine-grained consumer perceptions of sensory characteristics, going substantially beyond *"I do/do not like it",* using commercial orange juice samples. Secondly, we demonstrate how to leverage the information obtained from this tool to demonstrate how the formulation of a beverage and its preparation can determine rapid production routes using a novel formulation platform [7]. In order to expose similarities between formulated and commercial orange drinks, consumers were asked to indicate their perceptions using an interval valued sensory questionnaire for 15 sensory attributes, including overall product acceptance of the orange flavoured drinks. The consumers' responses were then modelled through FSs, which are compared for manufactured and commercial samples in order to evaluate product similarities.

The rest of the paper is structured as follows: Section II provides information on background and methodology, including interval-valued sensory questionnaires, selection of consumer panels, and the continuous beverage formulation platform. Section III presents the proposed model. Section IV shows results. Finally, Section V provides the conclusions and future work.

II. BACKGROUND AND METHODOLOGY

Acceptance of beverage products is identified by the evaluation of sensory attributes of appearance, flavor, taste, aroma and texture. The first stage of the consumer-driven beverage product development is to identify consumer groups and sensory vocabulary for the orange flavored drinks. Selection of the sensory evaluation method plays a critical role in collecting effective sensory information for the products and consumers. Once the sensory space is well understood, the next stage is to evaluate the correlations between sensory and physical attributes. The following subsections explain the state of the art for each stage in detailed.

A. Selection of Consumers and Linguistic Descriptors

The food industry has developed a sophisticated and standardised linguistic vocabulary for the sensory evaluation studies. However, this vocabulary requires trained sensory panels which is not suitable to use by end consumers. Consumer-centred sensory vocabulary [9] provides more effective and simple linguistic descriptors. Another major advantage of this method is to allow the development of a vocabulary that is both grounded in consumer wants and needs, as well as useful for distinguishing between different products within the same product category. Engaging consumers rather than sensory panels provide more realistic consumer data for consumer-driven food product development.

B. Interval Agreement Approach to Capture Uncertainty

Interval Agreement Approach (IAA) [5] [6] [7] was successfully used to capture the opinions of a group of individual in relation to specific concept. Participants can indicate their response using ellipses where the width of the ellipses indicates the assessor`s certainty in their response. A narrow ellipse is used when they are sure of their sensory feelings, and a wider ellipse is used when they are unsure of their perceptions. Fig. 1 shows an example of interval responses from three participants and the IAA FS that models their responses. The ellipses are aggregated into a FS that models the overall agreement between the participants by having the membership value of each point in the FS represent the percentage of participants that agree with that response.

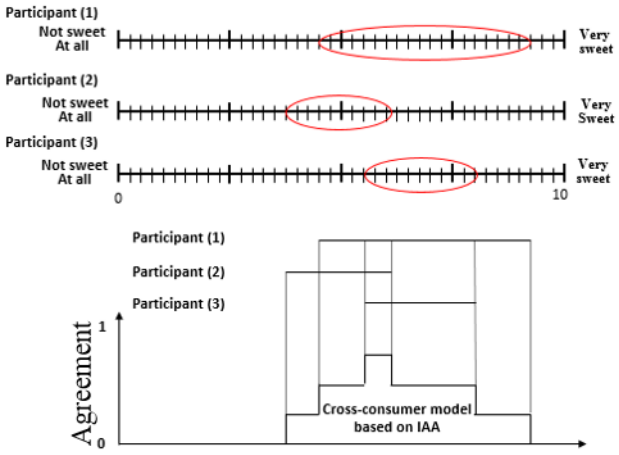

Fig. 1. Interval-valued sensory evaluation rating

Interval-valued sensory evaluation has many advantages compared to traditional sensory evaluation techniques. Firstly, the proposed method enables the modelling of inter- and intra-user (between individuals and within a single individual, respectively) variation, using type-1 (T1) and type-2 (T2) fuzzy sets. Secondly, the given method provides easy, cheap and powerful sensory analysis to collect inputs for beverage product formulation and decision making. After the sensory evaluation session, the resulting intervals are modelled as FSs by the IAA which generates a membership function for each sensory word based on the level of overlap of the intervals rated by the consumers. This provides the analysts and product developer a broader perspective of the crowd perception to large scale customisation without further data processing.

C. Continous Beverage Manufacturing Platfrom

Large scale customised beverage product formulation necessitates a flexible approach to sensory research as well as to production. A fundamental, but often difficult, task to facilitate the alignment of production with individual demand

Table I - LIST OF SAMPLES INCLUDING DESCPRIPTIONS AND PHYSICALK PROPERTY MEASUREMENT

Product	Type	Description	Physical Properties		
			pH	**Particle Size** (um)	**Color** (nm)
M1	Formulated	Water, orange soft drink from concentrate: Arabic gum, Xanthan gum and Orange oil (25%); citric acid, sodium benzoate; natural sweetener: Maltodextrin, Steviol Glycosides ; natural food colour: Beta-Carotene	4.80	4.18	574.92
C1	Commercial	Water, orange juice from concentrate (8%), Citric Acid, Acidity Regulator (Sodium Citrate), Natural Flavouring, Preservatives (Potassium Sorbate, Dimethyl Docorbonate), Sweeteners (Acesulfame K, Sucralose), Stabilizer (Xantham Gum), Natural Colour (Carotenes)	3.47	1.55	560.83
C2	Commercial	Water, Sugar, Orange Juice from Concentrate (12%), Acidity Regulator: Citric Acid; Flavourings, Antioxsidant Ascorbic Acid	3.72	6.14	572.67
M2	Formulated	Water, orange drink from concentrate (20%): Arabic gum, Xanthan gum and Orange oil; citric acid, sodium benzoate; natural sweetener: Maltodextrin, Steviol Glycosides ; natural food colour: Beta-Carotene	4.93	7.22	577.50
C3	Commercial	Orange Juice from Concentrate (50%), Water, Sugar, Vitamin C	3.90	88.26	571.23
M3	Formulated	Water, orange drink from concentrate (5%): Arabic gum, Xanthan gum and Orange oil; citric acid, sodium benzoate; natural sweetener: Maltodextrin, Steviol Glycosides; natural food colour: Beta-Carotene	5.07	30.25	568.85

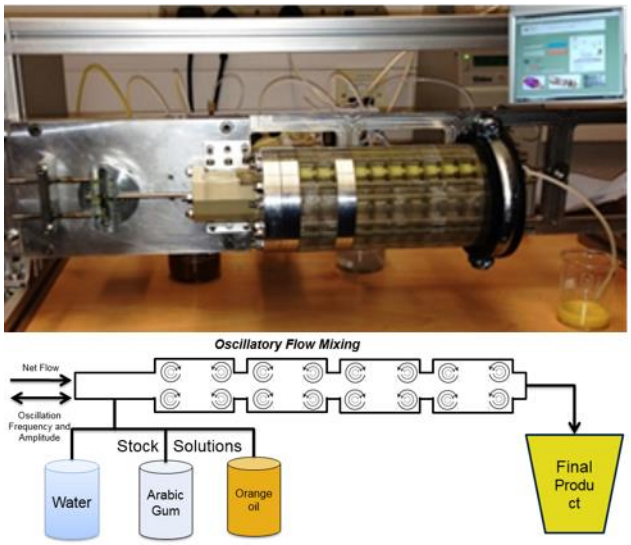

Fig. 2. Continuous Beverage Manufacturing Platform

is to create short, consistent product changeovers. A product changeover requires a new product recipe and new mixing conditions. Changeover time can be extremely long with traditional large batch production platforms, and the longer the changeover effect, the more detrimental the impact in delivering the demand.

Here, we developed a novel continuous oscillatory flow reactor that formulates a product according to individual needs by controlling all physical properties and mixing conditions during its manufacture. The platform comprises a computer-controlled ingredient dispensing section, an oscillatory baffled reactor, an oscillation mechanism and machine learning algorithms to generate individual recipes, as shown in Fig.2. The modular design provides superior mixing performance of beverage ingredients in continuous conditions in a small footprint, and the ability to reconfigure formulation parameters and processes rapidly. The uniform mixing along the reactor is achieved by the combination of a series of baffles and an agitation mechanism. This arrangement allows the control of the formulation process with three key variables: net flow, oscillation frequency and amplitude.

D. Samples

Six samples, three commercial (C1, C2, C3) and three produced by our continuous manufacturing system (M1, M2, M3), were selected for sensory evaluation. The commercial samples were produced using traditional manufacturing techniques in batches. The choice of ingredients and their concentrations we used in our formulations were similar to those of the commercial products. Here, we explore the ability of our manufacturing approach to produce similar or better product quality but faster and at lower energy compare to batch techniques. The correlation between physical attributes and sensory attributes has previously been explored [7]. pH, viscosity and particle size of each sample were measured to compare these physical attributes with corresponding sensory attributes. The list of ingredients, concentrations and measurement results are shown in Table I.

III. PROPOSED METHODOLOGY

What makes the individual`s beverage product choices challenging is that their perception about the sensory attributes is highly variable and uncertain, more specifically, it exhibits both intra-consumer uncertainty (the same consumer's perceptions change with time and context) and inter-consumer uncertainty (the perceptions vary across consumers). Additionally, each individual does not necessarily consider each sensory attribute to be equally important for their food product selection, for example, for some people, the colour of orange juice is amongst the most important attribute, however this is not always the case.

Fundamentally, the problem for food manufacturers is how to capture complex perception data for fine-grained consumer groups and then how to use this data to inform manufacturing.

In the following subsections, we describe a proposed process which addresses this challenge, starting with the establishment of the necessary linguistic descriptors, an associated approach to collect the relevant consumer data in a workshop setting. Finally, we describe the actual manufacturing stage, specifically the continuous manufacturing process which can be adapted rapidly in response to the collected data.

A. Establishing Beverage Sensory Descriptors

In order to determine a set of linguistic descriptors to use, three short activities were conducted to engage with consumers and to elicit a sensory vocabulary for orange juice drinks:

1. Consumers wrote a free text description of their "ideal orange-flavoured beverage".

2. Consumers specified descriptors that they want to see in a filter-based search interface for a website selling orange drinks.

3. Consumers tasted three different samples of orange-flavoured drinks and describe how they differed.

For this paper, a list of words from 16 participants was collated and assigned to sensory and non-sensory categories. The resulting vocabulary list, shown in Table II. comprises the sensory descriptors that were used by at least three participants. Two more attributes, appearance and aromatic smell, were added to the consumer vocabulary list because visual acceptance and smell are highly common in food and drink manufacturing.

B. Interval-valued Sensory Evaluation Study

Interval-valued questionnaires were employed to capture the voice of consumers by evaluating the intensity of 15 sensory attributes. We conducted a two-day sensory evaluation workshop.

Table II - ORANGE DRINK SENSORY VOCUBLARY ESTABLISHED WITH CONSUMER GROUPS

Appearance	***Smell***	***Taste***		***Flavor***	***Texture***
Color	Aromatic Smell	Bitter	Natural	Acidic	Fizzy
		Sour	Tangy		Thick
		Sweet	Artificial	Fruity	Watery
		Fresh			Smooth

First, we engaged with a larger consumer group including broad consumer demographics during a manufacturing exhibition at Cranfield University, UK. During the event, we served commercial and manufactured orange drink samples. Then participants were requested to rate the specific sample. As shown in Fig. 1, we asked participants to indicate their perception response using ellipses which allows participants to express their uncertainty for a given sensory attribute. The width of the ellipse indicates the assessor`s certainty in their response. A narrow ellipse is used when they are sure of their sensory feelings, and a wider ellipse is used when they are unsure of their perceptions.

Once participants' interval-valued responses had been collected, they were aggregated into T1 FS agreement models using the IAA. The FSs are used to visually compare the participants perceptions of the beverages, and the centroids (as a measure of central tendency) of the resulting FSs were calculated to attain a simple summary of consumers' agreement. These FS models can be directly used in manufacturing processes to inform recipe design for personalised beverage product formulation. For more detail on the calculation of centroids and the development of T1 FS models, we refer the reader to [6].

C. *Customised Beverage Formulation and Continuous Manufacturing of Orange Drinks*

Ingredient pairing plays an important role in order to deliver consumer demands. Physical properties of beverage products may alter during processing due to uncontrollable environmental conditions, which can lead to delivering undesirable sensory attributes. Color and smell of the food can affect the flavor perception. Mouthfeel is defined as the *"combination of sensations in the oral cavity that are related to physical and chemical properties of a stimulus by a material"* [10]. *Thickness* is related to the rheological structure of the beverages. *Acidic* is the sensory term used to define sourness of the beverage. pH is the instrumental measurement to identify the level of any organic and inorganic acid in the food products.

All these terms are related to the consumer`s perceptions of drinkability and must be carefully taken into account during ingredient pairing. Formulated samples were manufactured with our continuous beverage formulator platform by using a natural food coloring agent (Beta-Carotene). The food coloring does not alter the flavor of samples and the amount of the coloring ingredient was chosen to result in color variations (between samples) strong enough to be perceived by consumers.

With the aim of the link sensory consumer perceptions and physical attributes, the samples` were then measured and colour, pH and particle size differences for each formulated sample calculated as shown in Table I. In previous work [7], the correlation between sensory attributes and physical properties were shown using IAA models and sensor-based measurements.

IV. RESULTS

In this paper, we explore the capacity for the continuous beverage manufacturing approach to deliver adequate orange flavored drinks in response to consumer demand. Specifically, as an initial step, we evaluate consumers' perceptions of both commercial and purposely manufactured orange flavoured beverages using the proposed data capture (through interval responses) and modelling approach (with FSs via the IAA). In this section, the resulting FSs are compared visually to observe similarities in the levels of agreement among participants for the commercial and manufactured drinks. We also use the centroid defuzzified values of the FSs to determine if the drinks received similar average response. Through this, we can compare the perceptions for the commercial and the manufactured drinks to establish if the latter map well to the former.

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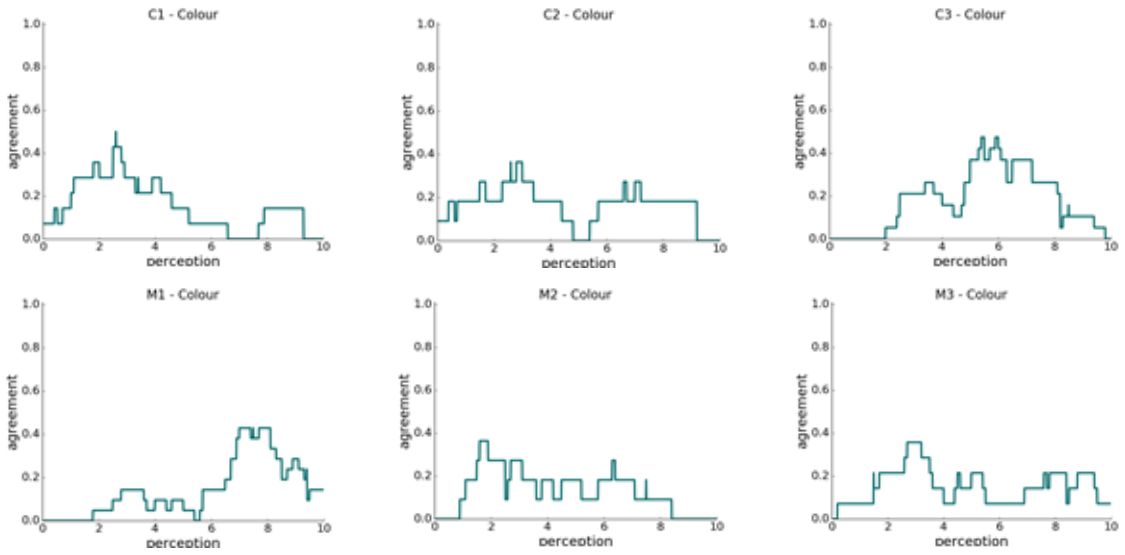

Fig. 3. Interval-valued agreement for color perception

A. *Interval-valued Sensory Evaluation Results*

We analysed the acceptance of the colour and aromatic flavour of each orange drink sample using the IAA. The results of the aggregated interval data are shown in Fig.3 and Fig.4 for appearance and overall product acceptance respectively. The increasing scores on the y-axis indicate higher agreement among consumers and increasing scores on the x-axis reflect higher perception of the sample.

Two trends are apparent. There is higher acceptance for the tropical orange colour of samples M1 and C3. The colour of C1 was yellowish and there is lower acceptance with high agreement for the yellow orange juice, i.e. most consumers agree that this is not a desirable colour. For the remaining three samples with light orange colour, there is little agreement and ratings were widely spread as shown in Fig.3.

There is low agreement for the perception of odour compared to colour among participants. Samples M1 and M3, which are both formulated samples, were rated as more desirable with strong agreement. Orange juice concentration has an important influence on the odour of orange drink.

Formulation of thickness and acidity is another important aspect for the success of beverage product. The acidity is directly linked to the pH level and, similarly, thickness is linked to particle size. Citric acid was used to change the acidity of the samples and different mixing conditions were used to make smaller droplets in order to modify the mouthfeel. Particle size and pH were then measured and differences between samples are shown in Table I. The centroids provide a convenient, albeit simplistic, way to capture the central tendency of each IAA model and to explore similarity across models. For example, considering the results from Table I and Table III, there is a strong correlation between consumers' agreement on juice acidity and pH measurement (with a Pearson correlation coefficient of 0.724).

Table III - CENTROIDS AS SUMMARY OF SENSORY EVELATUION AND SIMILARITY

Sensory Attribute	Centroids					
	M1	**C1**	**C2**	**M2**	**C3**	**M3**
Colour	6.9008	3.7314	4.548	4.135	5.7997	5.0353
Aromatic Flavour	6.1722	4.8422	5.8963	4.8526	4.9598	6.603
Acidity	3.0064	2.7428	2.2853	3.8398	3.6228	4.4323
Thickness	4.7223	3.571	2.3339	6.7044	5.0099	6.6805
Fizzy	2.5589	3.6058	3.3316	4.9125	2.2915	4.3738
Watery	5.065	5.9331	4.8827	5.2688	5.9547	4.522
Overall Acceptance	4.8824	4.6156	5.7484	3.799	5.6661	5.089

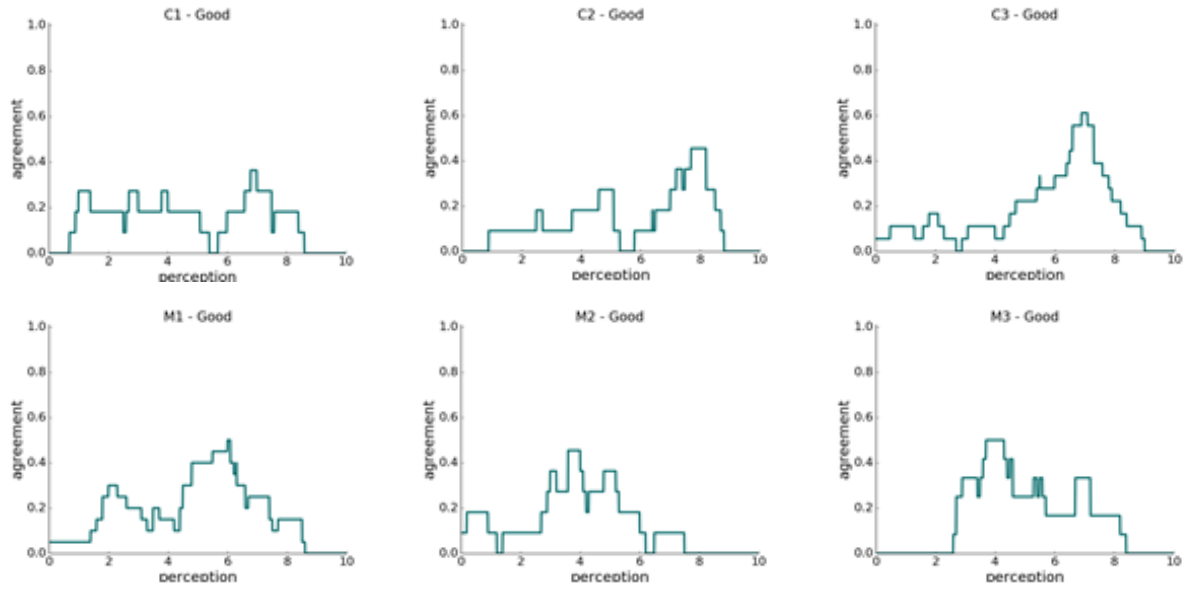

Fig. 4. Interval-valued Agreement for Overall Product Acceptance

B. Similarities Between Commercial and Manufactured Products

The centroids as summaries of the agreement models are given in Table III. It is clear that it is difficult/impossible to identify one single combinations of sensory attribute levels resulting in the winning orange drink recipe. This is expected as the interplay of different attributes is complex and thus different combinations can result in a pleasing outcome/drink.

However, the results for the same sensory attributes across the six drinks showed that there are significant similarities between the manufactured products (M1, M2, M3) and the commercial samples (C1, C2, C3). For example, the rating of color is highest in the manufactured product M1 (centroid = 6.90) and the second highest rated product in terms of color was the commercial product C3 (centroid = 5.79). Similar preferences were also observed for the aromatic flavor acceptance. Manufactured samples M3 and M1 were rated with higher agreement (centroids 6.60 and 6.17 respectively), and the commercial sample C2 was rated as the third best product in terms of aromatic flavor (centroid = 5.89).

For each attribute, the centroids of the manufactured drinks do not deviate significantly from the commercial juices. Additionally, although the agreement models differ between the drinks, none of the six drinks are shown to be significantly better or worse than others.

These results demonstrate that it is possible to formulate and manufacture personalised orange drinks that are accepted with similar levels of agreement to (batch-produced) commercial drinks.

V. Conclusions and Future Work

In this paper, sensory attributes of orange drinks were established and then used in combination with an interval-valued sensory evaluation technique to allow consumers to rate both manufactured and commercial orange flavoured drinks.

Subsequently, fuzzy set based interval agreement models were generated from the interval-valued data and then analysed using summary statistics, namely their centroid.

An initial evaluation of the results shows that there are high similarities between manufactured samples and commercial samples. The results indicate that the previously introduced continuous beverage formulation and manufacturing platform [7] is able to produce customized drinks of comparable acceptability to commercial orange flavoured drinks. The latter is an important step towards the production of new, personalised beverages in direct response to consumer preferences.

This paper conducted the evaluation of the results solely based on the centroids of the agreement models, which, like all models of central tendency, risk omitting important detail. In the future, we will employ fuzzy set similarity to compare drinks or more specifically, to compare the consumer perceptions of these drinks.

Further, the comparison of both commercial and manufactured orange flavoured beverages as conducted in this paper is only a first step. At the moment, we are developing the approach to enable the capture of preferred drink characteristics from consumers which then directly drives the manufacture of the desired beverage, thus effectively allowing instantaneous, personalised orange drink manufacture.

Acknowledgement

This work has been fully funded by the UK Engineering and Physical Sciences Research Council (EPSRC) by grant with number EP/K014234/2. The authors fully acknowledge and wish to thank EPSRC for the financial support.

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