Consumer Acceptability and Temporal Sensory Evaluation of Beans Across Cooking Methods

by

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Abstract

Dry beans have gained so much popularity in many local, regional and global cuisines because of their nutritional value. A diet that includes beans is an excellent source of minerals and essential nutrients and provides numerous health benefits. Replacing meat with beans is considered a nutritious alternative because of their high protein content and overall nutritional value. Hence, beans are regarded as a suitable alternative in vegan and plant-based diets. In addition, because beans are both nutritious and affordable they have long been recognized as an economical alternative to animal protein. However, one of the key sensory characteristics associated with beans and bean-based food is their beany aroma. This characteristic is considered undesirable by many consumers and limits the full utilization and potential of the crop despite its rich nutritional profile. Beany aroma is influenced by compounds such as hexanal, 2-pentyl furan, 1-octen-3-one that contribute to this undesirable flavor. Cooking has been shown to reduce the intensity of beany aroma, thereby improving the sensory quality of bean products. This work investigates how different cooking methods affect the sensory profiles of various beans. The specific objectives of this study were: 1) to evaluate overall consumer acceptability and sensory profiles of selected bean varieties subjected to different cooking methods; 2) to utilize the Temporal Check All That Apply (TCATA) method to evaluate the evolution/dynamic perception of aroma and flavor attributes of dry beans prepared using different cooking methods; and 3) to integrate CATA (a method where panelists check all attributes they perceive from a predefined list after the product has been evaluated) and TCATA methods to evaluate the degree of alignment between consumer perceptions and the temporal sensory perceptions provided by a semi-trained panel.

Three different bean types (i.e. black bean, pinto bean and Bambara bean) were subjected to four different cooking methods: slow cooking, baking, pressure cooking and boiling. A consumer study

(n=76) was conducted to determine consumer acceptability and sensory profiles of each bean type subjected to all the cooking methods. Also, TCATA (n=10) was conducted to determine the evolution of attributes over time during evaluation.

The results from the consumer study showed significant sensory differences among beans subjected to different cooking methods. Samples with low beany aroma intensity ratings were subsequently rated higher in overall liking, indicating consumers prefer richer, cooked, less beany flavors. This implies and emphasizes that cooking method plays an important role in shaping flavor profiles. Results from the TCATA evaluation, which captured the evolution of attribute perception over time, indicated that beany and potato/starchy attributes were dominant throughout the evaluation period. Although these two attributes were dominant, cooking method influenced the complexity and expression of secondary attributes, resulting in distinct sensory profiles among the samples. Integration of the CATA and TCATA data showed some degree of alignment, suggesting that TCATA may help identify sensory characteristics associated with consumer perceptions. Overall, this work offers meaningful insights into the effects of processing on the sensory profile of the three bean types; however, future studies should examine additional bean varieties and processing conditions to further expand these findings.

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Chapter 1 - Literature Review

1.1. Introduction

Dry beans have been characterized as one of the most nutrient-dense foods available because of their high nutrients and diverse micronutrient composition. Beans are consumed throughout the world and are often the staple ingredient in many regional cuisines. Global pulse production reached 96 million tons in 2022, with an average per-capita consumption of 7 kg per year (FAO, 2022). FAO statistics indicate that dry bean consumption averaged 2.51 kg per capita in 2021, with historical highs of 3.15 kg in 1964 and lows of 2.18 kg in 2005, highlighting the sustained global relevance of beans as an accessible and nutritious food source. Beans carry cultural importance, shaping food traditions and culinary practices across the globe (Mbiu *et al.,* 2025). Their consumption continues to rise in most regions, except for Central and East Asia where consumption decreased from 2 million tons in 1980 to 1 million tons in 2007. (Grain Legumes Production, Consumption and Trade Trends in Developing Countries Science with a Human Face, 2015). This decline is likely linked to dietary transitions in Central and East Asia, where rapid urbanization, rising incomes, and increased access to animal protein and processed foods have shifted consumer preferences away from traditional legume-based diets. In several countries within these regions, rice, wheat, and meat have become more dominant staples, reducing the overall reliance on dry beans (Grain Legumes Production, Consumption and Trade Trends in Developing Countries Science with a Human Face, 2015).

A wide variety of bean market classes such as navy, pinto, carioca, great northern, yellow, black, red, pink, and kidney beans are diverse in seed color, pattern, size, and shapes (Xiong, Zhao & Balasubramanian, *et al.,* 2020). Although dry beans are considered the poor man's meat (Tharanathan & Mahadevamma, 2003), nutritionally, they provide an affordable source of protein, they are a rich source of fiber, folic acid, and minerals such as calcium, potassium, phosphorus, iron, zinc and magnesium (Perseguini *et al.,* 2016). A diet including beans provides substantial health benefits, such as decreasing the risk of heart and renal diseases, protecting against several cancer types, and helping in the control of obesity (Luciana Mariana, 2014). Beans are easy to plant, grow, and store, hence they are among the oldest cultivated and most widely used foods in the world. Beans are also relatively inexpensive to produce, portable, and have a long storage life, which has further contributed to their global popularity. Historically, beans have served as a food staple for at least 10,000 years, and some food historians double that figure (D. Winham *et al.,* 2008). Dried beans play a prominent role in the diets of many vegetarians and may contribute to the health benefits associated with this eating pattern. These benefits stem from their unique nutritional profile, including low saturated fat content and high levels of essential nutrients and phytochemicals, as well as because they often replace animal products in the diet, which can lead to lower intakes of saturated fat and improved overall diet quality.

Beans are also regarded as ecologically sustainable protein sources compared to animal-based proteins (McDermott & Wyatt, 2017) . Though beans provide 20-25% protein, slightly lower than animal sources like beef (26%) or chicken (27%), they supply high lysine and pair well with cereals to improve overall amino-acid quality (Perseguini *et al.,* 2016). They are also far more resource-efficient, requiring much less water and land per gram of protein, which makes their protein more accessible and sustainable than most animal-based options (McDermott & Wyatt, 2017). They also offer economic benefits, particularly for women in Sub-Saharan Africa, who are disproportionately involved in their production, processing, marketing, and preparation.

Beans can be grown in a variety of eco-agricultural regions and can be distributed in multiple forms, such as whole unprocessed seeds, as part of mixes, canned products, or as a gluten-free wheat flour substitute. As a result, dry beans are consumed worldwide and account for approximately 50% of grain legumes used as a human food source (Câmara *et al.,* 2013).

Consumption of dry beans has the potential to provide a variety of health benefits, including a reduced risk of developing diabetes mellitus (D. M. Winham *et al.,* 2016), obesity (Anderson & Major, 2002) cardiovascular disease and colon-related diseases (Tharanathan & Mahadevamma, 2003). In developing countries, where malnutrition remains prevalent, dry beans are particularly important for promoting nutrition security (Venter & Van Eyssen, 2001). However, with increasing urbanization, consumer preferences are shifting toward convenience foods and commodities that require less preparation time.

According to Popoola *et al.* (2023), legumes, including dry beans, are classified into minor and major species. Minor legumes, which are often neglected, underutilized, and less exploited, include lima bean, winged bean, marama bean, rice bean, and Bambara groundnut. Major legumes, such as cowpea, common bean, soybean, chickpea, groundnut, and others, are well known for their established agronomic practices, widespread cultivation, utilization, and domestication. Underutilized and neglected legumes could contribute to improved livelihoods in several ways, including diversifying production systems, enhancing nutrition, supporting food security, establishing new markets, stabilizing ecosystems, and providing resilient crop alternatives under stress conditions.

1.2. Bambara Bean

Many dry beans, both native and non-native to the United States have been fully explored. However, there are some underutilized and/or novel yet highly nutritious beans which have not been fully explored, an example is the Bambara bean (groundnut). Bambara groundnut *(Vigna subterranea)* is an underutilized grain legume grown in several countries in Sub Saharan Africa (Arise et al., 2015). It is the third most important legume after cowpea (*Vigna unguiculata*) and groundnut (*Arachis hypogea*) in Africa (Arise *et al.,* 2015). Bambara groundnut is thought to have its center of origin between West and Central Africa (NC, 2018). It has grown popularly in Sub-Saharan Africa and is available at low levels in Thailand, Malaysia, and Indonesia as well (Tan *et al.,* 2020) . Higher preference for Bambara beans has been observed in dry regions prone to drought (Mubaiwa *et al.,* 2018). This is linked to its high resistance to such unfavorable conditions leading to its ability to produce reasonable yields under such conditions, hence acting as a safety net for farmers. Bambara groundnut production in Africa is reported to be ~0.3 million tons annually with an average of 0.85 t/ha, even though the yield potential is reported to be over 3 t/ha (Hillocks *et al.,* 2011). Nigeria is regarded as the largest producer of Bambara beans with a mean production of 0.1 million tons, followed by Burkina Faso 44,712 tons, and Niger 30,000 tons (Hillocks *et al.,* 2011).

Bambara groundnut remains largely unknown in the United States, even though global production exceeds 0.3 million tons annually (FAO, 2022). There are two botanical varieties known as V. subterranean var. *spontanea* which includes wild varieties and V. subterranean var *subterranean* which includes cultivated varieties (Bambara Groundnuts Agriculture, Forestry & Fisheries Department: Agriculture, Forestry and Fisheries Republic of South Africa, 2016). Bambara groundnut is primarily cultivated for human consumption. The seed constitutes a nutritionally complete food as multiple analyses of its biochemical composition have shown that it contains adequate levels of nutrients as shown in Table 1.1 and 1.2 below. Despite these nutritional advantages, Bambara groundnut remains largely unknown in the United States, highlighting the need for further research and broader exploration.

1.2.1. Nutritional composition of Bambara beans

There is a growing trend toward increased consumption of plant-based diets, which has led to the need for more plant-based protein foods. The Bambara bean, having earned a reputation as a "nutrient -dense food" is a crop of particular importance, as it serves as a key source of essential nutrients in regions where access to animal protein is limited (Adebowale *et al.,*2011). Bambara beans have nutrients in adequate quantities to provide a balanced diet. It has a high nutritional value with carbohydrates, proteins, dietary fiber and fat in the range 55-70%, 17-25%, 5.2-6.4% and 1.4-12%, respectively (Maphosa, 2016). The nutritional composition of the Bambara groundnut is summarized in Table 1.1 below

Table 1.1: Approximate nutritional composition of Bambara beans

Nutrient	Composition (g/100 g) (amino acids expressed in mg/g of protein)
Fat	1-12
Carbohydrates	55-71
Protein	17-26
Starch	22-50
Dietary fiber	5-12
Soluble fiber	1-24
Insoluble fiber	10-16
Sugars	24
Ash	3-12
Moisture	13-1
Essential amino acid	67.28
Non-essential amino acid	32.72

Maphosa *et al.,* 2022

It was also reported by Vilakazi *et al.,* 2025 as shown in Table 1.2 below, that the levels of some nutrients, as well as the gross energy value in Bambara beans, were relatively higher than those found in commonly consumed legumes such as chickpea, common bean and soybean, although these levels vary by cultivar and growing conditions.

Table 1.2: Nutritional composition of Bambara beans versus other major legumes

	Energy (kcal)	Protein	Fat	Carbohydrate	Dietary fiber
Soybean	374	33.0-45.0	19.9	30.0	10.3
Common bean	340	16.5-25.2	0.3-1.3	43.5-67.9	10.3
Groundnut	602	26.0-30.0	48.0	15.5-16.13	3.0
Chickpea	343	12.6-30.5	3.8-10.2	52.4-70.9	22.7
Pea	245	24.4-32.5	0.8-3.9	51.3	13.4
Bambara bean	381	17.4-25.2	6.0-7.9	51.0-70.0	18.9

(Vilakazi *et al.,* 2025)

1.2.2. Essential mineral composition of Bambara beans

The most abundant minerals in Bambara beans are potassium, magnesium, phosphorus, zinc, and iron (S. A. Oyeyinka *et al.,* 2018; Olaleye *et al.,* 2018). A summary of the mineral composition is presented in Table 1.3 below.

Table 1.3: Mineral composition of Bambara beans

Mineral	Composition (mg/100 g of seed)
Potassium	1545-2200
Magnesium	32-335
Calcium	30-128
Sodium	16-25
Iron	2-9
Phosphorus	81-563
Zinc	11-40

Olaleye *et al.,* 2018

It is also reported that the concentration and bioavailability of calcium, magnesium, iron, and zinc in Bambara bean seeds were influenced by factors such as storage period, processing method, location of mineral in the seeds (testa vs cotyledons), and the degree and strength of mineral chelation. Bambara bean seeds also contain phytochemicals such as flavonoids and tannins. These compounds are usually found in seed coats and are more abundant in seeds with dark or red-colored seed coats (Boye *et al.,* 2010). Antioxidant activity has been reported in brown and red Bambara groundnut seeds, with levels comparable to those of commonly consumed legumes, but inferior to the powerful antioxidant ascorbic acid (Nyau *et al.,* 2015).

1.2.3. Essential Amino acid composition of Bambara beans.

Among the essential amino acids; leucine, aspartic acid, and lysine are present at relatively higher concentrations while methionine is one of the lowest (Adebiyi *et al.,* 2019; Hussin *et al.,* 2020; Azman Halimi *et al.,* 2010; Olaleye *et al.,* 2013) as shown in table 1.4. Other essential amino acids reported at relatively high levels are phenylalanine and valine while tryptophan has been reported as the limiting amino acid (A. T. Oyeyinka e*t al.,* 2017). Bambara beans are therefore considered a good complementary protein source because its amino acid profile helps balance the deficiencies commonly found in cereal-based diets as it is rich in lysine and but deficient in methionine.

Table 1.4: Amino acid composition of Bambara beans

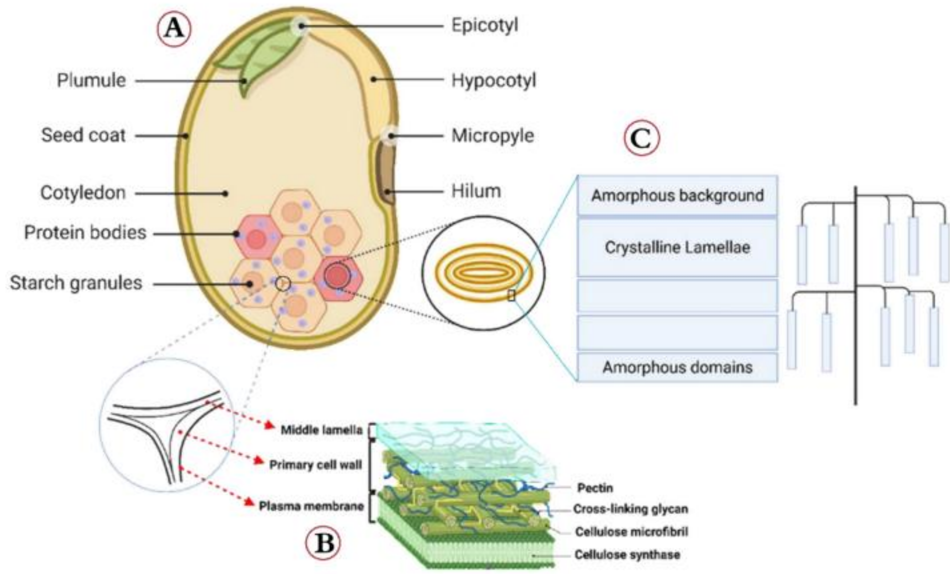
Amino acid	Mg/g of crude protein
Histidine	38.6
Isoleucine	54.5
Leucine	102.1
Lysine	80.2
Threonine	44.3
Tryptophan	6.0
Valine	62.4
Methionine	6.4
Cysteine	24.1
Tyrosine	31.3
Phenylalanine	76.9
Aspartic acid	146.1
Serine	68.5
Glutamic acid	209.5
Proline	53.6
Glycine	46.5
Alanine	51.4
Arginine	74.8

Olaleye *et al.,* 2013

1.2.4. Hard-to-Cook Phenomenon

The hard-to-cook (HTC) trait in Bambara beans represents one of the major challenges limiting their use. The HTC feature is related to the resistance of legume cotyledon tissues to softening during cooking, resulting in extended cooking time required to achieve a desirable texture. The high cooking time can be attributed to factors such as the hydration rate, changes in microstructure, storage time, temperature, and moisture content, as well as to components of the cell wall and chemical and/or enzymatic changes occurring in the seed coat and cotyledons. (Njoroge *et al.,* 2015). On the other hand, Kinyanjui *et al.,* 2015 mentioned that the hardening phenomenon increases the time required to obtain soft beans due to the low capacity of water sorption. There are two forms of resistance to cooking, the first known as a “hard shell” or impermeable seed coat, which is promoted by high temperatures and low moisture and is mainly characterized by the impermeability of the seed coat to the passage of water (Njoroge *et al.,* 2015). The second is known as “hard-to-cook”, which corresponds to high temperatures and high moisture and whose main characteristic is the resistance of cotyledon softening during cooking due to a low capacity to absorb and uniformly distribute the water through the cotyledon (Kinyanjui *et al.,* 2015). Development of the phenomenon can be genetically determined but also influenced by other factors such as prolonged storage under elevated temperature (>25◦C) and high relative humidity (>65). The pectin-cation-phytate model is the most widely accepted postulated mechanism for the development of HTC (Liu, 1995). As shown in Figure 1.1 below, -pectin is found in the middle lamella where it acts as intercellular cement. Phytic acid, which is a powerful chelator for cations, is usually bound to divalent cations, especially Ca^{2+} and Mg^{2+}. During storage, phytase hydrolyzes the phytatecation complex, liberating divalent cations, while pectin methyl esterase removes the methyl esters of pectin, thus producing free carboxyl groups ($-COO^{-}$). These carboxyl groups readily bind free divalent cations, leading to the formation of insoluble Mg- or Ca-pectate complexes. The resulting strengthening of the cell wall structure and cell-to-cell adhesion, restrict cell separation and limit softening during cooking (Chigwedere *et al.,* 2018).

Figure 1.1: Diagram of common bean (Phaseolus vulgaris L.) seed structure across multiple scales, showing external and internal seed anatomy (A), the cellular structure of cotyledonary cells (B), and starch granule's structure (C).



Ghaitaranpour *et al.,* 2026

According to Mubaiwa *et al.,* (2018), phenolic compounds such as tannins and hydroxycinnamic acid can bind to pectin, forming insoluble pectate complexes that reinforce cell adhesion. In addition to this mechanism, other processes including lipid peroxidation (Richardson & Stanley, 1991; Liu *et al.,* 1992) cell membrane damage, and ion redistribution, may occur during storage, soaking, and cooking. The synergistic interaction of these reactions may further intensify structural rigidity, contributing to the development of HTC (Liu, 1995) . The HTC defect has been reported to affect the nutritional quality of Bambara beans; specifically, seed aging associated with HTC development has shown to decrease in vitro bioaccessibility of essential minerals such as calcium and magnesium in Bambara ground nut seeds.

1.3. Volatile Compounds of Dry Beans

Volatile compounds are organic compounds with low molecular weight and strong hydrophobicity that can reach the olfactory receptors due to their high volatility (Wang *et al.,* 2021). Off-flavors are volatile compounds that can produce unpleasant sensations when released by food raw materials and their processing (Viana, 2021). This includes ketones, aldehydes, alcohols, carboxylic acid, terpenes, sulfur-containing compounds, aromatic hydrocarbons, and methoxypyrazines. The generation of volatile compounds begins during seed development and continues through harvesting, processing, and storage. Volatiles production is usually intensified when pulses are exposed to environmental or mechanical stressors, including elevated temperature, mechanical damage, insect infestation, and water stress (Vincenti *et al.,* 2019) . Consequently, the formation of these compounds is commonly associated with plant defense responses to adverse conditions (López *et al.,* 2011). Many of these volatiles contribute to an undesirable sensory attribute described as "beany," which represents a major barrier to consumer acceptance of pulse-based foods. Beany flavor is particularly prevalent in soy-based products and other plant proteins, limiting their broader utilization in food applications.

Beany off-flavors are most frequently associated with soybeans and other legume-based foods, and extensive research has been conducted to identify the compounds responsible for their development. Beany flavor is commonly described as an undesirable sensory attribute characterized by fatty, grassy, earthy, and bitter notes (Ravi *et al.,* 2019). Chemically, it represents a complex mixture of low molecular weight compounds, often described using terms such as "beany," "green," "earthy," and other unpleasant flavor descriptors.

To date, more than 30 volatile compounds have been associated with beany flavor: predominantly aldehydes, ketones, alcohols, and other compounds with low molecular weight (Wang *et al.,* 2021).

The formation of these compounds is largely attributed to enzymatic oxidation of linoleic and linolenic acids, catalyzed by lipoxygenases. Among these volatiles, aldehydes play a dominant role in beany flavor perception. Hexanal particularly, was commonly associated with the grassy note in soymilk. Other important odor-active compounds include hexanol, 1-octen-3-ol, 1-octen-3-one, trans, trans-2,4- decadienal, and trans, trans-2,4-nonadienal (Chambers IV & Koppel, 2013a).

A total of 62 volatile compounds has been identified in uncooked common beans (*Phaseolus vulgaris L.*) from three major market classes: black beans, dark red kidney beans, and pinto beans. These volatiles belong to several chemical classes, including aromatic hydrocarbons, aldehydes, alkanes, alcohols, and ketones. The bean cultivars differed markedly in both the abundance and composition of their volatile profiles. Among these compounds, hexanal, 3,5-octadien-2-one, 1-penten-3-ol, and benzaldehyde have been proposed as key volatile markers for common beans (Oomah *et al.,* 2007). Additional studies have reported a broad range of volatile compounds in common beans including aliphatic ketones and alcohols, aromatic oxygenated, heterocyclic, and hydrocarbon compounds, as well as terpenes, furans, pyrazines, pyridines, thiazoles, thiazolines, other sulfur-containing heterocyclics, and benzene derivatives. Despite the extensive characterization of volatile profiles, information linking specific compounds to off flavor of common beans remains limited (Roland *et al.,* 2017). Notably, Geosmin, an oxygenated hydrocarbon, has been reported as a primary contributor to the musty, moldy, and earthy off flavors of dry white navy beans (Roland *et al.,* 2017).

1.4. Sensory Analysis

Sensory evaluation is a scientific discipline that applies principles from various fields such as food science, physiology, psychology, and statistics to evoke, measure, and interpret human responses to foods and other materials as perceived through the human senses of sight, smell, taste, touch, and hearing (Stone *et al.,* 2012a). It acts as a direct means of evaluating a product's qualities, which include texture, flavor, color, and overall acceptability. The flavor attribute is usually a combination of taste and aroma (Roland *et al.,* 2017). It provides techniques to define product specifications and to assess consumer hedonic perception. Based on the objective of the study, sensory tests may involve expert, trained, or consumer panels.

It is widely applied in research, product development, quality control, and shelf-life studies and plays a crucial role in various stages of product development with the key role on evaluation of food products based on their sensory attributes. Sensory tests can be categorized into analytical and affective tests (Penfield & Campbell, 1990). Analytical tests include discrimination testing and descriptive analysis. These involve the objective evaluation of product attributes and their intensities by trained panels. Trained panels include individuals trained for a specific sensory method who can identify differences and describe product attributes. Affective tests methods involve the use of consumer panels to measure consumer acceptance and preferences using the hedonic scale (Lawless and Heymann, 2010). It includes acceptance test, preference test, ranking tests, Check-All-That-Apply (CATA) among others. These tests are used to evaluate consumers responses preferences and acceptance of food products qualitatively or quantitatively (Hein *et al.,* 2008).

In affective tests, the consumer panels used are made up of untrained individuals who are typical consumers of a specific product or the product category being tested and their responses are subjective, influenced by demographic and experiential factors (Sinesio, 2005).

Unlike descriptive sensory evaluation which is used to determine the nature of the differences between products (Oh *et al.,* 2022), consumer evaluation which determines product acceptance is particularly useful in directing the production and marketing industries toward a particular food or food product for commercial success (Sparvoli *et al.,* 2021). Quantitative consumer testing can be either conducted in a Central Location Test (CLT), which offers controlled, cost- and time-efficient conditions, or as Home Use Tests (HUTs) provide insights into product performance in natural consumption settings (Sveinsdóttir *et al.,* 2010). Qualitative approaches also exist, and this includes focus groups, ethnographic studies, and in-depth interviews, which offer deeper insights into product concepts and prototypes (Lawless & Heymann, 2010).

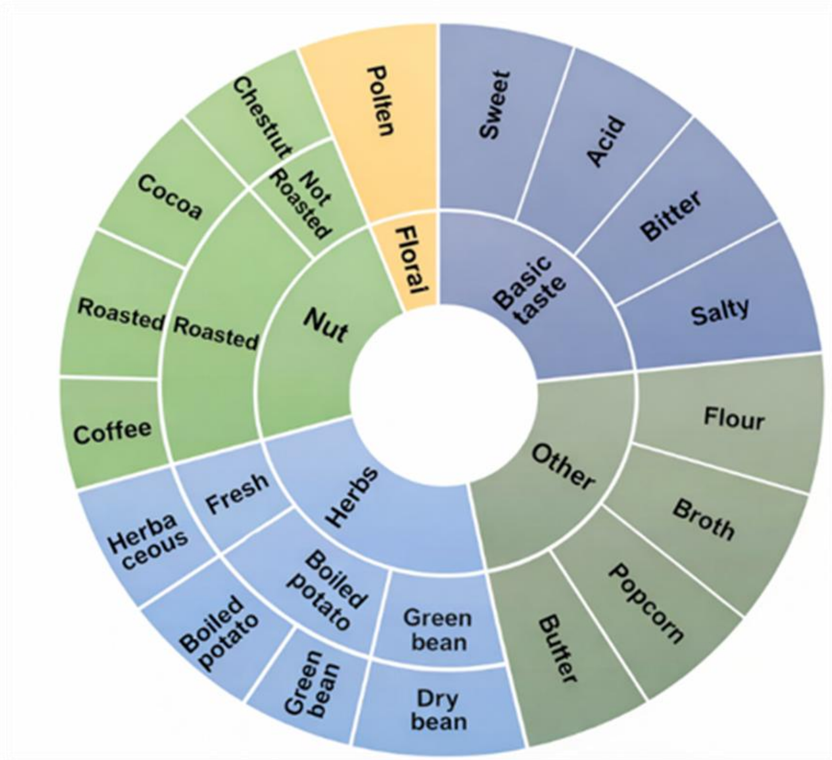
According to a comprehensive review done by (Roland *et al.,* 2017) , common beans are usually characterized by off-flavors that basically form part of their composition and are also produced during harvesting, processing, and storage. These off-flavor compounds contribute to the flavor (taste and aroma) perception and overall acceptability of beans. Texture is considered as one of the most important attributes of the cooked product (Calvo *et al.,* 1999). Texture of beans is assessed through subjective and objective hardness measurements, while flavor perception uses a more complex multimodal nature that includes olfaction, taste, somatosenses, and other sensory elements processed by the brain (Muroki *et al.,* 2024). According to research by *(Ghasemlou et al.,* 2013), consumers prefer beans with a relatively soft texture. Bean samples with an average firmness between could be assumed to have the best sensory attributes. The most undesirable sensory properties were observed in bean samples having a high value of firmness.

Sensory attributes (appearance, texture, aroma and flavor) are a function of the physico-chemical composition of the beans (Roland *et al.,* 2017) which is influenced by the quality and composition therefore by determining which product sensory attributes are most important to consumers, one can focus research and development efforts on satisfying their expectations (Stone *et al.,* 1991).

Sensory profiling methods have also been developed ever since the flavor profile method was introduced (Murray *et al.,* 2001.) It is a class of methods for the description and quantification of sensory attributes as perceived by humans. Hence, these tools are of major importance to the food industry, both for product development and marketing. There are both conventional/traditional profiling methods and alternative/rapid profiling methods. Conventional profiling methods focus on the training of subjects on a sensory vocabulary, while alternative or rapid methods let subjects freely decide how to determine between samples (Delarue & Sieffermann, 2004).

Several sensory studies have been done which have described the sensory profile of common bean varieties and the impact of cooking methods, however, there had not been consensus on the most significant, descriptive, and discriminating sensory attributes that define the sensory landscape of common beans (Mkanda, 2007) until in recent times where a research by (Romero del Castillo *et al.,* 2025) developed a preliminary lexicon for common beans. A total of 205 descriptors for odor and 234 for flavor, with each panelist proposing between 3 and 28 attributes for odor and 9–35 for flavor. Panelists then refined their lists' descriptors and evaluated the 30 bean varieties using their selected attributes. Further analysis facilitated the unification of some attributes, which were then discussed and refined to obtain list of key attributes contributing to the sensory profile of common beans. The final lexicon included 12 odor attributes and 13 flavor attributes, with basic tastes (sweet, acid, bitter, and salty) also incorporated. The attributes finally selected were grouped in a sensory wheel (Figure 1.2).

Figure 1.2: Sensory wheel of common bean odor, flavor and taste attributes



Romero del Castillo *et al.,* 2025

Although static methods such as consumer acceptance tests measure product acceptability and preference at a single point in time, there is also a need to understand how sensory perceptions evolve throughout the consumption experience. Therefore, dynamic sensory methods provide a means of understanding how sensory characteristics of beans evolve during consumption.

1.4.1. Temporal Sensory Methods

One of the limitations in sensory evaluation is characterizing the rapidly evolving sensations that consist of the dynamic properties of products. Temporal sensory evaluation of foods and beverages is a complex endeavor, but also one that is relevant for understanding how products are perceived in the mouth during consumption (Castura & Li, 2016). It involves the evaluation of many in-mouth sensations that are olfactory (smell), gustatory (taste), and trigeminal (chemical irritation sensations such as heat, cooling, or pungency), as well as sound, texture, and temperature. These sensations are not static but dynamic as they evolve over time (Lawless & Heymann, 2010). Various temporal sensory methods are available for characterization of dynamic product properties. For example, Time-Scanning, Descriptive Analysis, Multi-Attribute Time Intensity (Kuesten *et al.,* 2013), Time Related Profiling and Sequential Profiling.

The Temporal Order of Sensations (TOS) method captures the order in which the first few attributes emerge with each bite of a multi-bite evaluation. TOS data are ordinal, which allows the possibility of paper-based data collection. Temporal Dominance of Sensations (TDS) (Pineau *et al.,* 2009a) was originally proposed as a multi-attribute temporal sensory method that scaled the intensities of a sequence of dominant attributes. Pineau *et al.,* 2012 proposed a variant of TDS in which the dominant attribute is selected, without scaling its intensity, an approach often followed by other researchers (Thomas *et al.,* 2015; Zorn *et al.,* 2014).

Some temporal methods focus on changes in attribute intensity and have traditionally been used within analytical sensory evaluation for dynamic sensory characterization. One example is the continuous time intensity (TI) method, which measures the intensity of a single sensory attribute over time (ASTM, 2013). Although this methodology provides an accurate description of the dynamics of attribute intensities, it requires a well-trained panel and is highly time-consuming because many sessions are needed for characterizing complex products with several distinct characteristics (Cadena *et al.,* 2014). These limitations led to the development of Temporal Dominance of Sensations (Pineau *et al.,* 2009a) which is a multi-attribute temporal method that can be performed with both trained and untrained assessors (Pineau *et al.,* 2009a).

TDS relies on the concept of dominance, defined as the sensation that catches attention (Pineau *et al.,* 2012). It consists of presenting assessors with a list of terms and asking them to select the dominant one at each moment of the evaluation (Cadena *et al.,* 2014). TDS has already been used to evaluate a wide range of products with different degrees of complexity (Dinnella *et al.,* 2013; Meillon *et al.,* 2009; Zorn *et al.,* 2014). One of its main disadvantages is that it focuses on the dominant attribute exclusively, not considering all the sensory characteristics that might be perceived simultaneously while evaluating a product. This leads to a loss of relevant sensory information when dealing with products with more complex sensory profiles, which elicit several simultaneous sensations during consumption (Zorn *et al.,* 2014). The Temporal Check-All-That-Apply method (TCATA) was developed to overcome these limitations.

1.4.2. Temporal Check-All-That-Apply

Temporal Check-All-That-Apply (TCATA) is an extension of the Check-All-That-Apply (CATA) method (Meyners & Castura, 2014) and has also been used for the sensory characterization of cosmetic products (Visalli & Galmarini, 2022). TCATA extends the traditional CATA method by incorporating a temporal dimension to the evaluation.

Check-All-That-Apply (CATA) questions allow consumers to indicate the sensory attributes they perceive, while simultaneously providing hedonic evaluations of the samples. CATA questions generate multivariate binary data that indicate the applicability of the sensory descriptors provided to each sample. However, CATA questions do not directly measure attribute intensity. Previous studies have reported strong correlations between CATA citation frequencies and attribute intensities (Bruzzone et al., 2012; Reinbach et al., 2014).

The TCATA methodology has been applied to many products including chocolate-flavored milk (Castura *et al.,* 2016), cosmetic creams (Boinbaser *et al.,* 2015), red wine finish (Baker *et al.,* 2016), yogurt, salami, cheese, orange juice, French bread, marinated mussels (Ares, Antúnez, *et al.,* 2015), dried apricots, peanuts, and milk chocolate (Jaeger *et al.,* 2015). The characteristics of TCATA data are similar to those of TDS (Pineau *et al.,* 2009b). However, TCATA allows the concurrent selection of applicable attributes, whereas TDS captures a sequence of dominant attributes (Castura *et al.,* 2016; Castura & Li, 2016). The TCATA approach is a consumer-friendly technique that enables tracking of multiple sensory attributes over time. A key feature of TCATA is that it can be used with untrained panelists and does not require participants to rate attribute intensity (Tan *et al.,* 2019). In TCATA, assessors are presented with a list of terms and are asked to select all the terms that apply to describe the sensations they perceive at each moment of the evaluation. Participants are provided with an attribute list relevant for a particular product and are asked to select any of the listed attributes that they perceive over the period of evaluation (Poveromo & Hopfer, 2019). They are allowed to check unselected terms when the sensory attribute is applicable, and to uncheck selected terms when the sensory attribute is no longer applicable. Multiple terms can be selected at the same time, which enables assessors to indicate sensations that arise. The method provides a more complete description of the dynamic sensory characteristics of products (Boinbaser et al., 2015). Given that CATA questions have been successfully used for sensory characterizations with consumers (Ares, Jaeger, *et al.,* 2015), TCATA questions provide accurate sensory characterization when used with semi-trained or trained assessors, enabling data collection within relatively short time frames.

1.5. Removal Methods of Beany Flavor: Cooking Methods

The beany flavor of most beans is the result of the action of an enzyme called lipoxygenase. This enzyme is present in varying amounts in most legumes and beans, with higher amounts reported to be present in soybeans (Yang *et al.,* 2023a) . As the name denotes, the enzyme is involved in the oxidation of lipids or fat, which results in the beany flavor. There are three forms of enzyme commonly referred to as lipoxygenase 1, 2 and 3 (Alhendi *et al.,* 2018). The reaction takes place at the double bonds of unsaturated fatty acids and can be accelerated by single oxygen, free radicals, light, and enzymes containing a transition metal prosthetic group such as lipoxygenase. However, lipoxygenase is difficult to eliminate once it is activated (Aryee *et al.,* 2022) .

Currently, there are three main approaches for removal of beany flavor: Biotechnological methods, physical methods, and chemical methods (B. Wang *et al.,* 2021b). Biotechnological methods usually involve fermentation or enzymatic treatments that modify beany-related compounds. Chemical methods involve the use of additives or reagents that bind, mask, or transform beany volatiles, sometimes in combination with physical treatments (Yang *et al.,* 2023b) .Physical methods mainly use radiation, heating (thermal processing), and high-frequency electromagnetic fields. Thermal processing is the most common method for beany flavor removal (Yang *et al.,* 2023b) .

Thermal processing is a key step in food production, widely used to modify the physicochemical properties of ingredients, such as protein denaturation, starch gelatinization, pectin degradation, inactivate spoilage microorganisms and enzymes, and enhance flavor via the Maillard reaction (Yang *et al.,* 2023b) . Depending on the processing temperature and thermal transfer medium, this essential step is broadly categorized into dry and wet thermal processing. Dry thermal processing, which includes roasting, frying, baking, and smoking (Bajo *et al.,* 2026) generally occurs at temperatures above 100 ◦C, with heat transfer achieved through thermal air circulation or direct contact with heated surfaces (Mananga *et al.,* 2022). Wet thermal processing methods include cooking, pasteurization, and ultra-high temperature sterilization.

Cooking is a form of wet thermal processing method which is an essential part of food preparation that not only enhances flavor but also affects the nutritional quality of the ingredients consumed. It includes boiling, slow cooking, steaming, braising, and pressure cooking among others. Soaking before cooking is the most common way of production of edible legumes. Soaking is carried out below the gelatinization temperature to increase the water content of the beans to accelerate the subsequent cooking step (Güzel & Sayar, 2012). Cooking is carried out above the gelatinization temperature to gelatinize starch, produce a tender edible product, develop aroma, and improve the overall acceptability of legumes (Tharanathan & Mahadevamma, 2003b). It also increases the bioavailability of the nutrients by inactivating the antinutritional factors (Chau *et al.,* 1997). Cooking methods can significantly influence the nutritional content of foods, with different methods affecting vitamins, minerals, and other beneficial compounds in different ways. Methods such as boiling, roasting, baking, pressure cooking, and slow cooking are fundamental techniques that are used in cooking to prepare food for consumption (Wu *et al.,* 2023) . These methods not only make food safe to eat by eliminating harmful pathogens but also enhance its overall sensory appeal. Each method applies heat differently, resulting in changes to the food's structure and sensory properties (Wu *et al.,* 2023).

1.5.1. Boiling

Boiling is one of the most common cooking methods and involves immersing food in water or broth heated to its boiling point (100°C or 212°F). Boiling is commonly used for vegetables, pasta, eggs, legumes, grain and meats (Wu *et al.,* 2023). The main conventional cooking method of dry or soaked legume seeds are boiling in water for an extended period of 1–2 h in an open pan (Güzel & Sayar, 2012). The heat causes food to soften and cook through the absorption of water, which can also help break down tough fibers in food, making it easier to digest. However, this method can lead to nutrient loss, especially water-soluble vitamins like Vitamin C and B vitamins, which leach into the cooking liquid (Kwan, 2024). To minimize nutrient loss when boiling, it is advisable to use minimal water and avoid prolonged cooking times (Kwan, 2024).

Boiling is usually used for household cooking of beans and can degrade or eliminate the anti-nutritional factors (Batista *et al.,* 2010). Antinutritional factors (ANFs) are commonly defined as natural or synthetic compounds found in food that reduce the bioavailability and utilization of nutrients, leading to impaired performance of gastrointestinal and metabolic processes (Samtiya *et al.,* 2020). Examples include phytic acid and tannins, both of which are found in several species of pulses.

Soaking and boiling are reported to reduce ANFs in plant-based foods. Water-soluble tannins are usually targeted by soaking and boiling processes, as they can be discarded through this treatment medium (Kumar Singh *et al.,* 2015). Research by (Mubarak, 2005) observed a 39% and 46% reduction in tannins when mung beans were soaked for 12 h and boiled for 90 min respectively.

Boiling has been found to directly affect the Resistant Starch (RS) content (Fabbri *et al.,* 2016). It has been observed that certain sources tend to exhibit an increase in RS content with boiling, while others show a decrease in RS content (Fabbri *et al.,* 2016; N. Wang *et al.,* 2010) for example, the RS% of beans was reduced after boiling, while the RS content of chickpeas increased after boiling when they were cooked to an edible state (N. Wang *et al.,* 2010). A study conducted by (Karunarathna *et al.,* 2024) showed that the RS% of chickpeas increased by 29% after 45 min of boiling.

In some beans such as soybeans, boiling not only produces melanoidins through the Maillard reaction, which can improve the free radical scavenging ability, but it also improves the antioxidant ability by breaking the plant cell wall to release bound minerals (Batista *et al.,* 2010; Žilić *et al.,* 2014a).

1.5.2. Baking

Baking is another popular cooking method, often used for preparing dishes like casseroles, bread, and roasted vegetables. Unlike boiling, it tends to retain more nutrients, particularly when food is cooked at moderate temperatures (Žilić *et al.,* 2014b). This method allows for a caramelization process that can enhance flavor while preserving the integrity of vitamins and minerals. However, it can also lead to nutrient loss if temperatures are too high or cooking times are extended. For instance, prolonged exposure to heat can degrade some vitamins, including B vitamins and vitamin C. Baking conditions, mostly time and temperature, significantly affect the final product as it brings about a number of physical and chemical changes (Rico *et al.,* 2020). These changes can be beneficial or detrimental, depending on the extent and type of treatment conditions as it is a complex process which involves many physical, chemical, and biochemical changes in food. During baking, starch gelatinization occurs affecting the palatability, digestibility, and softening of the raw starch matrix (Yang *et al.,* 2023a).

Baking, in addition to promoting the formation of reactive oxygen species, amino acid racemization, and Maillard reactions, appears to convert bound phenolic acids into their free forms. Although this increases the free phenolic fraction, the overall phenolic content generally decreases, likely because of the heat sensitivity of phenolic compounds (Alfeo *et al.,* 2020). Moreover, baking can promote the formation of antioxidant compounds. For example, ferulic acid has been reported to contribute to the formation of Maillard reaction products through the thermal degradation of intermediates such as 4-vinylguaiacol (Abdel-aal & Rabalski, 2022).

However, limited information is available regarding the temperature and time conditions required to optimize the nutritional and antioxidant properties of baked products, particularly legume-containing snacks. Baking processes may influence the antioxidant content of food due to the antioxidant release, destruction, or creation of redox-active metabolites (Faller & Fialho, 2009). Antioxidant compounds, such as ascorbic acid and some carotenoids, are very sensitive to heat and storage. However, polyphenols have shown a certain stability when exposed to high temperatures (Faller & Fialho, 2009).

1.5.3. Pressure cooking

Pressure cooking is an efficient cooking method compared to other methods such as boiling which is regarded as the least sustainable because of long cooking times and a high demand for energy (Melini *et al.,* 2024). Pressure cooking is an effective and rapid method to cook beans without the need for prior soaking (Balasubramaniam *et al.,* 2015). It has been applied in various industries to many foods such as meats, grains, legumes and vegetables.

In industrial systems, other forms of pressure-cooking such as High-Temperature High-Pressure processing HTHP and High-Pressure High-Temperature Assisted Sterilization (HPHAS) are used. In 2009, the Food and Drug Administration (FDA) approved the commercial use of pressure-assisted thermal processing/sterilization of mashed potatoes in the USA (Ahn *et al.,* 2007). Pressure-cooking is an efficient cooking method because cooking times are considerably shortened (Torrents-Masoliver *et al.,* 2025).

The increase in temperature during the pressure come-up is induced by compression work against intermolecular forces (Knoerzer, 2023). Compared with conventional thermal processing, the efficient heating achieved during pressure cooking minimizes product overprocessing, resulting in improved overall food quality, reduced impact on nutritional and sensorial characteristics, and reduced formation of process-induced contaminants associated with carcinogenic activity, such as acrylamide and 5-hydroxymethylfurfural (HMF), and furans (Vervoort et al., 2012). Some studies addressed the formation of HMF in an asparagine-glucose model solution (De Vleeschouwer *et al.,* 2010), carrot puree (Vervoort *et al.,* 2012), and vegetable-based baby food puree in HPTP pilot and laboratory equipment. The advantages of this method, along with scientific studies conducted at laboratory and pilot scales, position pressure processing as a transformative food processing technology to produce shelf-stable foods, meeting safety requirements and maintaining their quality (Knoerzer & Sevenich, 2025). Corzo-Ríos *et al.,* (2020) used a high-pressure cooking method for ten different bean varieties, reporting that after cooking, an increase in dietary fiber for all beans was observed; moreover, a decrease in some non-nutritional compounds, particularly in trypsin inhibitor content (995−100%), was found. Also, total phenolic compounds exhibited a reduction between 3.2 and 40.9% after cooking.

1.5.4. Slow cooking

The slow cooking method is an example of the low temperature long-time (LTLT) processing method of cooking. As the name indicates, the method consists in heating the product to a low endpoint temperature using extended heating times. The cooking temperature is often close to 60°C or lower, and the product is kept isothermally for a long time, from hours to even days. Another LTLT method which is mostly used is sous vide (SV) cooking (Dominguez-Hernandez *et al.,* 2018). Sous vide is a French word that means “under vacuum”. SV cooking involves slow heating of raw materials or sets/compositions of raw materials that are cooked at precisely controlled low temperatures under 100 ◦C (usually 50–85 ◦C) over extended periods of time (up to 48 h). Cooking using the LTLT method has been long known to produce food of a high sensorial quality (Christensen *et al.,* 2012; Mortensen *et al.,* 2012).

Heating of some foods such as meat modifies its eating quality including texture, color, and flavor (Dall Aaslyng *et al.,* 2003). In addition, heating increases digestibility and the amount of energy that can be obtained during consumption and has also been observed in starch-rich foods (Carmody *et al.,* 2011). The rate and extent of these changes depend on the amount of heat transferred and the heating rate (Oroszvári *et al.,* 2006).

Therefore, the ability to exert control over these variables defines to what extent the food becomes more palatable after cooking (Dall Aaslyng *et al.,* 2003.) This method is commonly used for cooking meat because tenderness, juiciness, and flavor are the primary factors influencing consumer choice and acceptance (Dall Aaslyng *et al.,* 2003). Therefore, the meat industry continually seeks to improve processing methods that enhance these desirable sensory attributes while ensuring that the final product remains safe for consumption (Holdsworth & Simpson, 2007.)

1.6. Research Objectives

This study has three specific objectives:

Objective 1: To evaluate the effects of different cooking methods on the overall acceptance and sensory profiles of selected bean varieties using consumer evaluation.

Objective 2: To use the Temporal-Check-All-That-Apply (TCATA) method to evaluate the temporal evolution of flavor attribute perception in beans prepared using different cooking methods.

Objective 3: To integrate CATA and TCATA data to evaluate the degree of alignment between consumer perceptions and the temporal sensory perceptions provided by the semi- trained panel.

1.7. References

Abdel-aal, E. S. M., & Rabalski, I. (2022). Changes in Phenolic Acids and Antioxidant Properties during Baking of Bread and Muffin Made from Blends of Hairless Canary Seed, Wheat, and Corn. *Antioxidants*, *11*(6). https://doi.org/10.3390/antiox11061059

Adebiyi, J. A., Njobeh, P. B., & Kayitesi, E. (2019). Assessment of nutritional and phytochemical quality of Dawadawa (an African fermented condiment) produced from Bambara groundnut (Vigna subterranea). *Microchemical Journal*, *149*. https://doi.org/10.1016/j.microc.2019.104034

Adebowale, Y. A., Schwarzenbolz, U., & Henle, T. (2011). Protein isolates from Bambara groundnut (Voandzeia Subterranean L.): Chemical characterization and functional properties. *International Journal of Food Properties*, *14*(4), 758–775. https://doi.org/10.1080/10942910903420743

Ahn, J., Balasubramaniam, V. M., & Yousef, A. E. (2007). Inactivation kinetics of selected aerobic and anaerobic bacterial spores by pressure-assisted thermal processing. *International Journal of Food Microbiology*, *113*(3), 321–329. https://doi.org/10.1016/j.ijfoodmicro.2006.08.012

Alfeo, V., Bravi, E., Ceccaroni, D., Sileoni, V., Perretti, G., & Marconi, O. (2020). Effect of baking time and temperature on nutrients and phenolic compounds content of fresh sprouts breadlike product. *Foods*, *9*(10). https://doi.org/10.3390/foods9101447

Alhendi, A., Yang, W., Goodrich-Schneider, R., & Sarnoski, P. J. (2018). Total inactivation of lipoxygenase in whole soya bean by pulsed light and the effect of pulsed light on the chemical properties of soya milk produced from the treated soya beans. *International Journal of Food Science and Technology*, *53*(2), 457–466. https://doi.org/10.1111/ijfs.13604

Anderson, J. W., & Major, A. W. (2002). Pulses and lipaemia, short- and long-term effect: Potential in the prevention of cardiovascular disease. *British Journal of Nutrition*, *88*(S3), 263–271. https://doi.org/10.1079/bjn2002716

Ares, G., Antúnez, L., Giménez, A., & Jaeger, S. R. (2015). List length has little impact on consumers' visual attention to CATA questions. *Food Quality and Preference*, *42*, 100–109. https://doi.org/10.1016/j.foodqual.2015.01.015

Ares, G., Jaeger, S. R., Antúnez, L., Vidal, L., Giménez, A., Coste, B., Picallo, A., & Castura, J. C. (2015). Comparison of TCATA and TDS for dynamic sensory characterization of food products. *Food Research International*, *78*, 148–158. https://doi.org/10.1016/j.foodres.2015.10.023

Arise, A. K., Amonsou, E. O., & Ijabadeniyi, O. A. (2015). Influence of extraction methods on functional properties of protein concentrates prepared from South African bambara groundnut landraces. *International Journal of Food Science and Technology*, *50*(5), 1095–1101. https://doi.org/10.1111/ijfs.12746

Aryee, A. N., Akanbi, T. O., Nwachukwu, I. D., & Gunathilake, T. (2022). Perspectives on preserving lipid quality and strategies for value enhancement. In *Current Opinion in Food Science* (Vol. 44). Elsevier Ltd. https://doi.org/10.1016/j.cofs.2021.12.011

Azman Halimi, R., Barkla, B. J., Andrés-Hernandéz, L., Mayes, S., & King, G. J. (2020). Bridging the food security gap: an information-led approach to connect dietary nutrition, food composition and crop production. *Journal of the Science of Food and Agriculture*, *100*(4), 1495–1504. https://doi.org/10.1002/jsfa.10157

Baker, A. K., Castura, J. C., & Ross, C. F. (2016). Temporal Check-All-That-Apply Characterization of Syrah Wine. *Journal of Food Science*, *81*(6), S1521–S1529. https://doi.org/10.1111/1750-3841.13328

Bajo, W., Chambal, B., & Macuamule, C. (2026). Effect of processing methods on mineral bioaccessibility in common beans. *Scientific Reports*. https://doi.org/10.1038/s41598-025-34639-3

Balasubramaniam, V. M. B., Martínez-Monteagudo, S. I., & Gupta, R. (2015). Principles and application of high pressure-based technologies in the food industry. In *Annual Review of Food Science and Technology* (Vol. 6, pp. 435–462). Annual Reviews Inc. https://doi.org/10.1146/annurev-food-022814-015539

Bambara Groundnuts agriculture, forestry & fisheries Department: Agriculture, Forestry and Fisheries republic of South Africa. (2016).

Batista, K. A., Prudêncio, S. H., & Fernandes, K. F. (2010). Changes in the functional properties and antinutritional factors of extruded hard-to-cook common beans (phaseolus vulgaris, l.). *Journal of Food Science*, *75*(3). https://doi.org/10.1111/j.1750-3841.2010.01557.x

Boinbaser, L., Parente, M. E., Castura, J. C., & Ares, G. (2015). Dynamic sensory characterization of cosmetic creams during application using Temporal Check-All-That-Apply (TCATA) questions. *Food Quality and Preference*, *45*, 33–40. https://doi.org/10.1016/j.foodqual.2015.05.003

Boye, J., Zare, F., & Pletch, A. (2010). Pulse proteins: Processing, characterization, functional properties and applications in food and feed. In *Food Research International* (Vol. 43, Number 2, pp. 414–431). https://doi.org/10.1016/j.foodres.2009.09.003

Bruzzone, F., Ares, G., & Giménez, A. (2012). Consumers' texture perception of milk desserts. II - comparison with trained assessors' data. *Journal of Texture Studies*, *43*(3), 214–226. https://doi.org/10.1111/j.1745-4603.2011.00332.x

Cadena, R. S., Vidal, L., Ares, G., & Varela, P. (2016.). *3 Dynamic Sensory Descriptive Methodologies Time-Intensity and Temporal Dominance of Sensations*.

Calvo, M. S., Atienza, J., & Rey, D. (1999). B A S E Sensory analysis of beans (Phaseolus vulgaris). In *Biotechnol. Agron. Soc. Environ* (Vol. 3, Number 4).

Câmara, C. R. S., Urrea, C. A., & Schlegel, V. (2013). Pinto beans (Phaseolus vulgaris l.) as a functional food: Implications on human health. *Agriculture (Switzerland)*, *3*(1), 90–111. https://doi.org/10.3390/agriculture3010090

Carmody, R. N., Weintraub, G. S., & Wrangham, R. W. (2011). Energetic consequences of thermal and nonthermal food processing. *Proceedings of the National Academy of Sciences of the United States of America*, *108*(48), 19199–19203. https://doi.org/10.1073/pnas.1112128108

Castura, J. C., Antúnez, L., Giménez, A., & Ares, G. (2016). Temporal Check-All-That-Apply (TCATA): A novel dynamic method for characterizing products. *Food Quality and Preference*, *47*, 79–90. https://doi.org/10.1016/j.foodqual.2015.06.017

Castura, J. C., & Li, M. (2016). Using TDS dyads and other dominance sequences to characterize products and investigate liking changes. *Food Quality and Preference*, *47*, 109–121. https://doi.org/10.1016/j.foodqual.2015.06.019

Chambers IV, E., & Koppel, K. (2013). Associations of volatile compounds with sensory aroma and flavor: The complex nature of flavor. In *Molecules* (Vol. 18, Number 5, pp. 4887–4905). https://doi.org/10.3390/molecules18054887

Chau, C. F., Cheung, P. C. K., & Wong, Y. S. (1997). Effects of cooking on content of amino acids and antinutrients in three Chinese indigenous legume seeds. *Journal of the Science of Food and Agriculture*, *75*(4), 447–452. https://doi.org/10.1002/(SICI)1097-0010(199712)75:4<447::AID-JSFA896>3.0.CO;2-5

Chavan, J.K., Kadam, S.S., Salunkhe, D.K., (1989). Chickpea. In: Salunkhe DK, Kadam SS (eds) Handbook of world food legumes: nutritional chemistry, processing technology and utilization,Vol I. CRC, Boca Raton, 247-288, 1989.

Chigwedere, C. M., Olaoye, T. F., Kyomugasho, C., Jamsazzadeh Kermani, Z., Pallares Pallares, A., Van Loey, A. M., Grauwet, T., & Hendrickx, M. E. (2018). Mechanistic insight into softening of Canadian wonder common beans (Phaseolus vulgaris) during cooking. *Food Research International*, *106*, 522–531. https://doi.org/10.1016/j.foodres.2018.01.016

Christensen, L., Gunvig, A., Tørngren, M. A., Aaslyng, M. D., Knøchel, S., & Christensen, M. (2012). Sensory characteristics of meat cooked for prolonged times at low temperature. *Meat Science*, *90*(2), 485–489. https://doi.org/10.1016/j.meatsci.2011.09.012

Corzo-Ríos, L. J., Sánchez-Chino, X. M., Cardador-Martínez, A., Martínez-Herrera, J., & Jiménez-Martínez, C. (2020). Effect of cooking on nutritional and non-nutritional compounds in two species of Phaseolus (P. vulgaris and P. coccineus) cultivated in Mexico. *International Journal of Gastronomy and Food Science*, *20*. https://doi.org/10.1016/j.ijgfs.2020.100206

Dinnella, C., Masi, C., Naes, T., & Monteleone, E. (2013). A new approach in TDS data analysis: A case study on sweetened coffee. *Food Quality and Preference*, *30*(1), 33–46. https://doi.org/10.1016/j.foodqual.2013.04.006

Dall Aaslyng, M., Bejerholm, C., Bertram, H. C., & Andersen, H. J. (2003). Cooking loss and juiciness of pork in relation to raw meat quality and cooking procedure. Retrieved www.elsevier.com/locate/foodqual

De Vleeschouwer, K., Van der Plancken, I., Van Loey, A., & Hendrickx, M. E. (2010). The effect of high pressure-high temperature processing conditions on acrylamide formation and other Maillard reaction compounds. *Journal of Agricultural and Food Chemistry*, *58*(22), 11740–11748. https://doi.org/10.1021/jf102697b

Delahunty, C. M., McCord, aA, & Morrisseyd, P. A. (1997). Sensory characterization of cooked hams By Untrained Consumers Using Free-Choice Profiling. In *Food Qwli& and Prrfccnce* (Vol. 8, Number 6).

Delarue, J., & Sieffermann, J. M. (2004). Sensory mapping using Flash profile. Comparison with a conventional descriptive method for the evaluation of the flavour of fruit dairy products. *Food Quality and Preference*, *15*(4), 383–392. https://doi.org/10.1016/S0950-3293(03)00085-5

Dominguez-Hernandez, E., Salaseviciene, A., & Ertbjerg, P. (2018). Low-temperature long-time cooking of meat: Eating quality and underlying mechanisms. In *Meat Science* (Vol. 143, pp. 104–113). Elsevier Ltd. https://doi.org/10.1016/j.meatsci.2018.04.032

Escofier, B., & Pagb, J. (1994). Multiple factor analysis (AFMULT package). In *Computational Statistics & Data Analysis* (Vol. 18).

Fabbri, A. D. T., Schacht, R. W., & Crosby, G. A. (2016). Evaluation of resistant starch content of cooked black beans, pinto beans, and chickpeas. *NFS Journal*, *3*, 8–12. https://doi.org/10.1016/j.nfs.2016.02.002

Faller, A. L. K., & Fialho, E. (2009). The antioxidant capacity and polyphenol content of organic and conventional retail vegetables after domestic cooking. *Food Research International*, *42*(1), 210–215. https://doi.org/10.1016/j.foodres.2008.10.009

Food and Agriculture Organization of the United Nations. (2022). A global mapping system for Bambara groundnut production. (FAO Agricultural Information Management Series No. 1). FAO.

Ghaitaranpour, A., Kebede, B., & Najafabadi, M. Y. (2026). *Advancing Canning Quality in Common Beans: An Integrated Farm-to-Can Framework Combining Breeding, Processing, and Artificial Intelligence*. Legume Science.

Ghasemlou, M., Gharibzahedi, S. M. T., & Emam-Djomeh, Z. (2013). Relating consumer preferences to textural attributes of cooked beans: Development of an industrial protocol and microstructural observations. *LWT*, *50*(1), 88–98. https://doi.org/10.1016/j.lwt.2012.06.018

Grain Legumes Production, Consumption and Trade Trends in Developing Countries Science with a human face. (2015). Retrieved www.icrisat.org

Güzel, D., & Sayar, S. (2012). Effect of cooking methods on selected physicochemical and nutritional properties of barlotto bean, chickpea, faba bean, and white kidney bean. *Journal of Food Science and Technology*, *49*(1), 89–95. https://doi.org/10.1007/s13197-011-0260-0

Hein, K A., Jaeger, S R., Carr, B T., & Delahunty, C M. (2008). Comparison of five common acceptance and preference methods. Food quality and preference, 19(7), 651- 661. https://doi.org/10.1016/j.foodqual.2008.06.001

Hillocks, R. J., Bennett, C., & Mponda, O. M. (2011.). Bambara Nut: A Review Of Utilisation, Market Potential And Crop Improvement. In *African Crop Science Journal* (Vol. 20, Number 1). Retrieved http://www.dainet.de/genres/bambara/

Holdsworth & Simpson, 2007 *Thermal Processing of Packaged Foods Second Edition*.

Hussin, H., Gregory, P. J., Julkifle, A. L., Sethuraman, G., Tan, X. L., Razi, F., & Azam-Ali, S. N. (2020). Enhancing the Nutritional Profile of Noodles With Bambara Groundnut (Vigna subterranea) and Moringa (Moringa oleifera): A Food System Approach. *Frontiers in Sustainable Food Systems*, *4*. https://doi.org/10.3389/fsufs.2020.00059

Jaeger, S. R., Beresford, M. K., Paisley, A. G., Antúnez, L., Vidal, L., Cadena, R. S., Giménez, A., & Ares, G. (2015). Check-all-that-apply (CATA) questions for sensory product characterization by consumers: Investigations into the number of terms used in CATA questions. *Food Quality and Preference*, *42*, 154–164. https://doi.org/10.1016/j.foodqual.2015.02.003

Karunarathna, S., Wickramasinghe, I., Brennan, C., Truong, T., Navaratne, S., & Chandrapala, J. (2024). Investigating the impact of boiling and pressure cooking on resistant starch levels in food. *International Journal of Food Science and Technology*, *59*(6), 3907–3917. https://doi.org/10.1111/ijfs.17138

Kemisola Arise, A., Dauda, A. O., Gbonjubola, V. A., & Akinlolu-Ojo, V. (2017). Physico-Chemical, Functional and Pasting Properties of Composite Flour made from Wheat, Plantain And Bambara for Biscuit Production. In *Annals. Food Science and Technology* (Vol. 18). www.afst.valahia.ro

Kinyanjui, P. K., Njoroge, D. M., Makokha, A. O., Christiaens, S., Ndaka, D. S., & Hendrickx, M. (2015). Hydration properties and texture fingerprints of easy-and hard-to-cook bean varieties. *Food Science and Nutrition*, *3*(1), 39–47. https://doi.org/10.1002/fsn3.188

Knoerzer, K. (2023). Modeling high pressure thermal processing. In *High Pressure Thermal Processing* (pp. 183–204). Elsevier. https://doi.org/10.1016/B978-0-12-823872-1.00008-9

Knoerzer, K., & Sevenich, R. (2025). From Concept to Commercialization: Unlocking the Potential of High-Pressure Thermal Processing. In *Food Engineering Reviews* (Vol. 17, Number 3, pp. 627–644). Springer. https://doi.org/10.1007/s12393-025-09414-9

Kumar Singh, P., Shrivastava, N., Sharma, B., & Bhagyawant, S. S. (2015). Effect of Domestic Processes on Chickpea Seeds for Antinutritional Contents and Their Divergence "Effect of Domestic Processes on Chickpea Seeds for Antinutritional Contents and Their Divergence. *American Journal of Food Science and Technology*, *3*(4), 111–117. https://doi.org/10.12691/ajfst-3-4-3

Kuesten, C., Bi, J., & Feng, Y. (2013). Exploring taffy product consumption experiences using a multi-attribute time-intensity (MATI) method. *Food Quality and Preference*, *30*(2), 260–273. https://doi.org/10.1016/j.foodqual.2013.06.007

Kwan, A. (2024). *Rapid Communication The impact of cooking methods on nutrient retention: Boil, bake, or grill? Revised*, 16. https://doi.org/10.35841/aajfsn-7.5.261

Lawless, H. T., & Heymann, H. (2010). Qualitative Consumer Research Methods. In H. T. Lawless & H. Heymann (Eds.), Sensory Evaluation of Food: Principles and Practices (pp. 379–405). Springer.

Liu, K. (1995). Cellular, Biological, and Physicochemical Basis for the Hard-To-Cook Defect in Legume Seeds. *Critical Reviews in Food Science and Nutrition*, *35*(4), 263–298. https://doi.org/10.1080/10408399509527702

Liu, K., Mcwatters, K. H., & Dixon Phillips, R. (1992). Protein Insolubilization and Thermal Destabilization during Storage as Related to Hard-To-Cook Defect in Cowpeast. In *J. Agrlc. Food Chem* (Vol. 40).

Lõpez, M. A., Vicente, J., Kulasekaran, S., Vellosillo, T., Martínez, M., Irigoyen, M. L., Cascõn, T., Bannenberg, G., Hamberg, M., & Castresana, C. (2011). Antagonistic role of 9-lipoxygenase-derived oxylipins and ethylene in the control of oxidative stress, lipid peroxidation and plant defence. *Plant Journal*, *67*(3), 447–458. https://doi.org/10.1111/j.1365-313X.2011.04608.x

Luciana Mariana, Ş. (2014). Amino acid compozition of some common bean landraces from Caraş-Severin county, of Romania. In *Forestry and Biotechnology* (Vol. 18, Number 2). www.journal-hfb.usab-tm.ro

Mananga, M.-J., Noah Joseph Karrington, E., Taptue Charles, K., Ndjigoui Brice Didier, K., & Elie, F. (2022). Effect of Different Processing Methods on the Nutritional Value of Red and White Bean Cultivars (<i>Phaseolus vulgaris </i>L.). *Journal of Food and Nutrition Sciences*, *10*(1), 27. https://doi.org/10.11648/j.jfns.20221001.15

Maphosa Y., & Jideani V.A. (2016). Physicochemical characteristics of Bambara groundnut dietary fibres extracted using wet milling. South African Journal of Science 112,1–8.

Maphosa Y., Jideani V.A., Maphosa L. (2022). Bambara groundnut production, grain composition and nutritional value: opportunities for improvements. The Journal of Agricultural Science 160,448–458. https://doi.org/10.1017/S0021859622000521

Meillon, S., Urbano, C., & Schlich, P. (2009). Contribution of the Temporal Dominance of Sensations (TDS) method to the sensory description of subtle differences in partially dealcoholized red wines. *Food Quality and Preference*, *20*(7), 490–499. https://doi.org/10.1016/j.foodqual.2009.04.006

Meyners, M., & Castura, J. C. (n.d.). *The analysis of temporal check-all-that-apply (TCATA) data*.

Mbiu, J., Assefa, T., Mukankusi, C., Rubyogo, J. C., & Philipo, M. (2025). Consumer traits of common beans: a global and regional perspective on seed coat darkening, cooking time, protein, and mineral content. *Frontiers in Nutrition*, *12*. https://doi.org/10.3389/fnut.2025.1658338

McDermott, J., & Wyatt, A. J. (2017). The role of pulses in sustainable and healthy food systems. In *Annals of the New York Academy of Sciences* (Vol. 1392, Number 1, pp. 30–42). https://doi.org/10.1111/nyas.13319

Melini, F., Lisciani, S., Camilli, E., Marconi, S., & Melini, V. (2024). Effect of Cooking on Phenolic Compound Content and In Vitro Bioaccessibility in Sustainable Foods: A Case Study on Black Beans. *Sustainability (Switzerland)*, *16*(1). https://doi.org/10.3390/su16010279

Mkanda, A. V. (2007). *Relating consumer preferences to sensory and physicochemical properties of dry beans (Phaseolus vulgaris L.)*.

Mortensen, L. M., Frøst, M. B., Skibsted, L. H., & Risbo, J. (2012). Effect of time and temperature on sensory properties in low-temperature long-time sous-vide cooking of beef. *Journal of Culinary Science and Technology*, *10*(1), 75–90. https://doi.org/10.1080/15428052.2012.651024

Mubaiwa, J., Fogliano, V., Chidewe, C., Jan Bakker, E., & Linnemann, A. R. (2018). Utilization of bambara groundnut (Vigna subterranea (L.) Verdc.) for sustainable food and nutrition security in semi-arid regions of Zimbabwe. *PLoS ONE*, *13*(10). https://doi.org/10.1371/journal.pone.0204817

Mubarak, A. E. (2005). Nutritional composition and antinutritional factors of mung bean seeds (Phaseolus aureus) as affected by some home traditional processes. *Food Chemistry*, *89*(4), 489–495. https://doi.org/10.1016/j.foodchem.2004.01.007

Muroki, M. W., Waswa, L. M., Fungo, R., Kabwama, A., Eric, N., Nepomuscene, N., Ndabashinze, B., & Mahungu, S. M. (2024). Sensory properties of selected biofortified common bean (Phaseolus vulgaris) varieties grown in Burundi. *Food Science and Nutrition*, *12*(5), 3199–3213. https://doi.org/10.1002/fsn3.3988

Murray, J. M., Delahunty, C. M., & Baxter, I. A. (n.d.). Descriptive sensory analysis: past, present and future. Retrieved www.elsevier.com/locate/foodres

NC, T. (2018). Origin and Ecology of Bambara Groundnut (Vigna Subterranea (L.) Verdc: A Review. *Journal of Ecology & Natural Resources*, *2*(4). https://doi.org/10.23880/jenr-16000140

Njoroge, D. M., Kinyanjui, P. K., Christiaens, S., Shpigelman, A., Makokha, A. O., Sila, D. N., & Hendrickx, M. E. (2015). Effect of storage conditions on pectic polysaccharides in common beans (Phaseolus vulgaris) in relation to the hard-to-cook defect. *Food Research International*, *76*(P1), 105–113. https://doi.org/10.1016/j.foodres.2015.03.005

Nyau, V., Prakash, S., Rodrigues, J., & Farrant J. (2015). Antioxidant Activities of Bambara Groundnuts as Assessed by FRAP and DPPH Assays. *American Journal of Food and Nutrition*, *3*(1), 7–11. https://doi.org/10.12691/ajfn-3-1-2

Oh, H., Jo, Y., & Kim, M. K. (2022). Descriptive Analysis of Seven Leguminous Plants in Korea. *Preventive Nutrition and Food Science*, *27*(2), 241–247. https://doi.org/10.3746/PNF.2022.27.2.241

Oomah, B. D., Liang, L. S. Y., & Balasubramanian, P. (2007). Volatile compounds of dry beans (Phaseolus vulgaris L.). *Plant Foods for Human Nutrition*, *62*(4), 177–183. https://doi.org/10.1007/s11130-007-0059-3

Oroszvári, B. K., Rocha, C. S., Sjöholm, I., & Tornberg, E. (2006). Permeability and mass transfer as a function of the cooking temperature during the frying of beefburgers. *Journal of Food Engineering*, *74*(1), 1–12. https://doi.org/10.1016/j.jfoodeng.2005.02.024

Oyeyinka, A. T., Pillay, K., & Siwela, M. (2017). Consumer awareness and acceptability of bambara groundnut as a protein source for use in complementary foods in rural KwaZulu-Natal. *South African Journal of Clinical Nutrition*, *30*(4), 87–92. https://doi.org/10.1080/16070658.2017.1282581

Oyeyinka, S. A., Tijani, T. S., Oyeyinka, A. T., Arise, A. K., Balogun, M. A., Kolawole, F. L., Obalowu, M. A., & Joseph, J. K. (2018). Value added snacks produced from Bambara groundnut (Vigna subterranea) paste or flour. *LWT*, *88*, 126–131. https://doi.org/10.1016/j.lwt.2017.10.011

Penfield, M. P., & Campbell, A. M. (1990). Chapter 4 - Evaluating food by sensory methods. In M. P. Penfield & A. M. Campbell (Eds.), Experimental Food Science (Third Edition) (pp. 51–77). Academic Press.

Perseguini, J. M. K. C., Oblessuc, P. R., Rosa, J. R. B. F., Gomes, K. A., Chiorato, A. F., Carbonell, S. A. M., Garcia, A. A. F., Vianello, R. P., & Benchimol-Reis, L. L. (2016). Genome-Wide Association Studies of Anthracnose and Angular Leaf Spot Resistance in Common Bean (Phaseolus vulgaris L.). *PLoS ONE*, *11*(3). https://doi.org/10.1371/journal.pone.0150506

Pineau, N., de Bouillé, A. G., Lepage, M., Lenfant, F., Schlich, P., Martin, N., & Rytz, A. (2012). Temporal Dominance of Sensations: What is a good attribute list? *Food Quality and Preference*, *26*(2), 159–165. https://doi.org/10.1016/j.foodqual.2012.04.004

Pineau, N., Schlich, P., Cordelle, S., Mathonnière, C., Issanchou, S., Imbert, A., Rogeaux, M., Etiévant, P., & Köster, E. (2009a). Temporal Dominance of Sensations: Construction of the TDS curves and comparison with time-intensity. *Food Quality and Preference*, *20*(6), 450–455. https://doi.org/10.1016/j.foodqual.2009.04.005

Pineau, N., Schlich, P., Cordelle, S., Mathonnière, C., Issanchou, S., Imbert, A., Rogeaux, M., Etiévant, P., & Köster, E. (2009b). Temporal Dominance of Sensations: Construction of the TDS curves and comparison with time-intensity. *Food Quality and Preference*, *20*(6), 450–455. https://doi.org/10.1016/j.foodqual.2009.04.005

Poveromo, A. R., & Hopfer, H. (2019). Temporal check-all-that-apply (TCATA) reveals matrix interaction effects on flavor perception in a model wine matrix. *Foods*, *8*(12). https://doi.org/10.3390/foods8120641

Ravi, R., Taheri, A., Khandekar, D., & Millas, R. (2019). Rapid profiling of soybean aromatic compounds using electronic nose. *Biosensors*, *9*(2). https://doi.org/10.3390/bios9020066

Reinbach, H. C., Giacalone, D., Ribeiro, L. M., Bredie, W. L. P., & Frøst, M. B. (2014). Comparison of three sensory profiling methods based on consumer perception: CATA, CATA with intensity and Napping®. *Food Quality and Preference*, *32*, 160–166. https://doi.org/10.1016/j.foodqual.2013.02.004

Richardson, J. C., & Stanley, D. W. (1991). *Relationship of Loss of Membrane Functionality and Hard-to-Cook Defect in Aged Beans*.

Rico, D., González-Paramás, A. M., Brezmes, C., & Martín-Diana, A. B. (2020). Baking Optimization as a Strategy to Extend Shelf-Life through the Enhanced Quality and Bioactive Properties of Pulse-Based Snacks. *Molecules*, *25*(16). https://doi.org/10.3390/molecules25163716

Roland, W. S. U., Pouvreau, L., Curran, J., Van De Velde, F., & De Kok, P. M. T. (2017). Flavor aspects of pulse ingredients. In *Cereal Chemistry* (Vol. 94, Number 1, pp. 58–65). American Association of Cereal Chemists. https://doi.org/10.1094/CCHEM-06-16-0161-FI

Romero del Castillo, R., Rivera, A., Roselló, S., Beltran, J., Campo, S., Casañas, F., & Casals, J. (2025). The odor and flavor of cooked common beans (Phaseolus vulgaris L.): Sensory lexicon, chemical background and diversity in the Spanish Core collection. *LWT*, *232*. https://doi.org/10.1016/j.lwt.2025.118453

Tan, V. W. K., Wee, M. S. M., Tomic, O., & Forde, C. G. (2019). Temporal sweetness and side tastes profiles of 16 sweeteners using temporal check-all-that-apply (TCATA). *Food Research International*, *121*, 39–47. https://doi.org/10.1016/j.foodres.2019.03.019

Thomas, A., Visalli, M., Cordelle, S., & Schlich, P. (2015). Temporal Drivers of Liking. *Food Quality and Preference*, *40*(PB), 365–375. https://doi.org/10.1016/j.foodqual.2014.03.003

Samtiya, M., Aluko, R. E., & Dhewa, T. (2020). Plant food anti-nutritional factors and their reduction strategies: an overview. In *Food Production, Processing and Nutrition* (Vol. 2, Number 1). BioMed Central Ltd. https://doi.org/10.1186/s43014-020-0020-5

Sinesio, F. (2005). Sensory Evaluation. In P. Worsfold, A. Townshend, & C. Poole (Eds.), Encyclopedia of Analytical Science (Second Edition) (pp. 283–290). Elsevier.

Sparvoli, F., Giofré, S., Cominelli, E., Avite, E., Giuberti, G., Luongo, D., Gatti, E., Cianciabella, M., Daniele, G. M., Rossi, M., & Predieri, S. (2021). Sensory characteristics and nutritional quality of food products made with a biofortified and lectin free common bean (Phaseolus vulgaris l.) flour. *Nutrients*, *13*(12). https://doi.org/10.3390/nu13124517

Stone, H., Bleibaum, R. N., & Thomas, H. A. (2012a). Chapter 5—Discrimination Testing. In H. Stone, R. N. Bleibaum, & H. A. Thomas (Eds.), Sensory Evaluation Practices (Fourth Edition) (pp. 167–231). Academic Press.

Stone, H., Bleibaum, R. N., & Thomas, H. A. (2012b). Chapter 6—Descriptive Analysis. In H. Stone, R. N. Bleibaum, & H. A. Thomas (Eds.), Sensory Evaluation Practices (Fourth Edition) (pp. 233–289). Academic Press.

Sveinsdóttir, K., Martinsdóttir, E., Thórsdóttir, F., Schelvis, R., Kole, A., & Thórsdóttir, I. (2010). Evaluation of Farmed Cod Products by a Trained Sensory Panel and Consumers in Different Test Settings. Journal of Sensory Studies, 25(2), 280–293.

Tan, X. L., Azam-Ali, S., Goh, E. Von, Mustafa, M., Chai, H. H., Ho, W. K., Mayes, S., Mabhaudhi, T., Azam-Ali, S., & Massawe, F. (2020). Bambara Groundnut: An Underutilized Leguminous Crop for Global Food Security and Nutrition. In *Frontiers in Nutrition* (Vol. 7). Frontiers Media S.A. https://doi.org/10.3389/fnut.2020.601496

Talavera-Bianchi, M., Chambers IV, E., & Chambers, D. H. (2010). Describing flavor using fewer and simpler “HITS” (high identity traits) profiling: An example with cheese. Journal of Sensory Studies, 25(4), 481–493.

Tharanathan, R. N., & Mahadevamma, S. (2003a). Grain legumes - A boon to human nutrition. In *Trends in Food Science and Technology* (Vol. 14, Number 12, pp. 507–518). Elsevier Ltd. https://doi.org/10.1016/j.tifs.2003.07.002

Tharanathan, R. N., & Mahadevamma, S. (2003b). Grain legumes - A boon to human nutrition. In *Trends in Food Science and Technology* (Vol. 14, Number 12, pp. 507–518). Elsevier Ltd. https://doi.org/10.1016/j.tifs.2003.07.002

Torrents-Masoliver, B., Jofré, A., Ribas-Agustí, A., & Bover-Cid, S. (2025). Novel high-pressure thermal processing at industrial scale efficiently inactivates bacterial spores while minimises process-induced contaminants in acid and low-acid infant food. *Food Research International*, *221*. https://doi.org/10.1016/j.foodres.2025.117247

Torres, A., & van de Velden, M. (2007). Perceptual mapping of multiple variable batteries by plotting supplementary variables in correspondence analysis of rating data. *Food Quality and Preference*, *18*(1), 121–129. https://doi.org/10.1016/j.foodqual.2005.09.005

Visalli, M., & Galmarini, M. V. (2022). Multi-attribute temporal descriptive methods in sensory analysis applied in food science: Protocol for a scoping review. In *PLoS ONE* (Vol. 17, Number 7 July). Public Library of Science. https://doi.org/10.1371/journal.pone.0270969

Venter, C. S., & Van Eyssen, E. (2001). *More Legumes for Better Overall Health Articles S32* (Vol. 14, Number 3).

Vervoort, L., Van Der Plancken, I., Grauwet, T., Verlinde, P., Matser, A., Hendrickx, M., & Van Loey, A. (2012). Thermal versus high pressure processing of carrots: A comparative pilot-scale study on equivalent basis. *Innovative Food Science and Emerging Technologies*, *15*, 1–13. https://doi.org/10.1016/j.ifset.2012.02.009

Vidal, L., Cadena, R. S., Antúnez, L., Giménez, A., Varela, P., & Ares, G. (2014). Stability of sample configurations from projective mapping: How many consumers are necessary? *Food Quality and Preference*, *34*, 79–87. https://doi.org/10.1016/j.foodqual.2013.12.006

Vilakazi, B., Mafongoya, P. L., Odindo, A. O., & Phophi, M. M. (2025). The Role of Neglected Grain Legumes in Food and Nutrition Security and Human Health. In *Sustainability (Switzerland)* (Vol. 17, Number 1). Multidisciplinary Digital Publishing Institute (MDPI). https://doi.org/10.3390/su17010350

Vincenti, S., Mariani, M., Alberti, J. C., Jacopini, S., de Caraffa, V. B. B., Berti, L., & Maury, J. (2019). Biocatalytic synthesis of natural green leaf volatiles using the lipoxygenase metabolic pathway. In *Catalysts* (Vol. 9, Number 10). MDPI. https://doi.org/10.3390/catal9100873

Wang, B., Zhang, Q., Zhang, N., Bak, K. H., Soladoye, O. P., Aluko, R. E., Fu, Y., & Zhang, Y. (2021a). Insights into formation, detection and removal of the beany flavor in soybean protein. In *Trends in Food Science and Technology* (Vol. 112, pp. 336–347). Elsevier Ltd. https://doi.org/10.1016/j.tifs.2021.04.018

Wang, B., Zhang, Q., Zhang, N., Bak, K. H., Soladoye, O. P., Aluko, R. E., Fu, Y., & Zhang, Y. (2021b). Insights into formation, detection and removal of the beany flavor in soybean protein. In *Trends in Food Science and Technology* (Vol. 112, pp. 336–347). Elsevier Ltd. https://doi.org/10.1016/j.tifs.2021.04.018

Wang, N., Hatcher, D. W., Tyler, R. T., Toews, R., & Gawalko, E. J. (2010). Effect of cooking on the composition of beans (Phaseolus vulgaris L.) and chickpeas (Cicer arietinum L.). *Food Research International*, *43*(2), 589–594. https://doi.org/10.1016/j.foodres.2009.07.012

Winham, D., Densie Webb, D., & Amy Barr, R. (2008). Beans and Good Health. In *Nutr Today* (Vol. 43, Number 5).

Winham, D. M., Florian, T. L. A., & Thompson, S. V. (2016). Low-income US women under-informed of the specific health benefits of consuming beans. *PLoS ONE*, *11*(1). https://doi.org/10.1371/journal.pone.0147592

Wu, T., Sheng, Y. N., Tian, Y., Yu, M., Bai, L., & Wang, C. Y. (2023). Exploring the effect of boiling processing on the metabolic components of black beans through in vitro simulated digestion. *LWT*, *184*. https://doi.org/10.1016/j.lwt.2023.114987

Xiong, M., Zhao, M., Lu, Z. X., & Balasubramanian, P. (2020). Genotypic variation for phenolic compounds in developing and whole seeds, and storage conditions influence visual seed quality of yellow dry bean genotypes. *Canadian Journal of Plant Science*, *100*(3), 284–295. https://doi.org/10.1139/cjps-2019-0153

Yang, L., Zhang, T., Li, H., Chen, T., & Liu, X. (2023a). Control of Beany Flavor from Soybean Protein Raw Material in Plant-Based Meat Analog Processing. In *Foods* (Vol. 12, Number 5). MDPI. https://doi.org/10.3390/foods12050923

Yang, L., Zhang, T., Li, H., Chen, T., & Liu, X. (2023b). Control of Beany Flavor from Soybean Protein Raw Material in Plant-Based Meat Analog Processing. In *Foods* (Vol. 12, Number 5). MDPI. https://doi.org/10.3390/foods12050923

Yao, D. N., Kouassi, K. N., Erba, D., Scazzina, F., Pellegrini, N., & Casiraghi, M. C. (2015). Nutritive evaluation of the Bambara groundnut Ci12 landrace [Vigna subterranea (L.) Verdc. (Fabaceae)] produced in Côte d'Ivoire. *International Journal of Molecular Sciences*, *16*(9), 21428–21441. https://doi.org/10.3390/ijms160921428.

Žilić, S., Mogol, B. A., Akillioğlu, G., Serpen, A., Delić, N., & Gökmen, V. (2014a). Effects of extrusion, infrared and microwave processing on Maillard reaction products and phenolic compounds in soybean. *Journal of the Science of Food and Agriculture*, *94*(1), 45–51. https://doi.org/10.1002/jsfa.6210.

Žilić, S., Mogol, B. A., Akillioğlu, G., Serpen, A., Delić, N., & Gökmen, V. (2014b). Effects of extrusion, infrared and microwave processing on Maillard reaction products and phenolic compounds in soybean. *Journal of the Science of Food and Agriculture*, *94*(1), 45–51. https://doi.org/10.1002/jsfa.6210

Zorn, S., Alcaire, F., Vidal, L., Giménez, A., & Ares, G. (2014). Application of multiple-sip temporal dominance of sensations to the evaluation of sweeteners. *Food Quality and Preference*, *36*, 135–143. https://doi.org/10.1016/j.foodqual.2014.04.003

Chapter 2 - Effect of Selected Cooking Methods on the Sensory Profile and Consumer Acceptance of Dry Beans

Abstract

The objective of this study was to determine the overall consumer acceptance of different bean types prepared using selected cooking methods through consumer evaluation. Three different bean types were each subjected to four cooking methods (boiling, slow cooking, pressure cooking and baking). A 3-day consumer study was conducted using 76 participants who evaluated all 12 samples. Participants evaluated 4 samples per day and answered questions on appearance, aroma, flavor, JAR, and CATA, among others. Consumer data was analyzed using Analysis of Variance (ANOVA) and Fisher's LSD at 95% confidence to determine significant differences among samples and cooking methods. CATA frequencies were analyzed using correspondence analysis.

Results from consumer evaluation showed that significant sensory differences exist among beans subjected to different cooking methods. Samples with a lower beany aroma intensity tended to rate higher in overall liking, indicating consumers that prefer richer, cooked, less beany flavors.

Results also indicated that cooking method plays an important role in shaping flavor profiles. The baking method reduced the perceived beany aroma the most, indicating greater alteration or loss of beany-associated flavors, followed by boiling and pressure cooking. Slow cooking reduced beany aroma the least, suggesting greater retention of the characteristic beany notes compared to other cooking methods. The CATA plot revealed consistent sensory patterns, highlighting a clear contrast between savory, roasted, and starchy attributes with dry, green, fermented, and metallic notes across cooking methods.

2.1. Introduction

Dry beans are highly nutritious (Bennink, 2005) and complement the nutrients provided by cereals, making them an important component of a balanced diet (Baudoin & Maquet, 1999). They are now domesticated in the Americas (Evans, 1976) and are consumed throughout the world. In the United States, dry bean consumption averages about 2-2.5 kg per person annually, with recent FAO statistics reporting 2.09 kg in 2023. Their acceptance in the marketplace is closely related to sensory characteristics, which can be evaluated by sensory panels composed of consumers and/or trained professionals (Antoun and Tsimidou, 1997; Gervi *et al.,* 1997; Meilgaard *et al.,* 2007; Suwannaporn and Linnemann, 2008; Tesfaye *et al.,* 2010; Elía, 2011). While descriptive sensory evaluation is key to determining the nature of differences among products (Stone & Sidel, 2004), evaluating consumer preferences and acceptability of the products is also important for guiding product development and marketing decisions (Booth, 1998). Consumer acceptance of beans is critical for their incorporation into the diet, particularly as market demand has shifted towards plant-based ingredients as alternatives to animal-derived products over recent decades. A major challenge in the development of novel plant-based foods is the presence of off-flavors, which can negatively affect acceptability when these ingredients are incorporated into traditional foods. Consumer acceptance of meat alternatives is strongly influenced by both perceived health benefits and sensory properties (Badjona *et al.,* 2023).

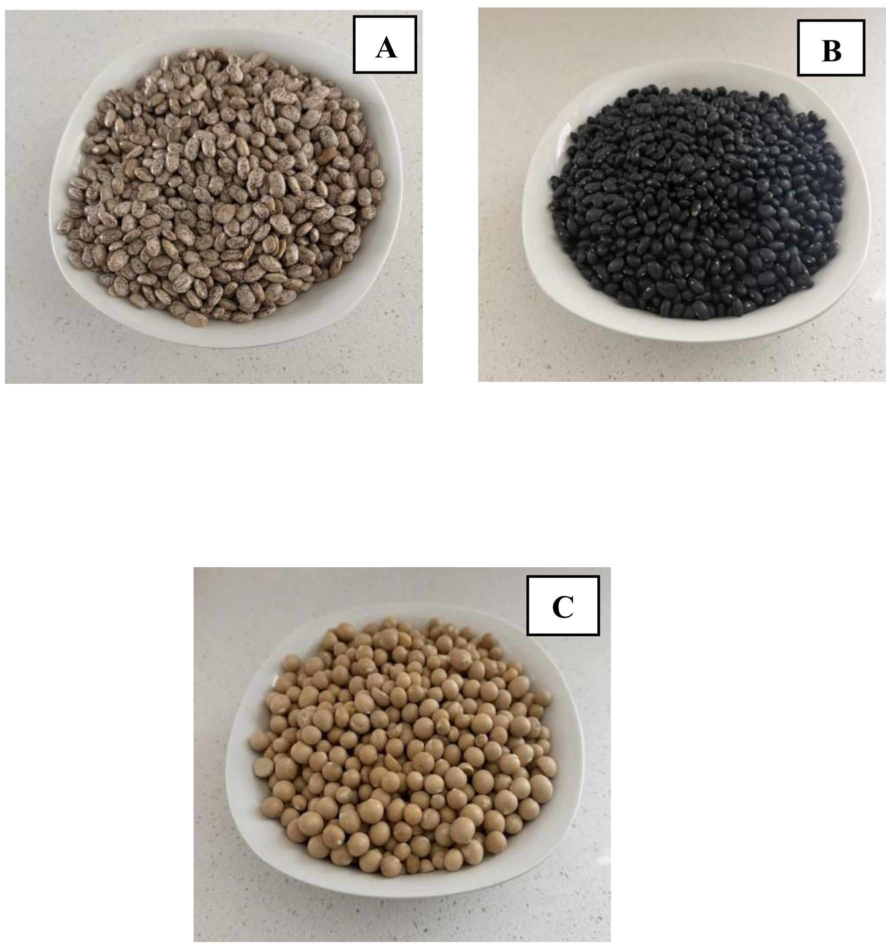
Hence, several studies have focused on the sensory properties of dry beans and bean products, as sensory acceptability is a critical determinant of their consumption (Obatolu *et al.,* 2017; Oyeyinka *et al*., 2017; Muroki *et al*., 2024). Understanding consumer attitudes and perceptions towards dry beans as an ingredient is essential before further development into diverse products (Tuccillo *et al.,* 2024). In developing countries, where malnutrition remains a significant concern, dry beans play an essential role in promoting nutritional security (Venter & Van Eyssen, 2001). Consumer preferences for dry beans are often believed to be influenced by factors such as seed size, seed color, cooking time, and flavor. Sensory evaluation is essential for assessing bean quality, as it can be used to characterize the sensory properties of beans and determine their acceptability to consumers (Mkanda, 2007). Furthermore, variability among dry beans is partly due to differences in sensory properties, which, along with other factors, influence consumer preferences. Flavor, seed size, color, and texture of the cooked product are among the factors that influence consumer preferences of dry beans (Tharanathan and Mahadevamma, 2003). The objective of this research was to determine the effects of different cooking methods on the sensory profile and consumer liking of selected dry beans.

2.2. Materials and Methods

2.2.1 Samples and preparation

Based on a thorough review of the literature, an initial list of approximately 50 bean market classes were compiled based on global availability, consumption frequency, relevance to U.S. markets, and rate of utilization. These were then narrowed down to three bean types (Black bean, Pinto bean and Bambara bean) (Figure 2.1) based on their consumption rate, nutritional benefits, and novelty in the United States (Bambara beans). The main goal of using three different bean classes was to assess the effect of cooking methods on beans with different sensory profiles. Black and Pinto beans (Best Choice Brands) were purchased from Price Chopper in Olathe, KS. Bambara beans were purchased from a local African supermarket in Kansas City, MO. All beans were inspected for physical integrity, sorted to remove broken or damaged beans, and stored at room temperature in a Pyrex bowl and covered with lid prior to use. Each bean type was subjected to four different cooking methods: boiling, slow cooking, pressure cooking, and baking, resulting in a total of 12 samples. For each cooking method, approximately 2.7 kg of each bean type were used. The 2.7 kg batch was divided into three 0.9 kg portions using a Taylor glass digital food scale. Approximately 3.5 liters of tap water was added to each 0.9 kg portion to completely submerge the beans, after which they were soaked overnight for approximately 14 hours at room temperature. This same sample preparation approach was used for all bean types across all cooking methods.

Figure 2.1. Three dry beans used in the study: A: Pinto beans; B: Black beans; and C: Bambara beans



2.2.2. Cooking methods

2.2.2.1. Boiling

The beans were prepared using the boiling method described by (Farinde *et al.,* 2017). Each of the three bean portions (0.9 kg each) was drained and rinsed after soaking. The Imperial gas stove (Figure 2.2A) was used for this method of cooking. Each portion of the rinsed beans was placed in a pot and covered with approximately 4 liters of tap water. Subsequently, 25 g of salt was added. The beans were brought to a rolling boil at 100ºC for approximately 20 min, after which the heat was reduced to a low simmer and the pot was covered. After about an hour, 1.5 liters of warm water was added to the beans to maintain a water level of at least 2.5 cm. A doneness test was conducted hourly to assess bean tenderness. This procedure was applied uniformly to all three bean types. Bambara beans was cooked for 2 h and 30 min, whereas pinto and black beans were cooked for approximately 1 h 10 minutes. The cooked beans were then drained and put in a food warmer for evaluation.

2.2.2.2. Slow Cooking

The slow-cooking method described by Romero del Castillo *et al.* (2012) was used in this study. Each of the three bean portions was drained and rinsed. Each portion was placed in a 7-quart Crock-Pot® electric slow cooker (Figure 2.2B) and covered with approximately 4 liters of tap water. Subsequently, 25 g of salt was added to each portion. Each portion was cooked on the high setting. After approximately 3 h of cooking, the average temperature inside the slow cooker was 90.6 ºC. This same approach was used to cook all three different beans. Bambara beans was cooked for 5 h 40min, whereas pinto and black beans cooked for 4 h 30min. The cooked beans were then drained and kept in a food warmer for evaluation.

2.2.2.3. Baking

The baking method described by Farinde *et al.* (2017) was used with slight modifications. The beans were drained and rinsed prior to baking. The Garland convection oven (Figure 2.2C) was used for baking. The oven was preheated to approximately 162.8 °C for 15 min. Each 0.9 kg portion of rinsed beans was placed on a baking sheet and covered with about 4 liters of tap water. Subsequently, 25 g of salt was added to each portion. Each baking sheet was covered with aluminum foil. The beans were inspected every 30 min, and a doneness test was performed to assess tenderness. This same approach was used to cook all three different beans. Pinto and black beans were cooked for approximately 1 h 30 min, whereas Bambara beans were cooked for approximately 2 h 5 min. The cooked beans were then drained and put in a food warmer for evaluation.

2.2.2.4. Pressure cooking

Each 0.9 kg portion of drained and rinsed bean was put in an Instant Pot Duo pressure cooker (8-quart capacity) (Figure 2.2D). Approximately 25 g of salt and 4 liters of tap water were added to each portion. This approach was applied uniformly to all three bean types. All bean samples required approximately 23 min to reach full pressure. Black and pinto beans were pressure-cooked for 5 min, whereas Bambara beans were cooked for 8 min. A natural pressure release was allowed for at least 30 min, followed by a quick release for approximately 5 min. The beans were then drained and kept in a food warmer for evaluation. The pressure-cooking procedure described by Nergiz & Gökgöz (2007) was used in this study.

Figure 2.2. Equipment used in various cooking methods. A: Imperial gas stove; B: Crock-Pot® slow cooker; C: Garland convection oven; and D: Instant Pot Duo pressure cooker

2.2.3. Central Location Testing

A total of 76 panelists were recruited from the consumer database of the Sensory and Consumer Research Center at Kansas State University (Olathe, Kansas, USA) to participate in the consumer evaluation studies. The demographics are presented in Table 2.1 and Figure 2.3. Panelists consumed beans at least once every month. Participants were required not to work for any food company to avoid bias. Participants were 48 females and 28 males from diverse age groups of 18-

65 years of age, and cleared the standard security screening for pregnancy, illness, allergy, represented different income backgrounds, and were willing to try new beans varieties.

A 3-day study was conducted at the Sensory and Consumer Research Center at Kansas State University Olathe, Kansas, USA. On each day, four different beans (Figure 2.4), representing different bean types and cooking methods, were evaluated during 40-minute sessions. In the end, all 76 consumers evaluated 12 different types of beans over 3 days. The test was administered using Compusense. The prepared bulk bean samples for each day's testing cooked were kept in a temperature-controlled food warmer at 60 – 66 °C until ready for evaluation. The beans were portioned into 4 oz Styrofoam cups with clear lids immediately before each session to minimize the loss of key volatile aroma compounds and were served at approximately 66°C. Sample cups were labeled with random three-digit codes. Participants answered questions on aroma, appearance, flavor, beany aroma intensity, JAR attributes, and CATA descriptors. The scales used included the 9-point hedonic scale (1= extreme dislike and 9= extreme like), a 7-point intensity scale (1 = Not At All Beany and 7 = Extremely beany), a 5-point JAR scale (1= Too Little and 5= Too Much), and a 5-point Expectation scale (1= Much Worse Than Expected and 5-Much Better Than Expected).

Participants were also asked to provide three single word descriptors to specify what they liked and disliked most about the samples evaluated.

Table 2.1 Consumer Demographics (Total N=76)

Characteristics	Categories	Number of Panelists
Gender	Male	28
	Female	48
Age	18-25 years	2
	26-35 years	6
	36-45 years	19
	46-55 years	28
	56-65 years	21
Bean (any type) consumption frequency	Once a week	24
	More than once a week	38
	2 to 3 times a month	12
	Once a month	2

Figure 2.3. Cooking method typically used by consumers

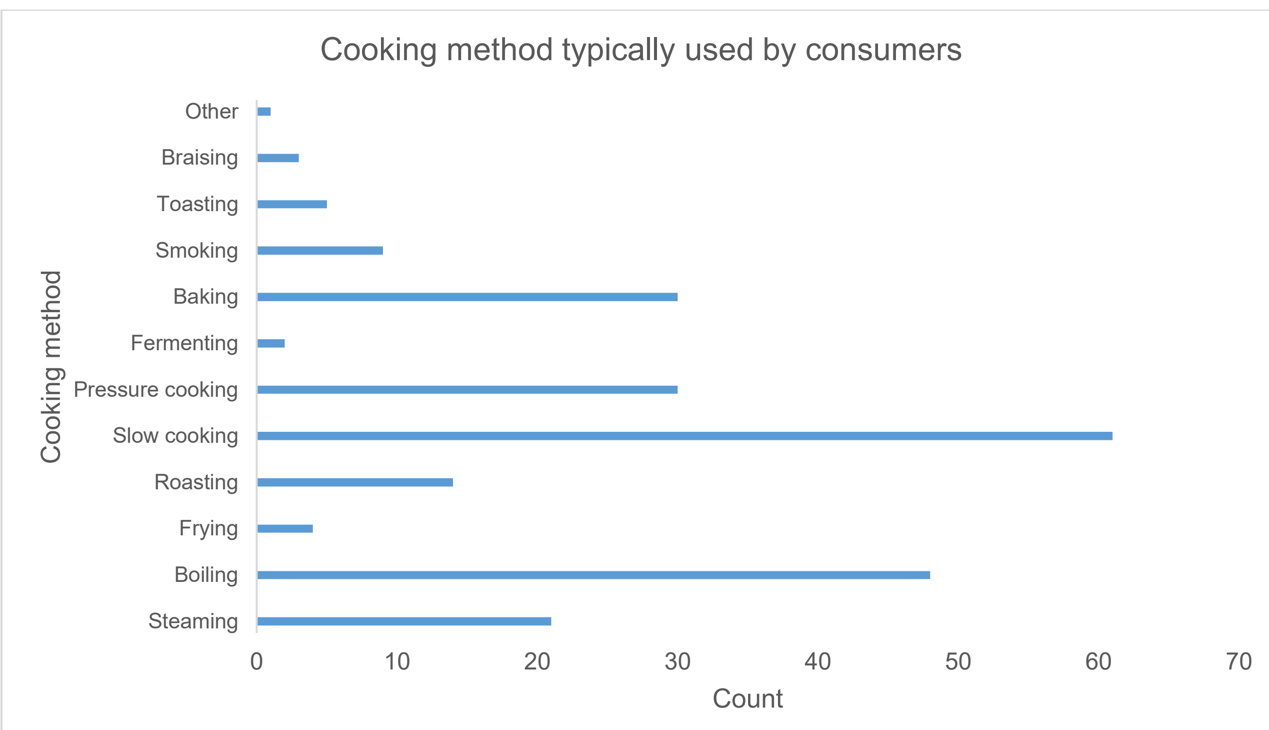
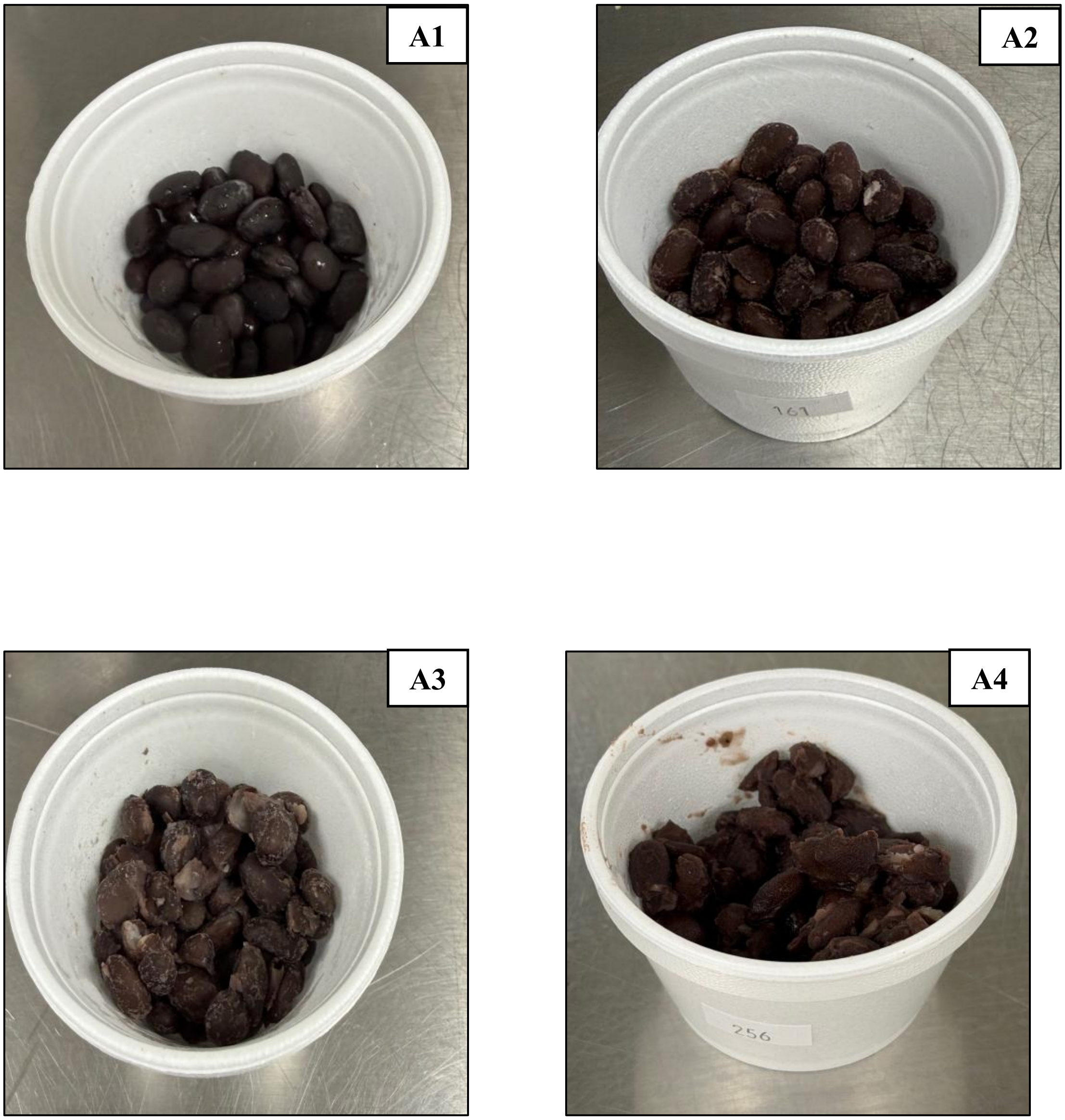


Figure 2.4. Samples used in the consumer study. A: Black bean; B: Pinto bean; C: Bambara bean; 1: Baking; 2: Slow Cooking; 3: Boiling; and 4: Pressure cooking.




B1
863


B2


B3


B4


C1


C2

2.3. Data Analysis

Analysis of Variance (ANOVA) was performed across bean types and within each bean type using Fisher's Least Significant Difference (LSD) test for mean separation of consumer liking data. Penalty analysis was conducted on JAR data to evaluate the impact on liking scores when a sample characteristic was not rated as "just about right." For the CATA data, Correspondence Analysis (CA) was performed to visually explore relationships among bean samples and the attributes perceived by participants. The data analysis was performed using XLSTAT statistical software (Lumivero, Denver, CO, USA).

2.4. Results and Discussion

2.4.1. Consumer Liking Results Within Bean Type

The within-bean results for all cooked dry bean samples are presented in Tables 2.2 – 2.4. The results for black beans are shown in Table 2.2 below. The results show significant differences among cooking methods for all evaluated liking attributes. This suggests substantial variation in consumer acceptance among the cooking methods. As shown in Table 2.2, the slow cooking method had the highest overall liking while pressure cooking was consistently rated high for flavor, aroma, texture liking, and beany aroma intensity. Baking had the highest score for appearance liking but scored consistently low for overall liking and other attributes. This indicates that for the consumers, appearance alone did not drive acceptance. Table 2.3 presents the within-bean results for pinto beans and indicates that all other attributes, except texture liking, were significant among cooking methods. Pressure cooking achieved the highest overall liking and best appearance, while slow cooking obtained the highest score for flavor liking but also higher beany intensity. Texture liking did not differ by method. Also, the overall liking scores for pinto bean ranged from 4.0 to 5.7. These results indicate that the degree of overall liking of all pinto beans fell under the category "Dislike slightly" to "Like slightly" which is similar to the results obtained by Muroki *et al.,* 2024, who indicated that overall liking scores of selected biofortified common bean varieties grown in Burundi fell within the same range.

In Table 2.4, all attributes for African Bambara beans were significantly different, except for aroma liking. The baked Bambara bean sample received the highest overall liking despite exhibiting lower flavor liking, texture liking, and beany aroma intensity scores. This finding suggests that factors other than the measured flavor and texture attributes may have contributed to overall acceptance. Boiled Bambara bean samples obtained the highest score for flavor and appearance liking while slow cooking was rated highest for texture liking.

Tables 2.2 – 2.4 present consumer liking and beany aroma intensity ratings for all bean types evaluated across cooking methods. The effect of cooking method varied by bean type; however, some general trends were observed. Across the bean types evaluated, baking was generally associated with lower beany aroma intensity ratings, indicating a greater reduction in the perception of beany aroma characteristics. Boiling and pressure cooking produced intermediate beany aroma intensity ratings, while slow cooking consistently resulted in higher beany aroma intensity scores. These findings suggest that slow cooking preserved beany character to a greater extent than the other cooking methods evaluated.

Table 2.2 Consumer liking and beany aroma intensity ratings for black beans evaluated across cooking methods (n = 76)

Category	Aroma Liking	Appearance liking	Overall Liking	Flavor liking	Texture Liking	Beany Aroma Intensity
Pressure cooking	6.3 a	4.3 bc	4.6 b	6.1 a	6.1 a	5.3 a
Slow cooking	5.1 b	4.8 b	6.0 a	5.9 ab	5.9 ab	3.9 b
Boiling	5.4 b	4.0 c	4.6 b	5.4 b	5.5 b	5.2 a
Baking	5.3 b	6.3 a	4.0 c	4.4 c	3.4 c	3.8 b
Pr > F(Model)	0.000	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001

Means with same letter are not significantly different (p>0.05)

Table 2.3 Consumer liking and beany aroma intensity ratings for pinto beans evaluated across cooking methods (n = 76)

Category	Aroma Liking	Appearance liking	Overall Liking	Flavor liking	Texture Liking	Beany Aroma Intensity
Pressure cooking	6.6 a	4.8 a	5.7 a	5.5 ab	5.3 a	4.6 b
Slow cooking	5.9 b	4.1 b	5.6 ab	6.0 a	5.9 a	5.5 a
Boiling	5.5 b	3.8 b	4.0 c	5.1 b	5.3 a	5.3 a
Baking	6.0 b	4.1 b	5.1 b	5.2 b	5.4 a	4.6 b
Pr > F(Model)	0.001	0.000	<0.0001	0.024	0.180	0.000

Means with same letter are not significantly different (p>0.05)

Table 2.4 Consumer liking and beany aroma intensity ratings for African Bambara beans evaluated across cooking methods (n = 76)

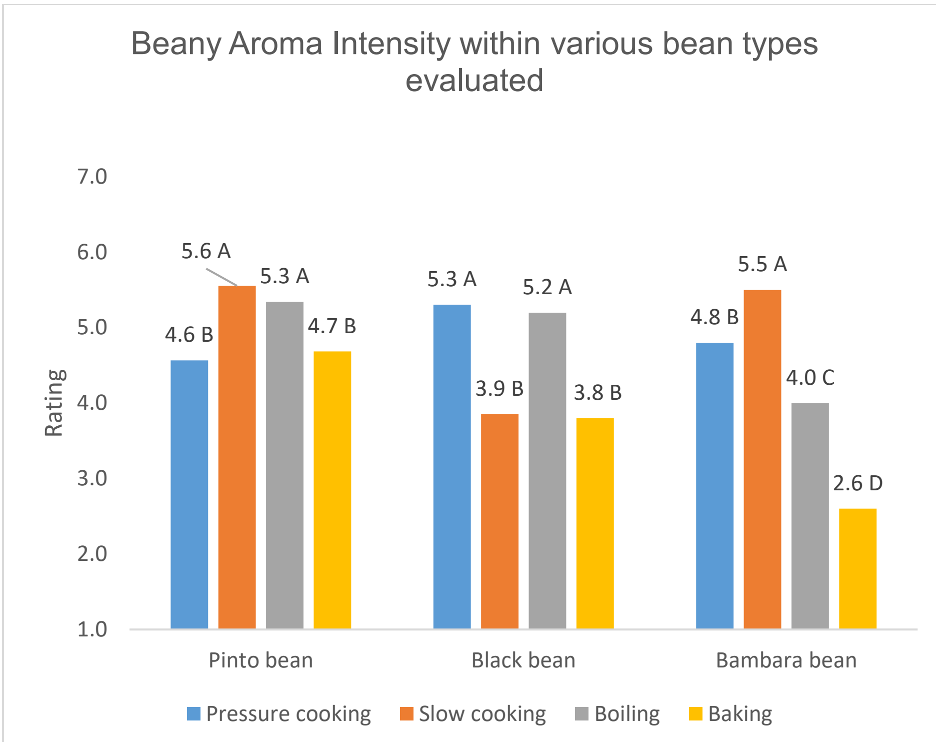
Category	Aroma Liking	Appearance liking	Overall Liking	Flavor liking	Texture Liking	Beany Aroma Intensity
Pressure cooking	5.4 a	3.9 b	4.9 b	5.3 b	5.5 a	4.8 b
Slow cooking	5.2 a	3.9 b	5.9 a	5.9 a	5.8 a	5.5 a
Boiling	5.1 a	5.1 a	5.7 a	6.0 a	5.5 a	4.0 c
Baking	5.1 a	4.1 b	6.2 a	3.0 c	3.7 b	2.6 d
Pr > F(Model)	0.684	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001

Means with same letter are not significantly different (p>0.05)

2.4.2. Beany Aroma Intensity Within Bean Type

Figure 2.5 shows the beany aroma intensity results for each bean type evaluated across cooking methods. For pinto beans, slow cooking produced the highest beany intensity rating, although it was not significantly different from boiling. For black beans, pressure cooking resulted in the highest beany aroma intensity score, while baking produced the lowest. Beany aroma intensity in Bambara beans differed significantly among cooking methods, with slow cooking receiving the highest intensity rating (5.5) and baking the lowest (2.6). Overall, baking tended to reduce perceived beany aroma intensity followed by boiling, whereas slow cooking generally preserved beany characteristics to a greater extent. A 2025 metabolomic study on mung beans by Sun *et al.,* 2025, on the "Impact of Thermal Processing and Storage on Precursor and Volatile Compounds" found that baking significantly reduced hexanal, a key "beany" odorant, while increasing roasted and pyrazine compounds. Results from the findings further revealed that baking resulted in the generation of flavor-enhancing compounds, such as gluconic acid 1 and pyrrole-2-carboxylic acid, whereas boiling helped to form a ketone compound, 3-hydroxy and nucleosides and their derivatives. Both processing methods helped to form key caramelization compounds, such as 2-furoic acid and aroma compounds derived from the Maillard reaction (Sun *et al.,* 2025). Also, the retention of beany aroma during slow cooking aligns with findings of Chigwedere *et al.*, 2019, on "the evolution of flavor compounds during cooking of common beans". Results suggested that gentle, moist-heat treatments preserve lipid-derived volatiles responsible for characteristic legume flavor. Compounds such as hexanal, nonanal, and 2-pentylfuran which are key contributors to beany aroma are retained to a greater extent compared to pressure or dry-heat methods. Slow cooking minimizes evaporation and limits the thermal degradation of these volatiles, therefore the beany aroma profile is retained allowing lipid-oxidation products, Strecker aldehydes, sulfur compounds, and furan derivatives to remain more effectively than in high-temperature dry-heat methods such as baking, where Maillard reactions and volatile loss reduce the intensity of beany notes.

Figure 2.5. Beany aroma intensity ratings for each bean type evaluated across cooking methods



2.4.3. Consumer Liking Results Across Bean Type

To further understand these differences, consumer liking ratings were compared across bean types within each cooking method. Across bean results are shown in Tables 2.5 – 2.8. For pressure cooking (Table 2.5), significant differences were observed across bean types for all attributes. Pinto beans showed the highest overall liking, aroma liking and appearance liking, while black beans scored the highest for flavor and texture liking. Black beans also exhibited the highest beany aroma intensity score among the three bean types, which may have contributed to its lower overall liking score compared to pinto beans. African Bambara beans received intermediate scores across most attributes, indicating consumer acceptance levels between those observed for black and pinto beans under pressure cooking.

Under the boiling method (Table 2.6), there was no significant difference across all bean types for aroma liking. However, African Bambara beans were most preferred overall, as they obtained the highest overall liking, appearance, and flavor liking scores. Black beans and pinto beans showed significantly lower overall liking, with Pinto Beans scoring lowest. Bambara beans also showed a lower beany aroma intensity, which may have contributed to higher acceptance. Lastly, texture did not differ significantly among the three bean types, indicating that boiling may have produced a similar mouthfeel across bean types.

Slow cooking results are shown in Table 2.7 and indicate no significant differences in overall liking, flavor liking, or texture liking across bean types. However, significant differences were observed for aroma and appearance liking, with pinto beans scoring highest in aroma and black beans highest in appearance. Black beans also scored the lowest for beany aroma intensity.

Results in Table 2.8 show that baking method produced the strongest differentiation across bean types (all $p < 0.0001$). African Bambara beans received the lowest score in flavor liking, texture liking and beany aroma intensity, however, they scored the highest overall liking score. This may suggest that overall liking may be driven by a combination of reduced beany aroma intensity and other factors not measured in this study. Black beans were scored high as having the most liked appearance but had lowest scores for texture and flavor. This was reflected on a low overall liking score. Pinto beans performed the best for aroma liking and consistently scored moderately across other attributes.

Table 2.5 Consumer liking and beany aroma intensity ratings for the pressure-cooking method evaluated across bean types (n = 76)

Category	Aroma Liking	Appearance liking	Overall Liking	Flavor liking	Texture Liking	Beany Aroma Intensity
Black Beans	6.3 a	4.3 ab	4.6 b	6.1 a	6.1 a	5.3 a
Pinto Beans	6.6 a	4.8 a	5.7 a	5.5 ab	5.3 b	4.6 b
African Bambara Beans	5.4 b	3.9 b	4.9 b	5.3 b	5.5 ab	4.8 b
Pr > F(Model)	<0.0001	0.005	0.001	0.031	0.030	0.024

Means with same letter are not significantly different (p>0.05)

Table 2.6 Consumer liking and beany aroma intensity ratings for the boiling cooking method evaluated across bean types (n = 76)

Category	Aroma Liking	Appearance liking	Overall Liking	Flavor liking	Texture Liking	Beany Aroma Intensity
Black Beans	5.4 a	4.0 b	4.6 b	5.4 b	5.5 a	5.2 a
Pinto Beans	5.5 a	3.8 b	4.0 c	5.1 b	5.3 a	5.3 a
African Bambara Beans	5.1 a	5.1 a	5.7 a	6.0 a	5.5 a	4.0 b
Pr > F(Model)	0.380	<0.0001	<0.0001	0.010	0.713	<0.0001

Means with same letter are not significantly different (p>0.05)

Table 2.7 Consumer liking and beany aroma intensity ratings for the slow cooking method evaluated across bean types (n = 76)

Category	Aroma Liking	Appearance liking	Overall Liking	Flavor liking	Texture Liking	beany Aroma Intensity
Black Beans	5.1 b	4.8 a	6.0 a	5.9 a	5.9 a	3.9 b
Pinto Beans	5.9 a	4.1 b	5.6 a	6.0 a	5.8 a	5.6 a
African Bambara Beans	5.3 b	3.9 b	5.9 a	5.895 6.0 a	5.8 a	5.5 a
Pr > F(Model)	0.009	0.000	0.416	0.898	0.934	<0.0001

Means with same letter are not significantly different (p>0.05)

Table 2.8 Consumer liking and beany aroma intensity ratings for the baking cooking method evaluated across bean types (n = 76)

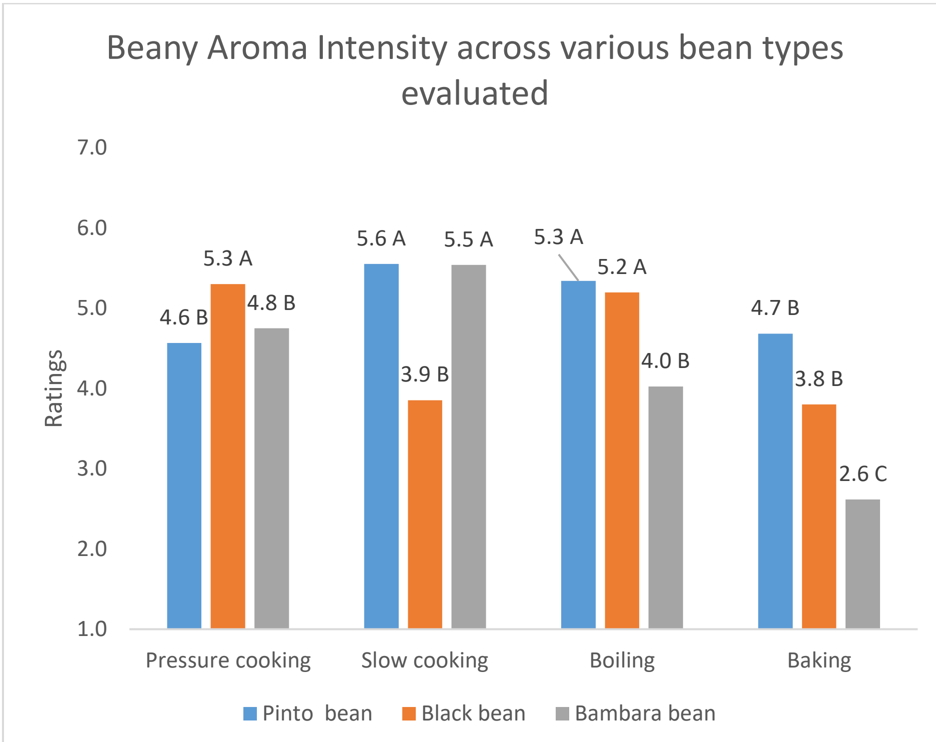
Category	Aroma Liking	Appearance liking	Overall Liking	Flavor liking	Texture Liking	Beany Aroma Intensity
Black Beans	5.3 b	6.3 a	4.0 c	4.4 b	3.4 b	3.8 b
Pinto Beans	6.0 a	4.2 b	5.1 b	5.3 a	5.4 a	4.7 a
African Bambara Beans	5.1 b	4.1 b	6.2 a	3.0 c	3.7 b	2.6 c
Pr > F(Model)	0.006	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001

Means with same letter are not significantly different (p>0.05)

2.4.4. Beany Aroma Intensity Across Bean Type

Figure 2.6 below presents the across-bean comparison of beany aroma intensity ratings by cooking method. Under pressure cooking, black beans exhibited the highest beany aroma intensity, while pinto and Bambara beans received lower and statistically similar ratings. For slow cooking, Pinto and Bambara beans showed the highest beany aroma intensity ratings and did not differ significantly from one another, whereas black beans received significantly lower ratings. Under boiling conditions, black and pinto beans exhibited similarly high beany aroma intensity ratings, while Bambara beans were rated significantly lower. For baking, pinto beans received the highest beany aroma intensity rating, followed by black beans, while Bambara beans exhibited the lowest intensity rating. Overall, baking resulted in the lowest beany aroma intensity ratings across bean types, particularly for Bambara beans.

Figure 2.6. Beany aroma intensity ratings for each cooking method evaluated across bean types



2.4.5. Expectation Scores

Table 2.9 Expectation scores across cooking evaluated (n=76)

	Pinto bean	Black bean	Bambara bean
Pressure cooking	2.6 ab	2.9 a	2.9 b
Slow cooking	2.9 a	2.8 a	3.3 a
Boiling	2.7 ab	2.8 a	3.4 a
Baking	2.6 b	1.9 b	1.9 c
Pr > F(Model)	0.142	<0.0001	<0.0001

Means with same letter are not significantly different (p>0.05)

Table 2.10 Expectation scores across beans evaluated (n=76)

	Pressure cooking	Slow cooking	Boiling	Baking
Black bean	2.9 a	2.8 b	2.8 b	1.9 b
Pinto bean	2.6 b	2.9 b	2.7 b	2.6 a
African Bambara bean	2.9 ab	3.3 a	3.4 a	1.9 b
Pr > F(Model)	0.080	0.013	<0.0001	<0.0001

Means with same letter are not significantly different (p>0.05)

Tables 2.9. and 2.10 present the analysis of variance results for expectation scores evaluated within and across bean types. For within-bean analysis, no significant differences in expectation scores were observed among pinto bean samples ($p = 0.142$). In contrast, significant differences were observed for both black and Bambara beans ($p < 0.0001$), with baked samples consistently receiving the lowest expectation scores. The across-bean results show that, except for pressure cooking which showed no significant differences across beans ($p = 0.080$), all other methods were significant. This indicates similar consumer expectations across the three bean types when prepared using the pressure-cooking method. This implies that participants anticipated similar levels of tenderness, aroma, and overall flavor quality for samples prepared using the pressure cooker, regardless of the bean type. Significant differences among bean types were observed for both the slow-cooking and boiling methods. The results indicate significantly higher expectation scores for Bambara beans compared to pinto and black beans under both slow-cooking and boiling conditions. Baking produced the lowest expectation scores overall, with Bambara and black beans rating significantly lower than pinto beans. This could be attributed to differences in texture and the perception of more toasted or roasted notes. It could also indicate that baking is a less familiar or less preferred preparation method for these bean types.

Overall, the extent to which the products matched consumer expectations was influenced by both bean type and cooking method. Pressure cooking produced similar ratings across bean types, whereas slow cooking and boiling resulted in higher ratings for Bambara beans. Baking generally received the lowest ratings, particularly for black and Bambara beans.

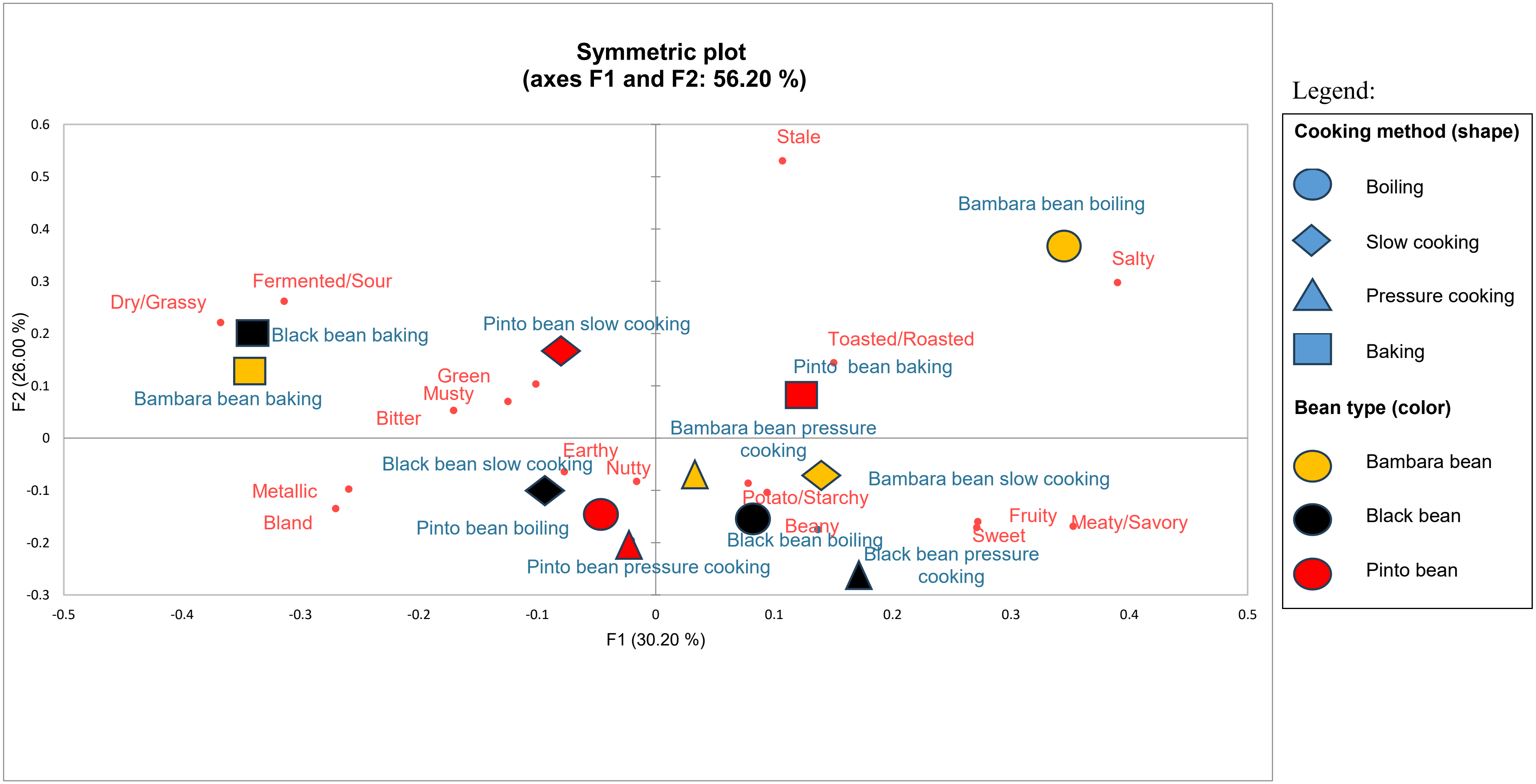
2.4.6. CATA Data Analysis

A total of 16 flavor attributes were included in the CATA questionnaire: toasted/roasted, green/vegetable, stale, musty, fermented, potato/starch, salty, dry/grassy, beany, bitter, meaty/savory, earthy, bland, sweet, metallic, and fruity. In addition, consumers were provided with an open-ended response option to describe any flavor attributes not included in the predefined list. The CATA data was analyzed using frequency counts, reflecting how often each sensory attribute was selected for each product. Correspondence analysis (CA) (Figure 2.7) below was conducted on the CATA data to visualize the relationships between bean samples and their perceived flavor attributes.

The plot below (Figure 2.7) shows how different cooking methods influence the sensory profiles of bean samples, with the first two dimensions (F1 and F2) explaining 56.20% of the total variance. The way samples are positioned indicates that cooking method has a stronger impact on their sensory profile. From the first dimension (F1) which explains 30.20% of the total variation, Baking and pressure cooking is associated with savory, roasted, and salty while boiling and slow cooking appear to be linked to green and bland notes. This pattern suggests methods involving dry heat and high-pressure (baking, pressure cooking) enhance flavor development and this may be due to some reactions such as browning, Maillard reactions and moisture reduction, while moist-heat methods (boiling, slow cooking) retain more of the natural bean flavor and vegetal notes.

The second dimension (F2) provides additional detail by showing how the samples differ beyond the F1 variation. Bambara beans under boiling appear close to salty reflecting stronger flavor transformation, whereas black and pinto beans cluster lower, near earthy and starchy, indicating milder profile.

Figure 2.7. Correspondence Analysis of all bean samples evaluated using CATA



2.5. Conclusion

Overall, the consumer study showed that both bean type and cooking method played a significant role in consumer acceptance and sensory perception of beans. Across all three bean types, cooking method influenced key liking attributes including flavor, texture, aroma, and appearance, as well as perceived beany aroma intensity, which was consistently associated with differences in consumer acceptance. Slow cooking minimizes differences across bean types, producing more uniform sensory profiles, while baking and pressure cooking created greater differentiation in consumer responses. Also, the baking method reduced perceived beany aroma intensity the most, followed by boiling and pressure cooking. Slow cooking reduced beany aroma the least, thereby preserving beany character to a greater extent than the other cooking methods.

CATA results highlighted the distinct flavors associated with each sample as each cooking method generated distinct flavor profiles. Baked samples showed the highest frequency of negative descriptors such as bitter, stale, or green notes. Conversely, boiled and pressure-cooked samples were associated with positive attributes such as savory, nutty, or roasted attributes depending on bean type.

Overall, the results indicate that cooking method is a key factor influencing the sensory profile and consumer acceptance of beans. Pressure cooking and slow cooking generally supported more favorable sensory outcomes, while baking was more frequently associated with undesirable sensory attributes. These findings are very useful as it is an indication that food scientists or manufactures can strategically select thermal treatments or processing methods to optimize flavor, texture, and aroma to strategically improve consumer acceptance of beans.

2.6. References

Antoun, N., & Tsimidoub, M. (1997). Gourmet olive oils: stability and consumer acceptability studies. In *Food Research International* (Vol. 30, Issue 2).

Badjona, A., Bradshaw, R., Millman, C., Howarth, M., & Dubey, B. (2023). Faba Bean Flavor Effects from Processing to Consumer Acceptability. In *Foods* (Vol. 12, Issue 11). MDPI. https://doi.org/10.3390/foods12112237.

Booth, D. A. (1998). *Proceedings of Technical Sessions* Fourth International Food Convention (Ifcon "98) Invited Lecture Optimization of Products" Sensory and Conceptual Features for Diverse Consumers and Uses.

Baudoin, J.-P., & Maquet, A. (1999). B A S E. Improvement of protein and amino acid contents in seeds of food legumes. A case study in Phaseolus. In *Biotechnol. Agron. Soc. Environ* (Vol. 3, Issue 4).

Bennink, M. (2005). Eat beans for good health. Annu. Rep. Bean Improv. Coop. 48, 1–5.

Bansah, G. S., Adi, D. D., Amatefe, G. S., & Tei-Mensah, E. (2024). Exploring the Nutritional Benefits and Consumer Acceptance of Canned Bambara Beans in Ghana: Proximate, Microbial Quality and Sensory Acceptability. *Universal Journal of Food Science and Technology*, *2*(1), 14–28. https://doi.org/10.31586/ujfst.2024.956.

Chigwedere, C. M., Tadele, W. W., Yi, J., Wibowo, S., Kebede, B. T., Van Loey, A. M., Grauwet, T., & Hendrickx, M. E. (2019). Insight into the evolution of flavor compounds during cooking of common beans utilizing a headspace untargeted fingerprinting approach. *Food Chemistry*, 297, 224-238.

Evans, A.M. (1976). Beans. In Evolution of Crop Plants (N.W. Simmonds, ed.) pp. 168–172, Longman, New York, NY.

Farinde, E. O., Obatolu, V. A., & Fasoyiro, S. B. (2017). Microbial, Nutritional and Sensory Qualities of Baked Cooked and Steamed Cooked Lima Beans. *American Journal of Food Science and Technology*, *5*(4), 156–161. https://doi.org/10.12691/ajfst-5-4-6

Gerbi, V., Zeppa, A., Antonelli, A., & Carnacinic, A. (1997). Sensory Characterisation of Wine Vinegars. In *Food Qualiq and Prefacncc* (Vol. 8, Issue I).

Nergiz, C., & Gökgöz, E. (2007). Effects of traditional cooking methods on some antinutrients and in vitro protein digestibility of dry bean varieties (Phaseolus vulgaris L.) grown in Turkey. *International Journal of Food Science and Technology*, *42*(7), 868–873. https://doi.org/10.1111/j.1365-2621.2006.01297.x

Mkanda, A. V. (2007). Relating consumer preferences to sensory and physicochemical properties of dry beans *(Phaseolus vulgaris L.)*.

Mkanda, A. v., Minnaar, A., & de Kock, H. L. (2007). Relating consumer preferences to sensory and physicochemical properties of dry beans (Phaseolus vulgaris). *Journal of the Science of Food and Agriculture*, *87*(15), 2868–2879. https://doi.org/10.1002/jsfa.3046

Meilgaard, M., Civille, G.V. and CARR, B.T. 2007. Sensory Evaluation Techniques, 4th Ed., Chap 1, pp. 1–5, CRC Press, New York, NY.

Muroki, M. W., Waswa, L. M., Fungo, R., Kabwama, A., Eric, N., Nepomuscene, N., Ndabashinze, B., & Mahungu, S. M. (2024). Sensory properties of selected biofortified common bean (Phaseolus vulgaris) varieties grown in Burundi. Food Science & Nutrition, 12, 3199–3213. https:// doi.org/10.1002/fsn3.3988.

Stone, H., & Sidel, J. L. (2004). Introduction to sensory evaluation. In H. Stone, & J. L. Sidel (Eds.), Sensory evaluation practices (pp. 1–19). Cambridge, MA: Elsevier Academic Press.

Sun, J.; Li, Y.; Cheng, X.; Zhang, H.; Yu, J.; Zhang, L.; Qiu, Y.; Diao, J.; Wang, C. Metabolomic Analysis of Flavor Development in Mung Bean Foods: Impact of Thermal Processing and Storage on Precursor and Volatile Compounds. Foods2025, 14, 797. https://doi.org/10.3390/foods14050797.

Suwannaporn, P. and Linnemann, A. 2008. Rice-eating quality among consumers in different rice grain preference countries. J. Sensory Studies 23, 1–13.

Tesfaye, W., Morales, M. L., Callejón, R. M., Cerezo, A. B., González, A. G., García-Parrilla, M. C., & Troncoso, A. M. (2010). Descriptive sensory analysis of wine vinegar: Tasting procedure and reliability of new attributes. Journal of Sensory Studies, 25(2), 216–230. https://doi.org/10.1111/j.1745-459X.2009.00253.x

Tuccillo, F., Lampi, A. M., Katina, K., & Sandell, M. (2024). Exploring the lack of liking for faba bean ingredients with different sensory profiles. *Food Quality and Preference*, *118*. https://doi.org/10.1016/j.foodqual.2024.105198.

Tharanathan, R. N., & Mahadevamma, S. (2003). Grain legumes - A boon to human nutrition. In *Trends in Food Science and Technology* (Vol. 14, Issue 12, pp. 507–518). Elsevier Ltd. https://doi.org/10.1016/j.tifs.2003.07.002.

Venter, C. S., & Van Eyssen, E. (2001). *More Legumes For Better Overall Health Articles S32* (Vol. 14, Issue 3).

Romero del Castillo, R., Costell, E., Plans, M., Simó, J., & Casañas, F. (2012). A Standardized method of preparing common beans (phaseolus vulgaris l.) for sensory analysis. *Journal of Sensory Studies*, *27*(3), 188–195. https://doi.org/10.1111/j.1745-459X.2012.00381.x

Chapter 3 - Evolution of the aroma and flavor attributes of dry beans using the Temporal Check-All-That-Apply technique

Abstract

The objective of this study was to evaluate the evolution/dynamic perception of flavor attributes of dry beans prepared using different cooking methods through TCATA. A total of twelve samples; 3 different beans across 4 cooking methods were evaluated. Ten semi-trained panelists participated in this study. A 3-day study was conducted which involved training and evaluation of the samples. The products were evaluated in two replicates over a 60 sec time frame by selecting attributes perceived and deselecting attributes which were no longer perceived. Citation analysis was used on the TCATA data to determine the evolution of attributes for the entire duration of the evaluation. Also, correspondence analysis was completed to determine the main relationships between the attributes and the twelve products evaluated. Results from citation analysis showed that beany and potato/starchy attributes had an early onset and were consistently dominant across bean types and cooking methods. Cooking method also significantly influenced the temporal evolution of secondary attributes. Pressure cooking produced more uniform and balanced profiles across samples, mainly characterized by beany, starchy, and savory notes, whereas boiling resulted in more variable profiles. Most slow-cooked samples showed a stable evolution of dominant attributes throughout the evaluation, while baking generated the most complex profiles, which was characterized with enhanced toasted/roasted, nutty, and savory notes. In the correspondence analysis, baked or slow-cooked black bean samples clustered around beany, earthy, and bitter attributes. Pressure- and slow-cooked pinto bean samples were more closely associated with salty, savory, and toasted/roasted notes, while baked pinto beans were associated with bitter notes.

Bambara beans formed a distinct cluster, consistently aligning with sweet, nutty, and straw/dry grass attributes, highlighting their unique flavor profile compared with black and pinto beans.

3.1. Introduction

Temporal Check-All-That-Apply (TCATA) is a temporal sensory method which serves as an extension of the Check-All-That Apply (CATA) approach (Meyners & Castura, 2014), which has already been used for the sensory characterization of various product categories (Visalli & Galmarini, 2022). TCATA extends CATA by adding a temporal dimension to the evaluation by capturing how attributes perception changes over time during evaluation

TCATA methodology has been applied to many products including chocolate-flavored milk (Castura *et al.,* 2016), cosmetic creams (Boinbaser *et al.,* 2015), red wine finish (Baker *et al.,* 2016), yogurt, salami, cheese, orange juice, French bread, salami, and marinated mussels (Ares, Antúnez, *et al.,* 2015), as well as dried apricots, peanuts, and milk chocolate (Jaeger *et al.,* 2015). The characteristics of TCATA data are similar to TDS (Pineau *et al.,* 2009b), but TCATA allows concurrent selection of applicable attributes, whereas TDS captures a sequence of dominant attributes (Castura *et al.,* 2016; Castura & Li, 2016). The TCATA approach is a consumer-friendly technique that enables tracking of multiple sensory attributes over time. A key feature of TCATA is that it can be used with semi-trained consumers and does not require participants to rate attribute intensity (Tan *et al.,* 2019). In TCATA, assessors are provided with a list of attributes salient for a particular product or category and are asked to select any of the listed attributes that they perceive during a predefined period of evaluation (Poveromo & Hopfer, 2019). Participants are allowed to check unselected terms when the sensory attribute is perceived, and to uncheck selected terms when the sensory attribute is no longer perceived. Multiple terms can be selected at the same time, which enables assessors to indicate sensations that arise at any point during the evaluation timeframe. The TCATA method provides a more complete characterization of the dynamic experience of product sensory perception (Boinbaser *et al.,* 2015) and has been successfully used for sensory characterizations with consumers in the past (Ares, Jaeger, *et al.,* 2015). The TCATA approach also provides accurate characterizations with trained and semi-trained assessors, enabling data collection in short time frames (Baker *et al.,* 2016)

CATA is a rapid and consumer-friendly sensory method that captures sensory attribute perception at a single point during consumption. In contrast, TCATA extends CATA by incorporating a temporal dimension, allowing researchers to evaluate how flavor attributes emerge, intensify, and decline throughout consumption. Although beans are widely consumed and cooking is known to influence their sensory characteristics, little is understood about how these attributes evolve dynamically during consumption. Most research on beans focuses on their nutritional and functional properties, while the limited sensory studies available rely primarily on static sensory methods that provide only a single assessment of attribute perception and do not capture temporal changes experienced by consumers. Addressing this knowledge gap is important because the dynamic perception of sensory attributes can influence consumer acceptance, product optimization, and the development of processing strategies aimed at maximizing the utilization of beans and bean-based products The objective of the study is to evaluate the evolution/dynamic perception of flavor attributes in beans prepared using different cooking methods through TCATA.

3.2. Materials and Methods

3.2.1. Samples and Preparation

Three dry bean varieties; Black bean, Pinto bean, and African Bambara bean were chosen to represent commonly consumed and novel beans in the United States. Black and Pinto beans were sourced from Price Chopper in Olathe, Kansas, while Bambara beans were obtained from a local African market in Kansas City, Missouri. All beans underwent an initial quality screening process.

Samples were manually inspected to remove defective, cracked, or visibly damaged beans. The screened beans were stored under at room temperature in a Pyrex bowl and covered with a liduntil use.

For each type of bean, approximately 2.7 kg of raw beans were used for cooking. This bulk amount was subdivided into three equal 0.9-kg portions using a Taylor glass digital scale. Each portion was soaked at room temperature in ~3.5 L of tap water for roughly 14 hours to ensure uniform hydration prior to cooking. This preparation method was used consistently across all bean types and cooking methods.

3.2.2. Cooking methods

Each bean variety was prepared using four different cooking techniques; boiling, slow cooking, baking, and pressure cooking which resulted in twelve total cooked samples. Although the equipment and heating conditions differed, all methods followed standardized steps for water level, salt addition.

3.2.2.1. Boiling

Following a modified version of Farinde *et al.* (2017), soaked beans were rinsed and transferred to large pots, covered with ~4 L of tap water, and seasoned with 25 g of salt. Beans were first brought to a boil and then simmered with the pot covered. Additional warm water was added as needed. Pinto and Black beans were cooked for ~1 h 10 minutes, whereas Bambara beans cooked for ~ 2h 30 minutes. All the cooked beans were drained, packaged and stored in a refrigerator.

3.2.2.2. Slow Cooking

Using a 7-quart Crock-Pot®, rinsed beans were submerged in ~4 L of tap water with 25 g of salt and cooked on the high setting. Internal temperature was around 90–91°C after about 3 hours of cooking. Black and Pinto beans cooked for ~4 h 30 minutes hours, while Bambara beans cooked for ~5 h 40 minutes. All the cooked beans were drained, packaged and stored in a refrigerator.

3.2.2.3. Baking

A convection oven preheated to ~163°C was used for this method. Rinsed beans were spread onto baking trays and covered with ~4 L of tap water, salted (25 g), and sealed with aluminum foil. Samples were checked every 30 minutes. Black and Pinto beans were baked for ~ 1 h 30 minutes, whereas Bambara beans was baked for ~ 2 h 5 minutes. All the cooked beans were drained, packaged and stored in a refrigerator.

3.2.2.4. Pressure Cooking

Rinsed beans were placed in an 8-quart electric pressure cooker with ~4 L of tap water and 25 g of salt. After a ~23-minute pressurization period, Black and Pinto beans cooked for 5 minutes, and Bambara beans for 8 minutes, followed by a natural pressure release (~30 minutes) and a brief quick release. All samples were drained, packaged and stored in a refrigerator.

3.2.3 Sample Evaluation

The three bean types across the four cooking methods were evaluated by 10 semi-trained panelists including five males and five females from diverse age groups of 18-65 years of age. Panelists had previously participated in a cooked dry bean consumer study and were further screened by reviewing their answers to the consumer study and administering a questionnaire which asked them about their interest in dry beans, and availability. The beans were served at approximately 60 – 66 °C in 4oz Styrofoam cups with clear lids and were placed in cups just before the session began to minimize loss of moisture and key volatile aroma compounds. Cups were labeled with random three-digit codes. The prepared bulk bean samples for each day's testing were microwaved for about 10 minutes using the GE® microwave to ensure they were warm enough ready for evaluation. The study was conducted in five sessions over three days with the first session of the first day being a training/overview session. During the training session, an introduction/overview of Temporal methods in general was provided, followed by a more specific explanation of the TCATA method and the TCATA question type. The entire training took about 70 minutes in total. Ten common aroma and flavor attributes for bean and bean products were presented to them along with references and definitions. In addition to this, their understanding of the beany attribute was aligned, followed by practice examples of TCATA questions using the Compusense® interface (Compusense Inc., Guelph, ON, Canada). After the overview and exposure to practice examples, panelists completed a trial exercise by evaluating four samples; two guided evaluations followed by two independent evaluations, to ensure they understood the procedure. During the subsequent four evaluation sessions, panelists assessed 12 samples in duplicate, with six samples evaluated per session. Each attribute was evaluated using the TCATA procedure over a 60-second evaluation period.

3.4. Data analysis

Citation analysis, which involved examining how frequently each sensory attribute was checked by panelists throughout the evaluation period, was used to analyze the TCATA data. Citation proportions were calculated as the proportion of times each attribute was selected to describe a sample at each point during the evaluation. TCATA curves were then generated from these citation proportions to illustrate the temporal evolution of attributes throughout the evaluation period. Data were analyzed using XLSTAT (Lumivero, Denver, CO, USA) based on the recorded start and end timestamps for all attributes and products evaluated. Correspondence analysis was also conducted to identify the attributes most strongly associated with each of the 12 products.

Table 3.1:List of Attributes, Definition and References

Attribute	Definition	Reference
Earthy	Flavor associated with damp soil, raw mushroom, wet foliage, or undercooked potato.	Raw mushroom
Beany	Flavor associated with cooked dry beans; a complex blend of characteristics including musty/earthy, musty/dusty, starchy, powdery, and one or more of the following: green/pea pod, nutty, or brown	Boiled soybean for 1h 30 mins
Potato/Starchy	Flavor characteristics associated with tubers and other starch-based foods, such as cooked potato	Cooked instant mashed Potato
Nutty	Flavor associated with nuts and certain whole grains	Unsalted peanuts
Toasted/Roasted	Flavor characteristics associated with dry heat treatment related to baked bread crust, toasted cereal, roasted nuts or roasted coffee	Toasted bread
Straw/Dry Grass	Flavor associated with dried hay or straw	Wheat Straw
Umami (Meaty/Savory)	Basic taste characteristic of cooked meat broth or stock, typically associated with monosodium glutamate (MSG).	MSG
Sweet	Basic taste typically associated with sugars such as sucrose	Sugar solution (0.5–1% sugar in water)
Bitter	Basic taste typically associated with compounds such as caffeine and quinine	Caffeine solution (0.05–0.1% w/v)
Salty	Basic taste associated with sodium chloride (table salt)	Salt solution (0.5-1.0% NaCl in water)

3.5. Results and Discussion

3.5.1. TCATA Results For Black Bean

TCATA results for black bean samples are shown below in Figure 3.1. The sensory citation profile for - black beans show the evolution of dominant attributes over time. Early on (0-10 seconds), beany and potato/starchy notes rise rapidly dominating the profiles of black beans across all cooking methods. This indicates that these attributes are key flavor characteristics of black beans regardless of the processing method. For the pressure-cooking method, a broader balance of flavors appear as time progresses (about 15–40 seconds). Earthy, nutty, and meaty/savory notes also increase with time. Pressure cooking may have accelerated flavor compound formation and softened beans quickly due to the use of high temperatures and pressure, releasing savory notes. This likely explains why savory and earthy notes increased steadily over time. Other less dominant attributes were salty and bitter, which appeared moderately at different levels. Toward the later stages of the evaluation (after approximately 40 seconds), attributes such as sweet and toasted/roasted remained at low citation proportions or declined over time. Figure 3.1 shows that pressure cooking emphasizes beany, starchy, and savory characteristics while producing fewer roasted or sweet notes, resulting in a relatively uniform flavor profile throughout the evaluation.

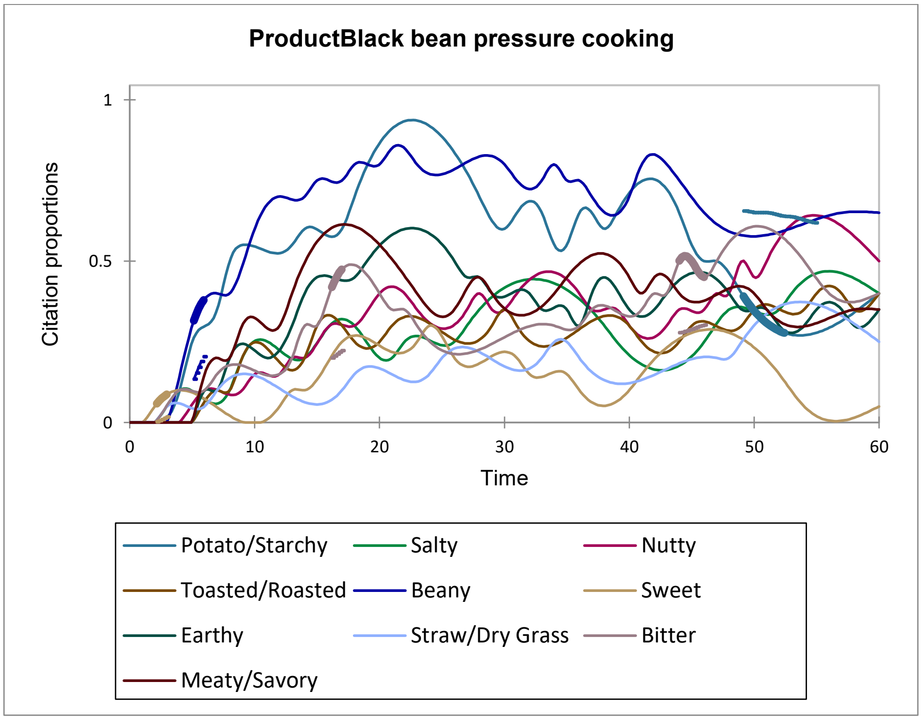
For boiled samples, the evolution of attributes was more dynamic. Although beany and starchy attributes remained prominent, earthy notes reached higher citation proportions than those observed for other cooking methods, particularly during the middle portion of the evaluation. Fluctuations in bitter, nutty, and straw/dry grass attributes contributed to a more variable sensory profile. Also, the bold/thicker lines seen in the profile for earthy and salty highlight regions where these attributes were cited more strongly or more frequently by panelists over that time interval.

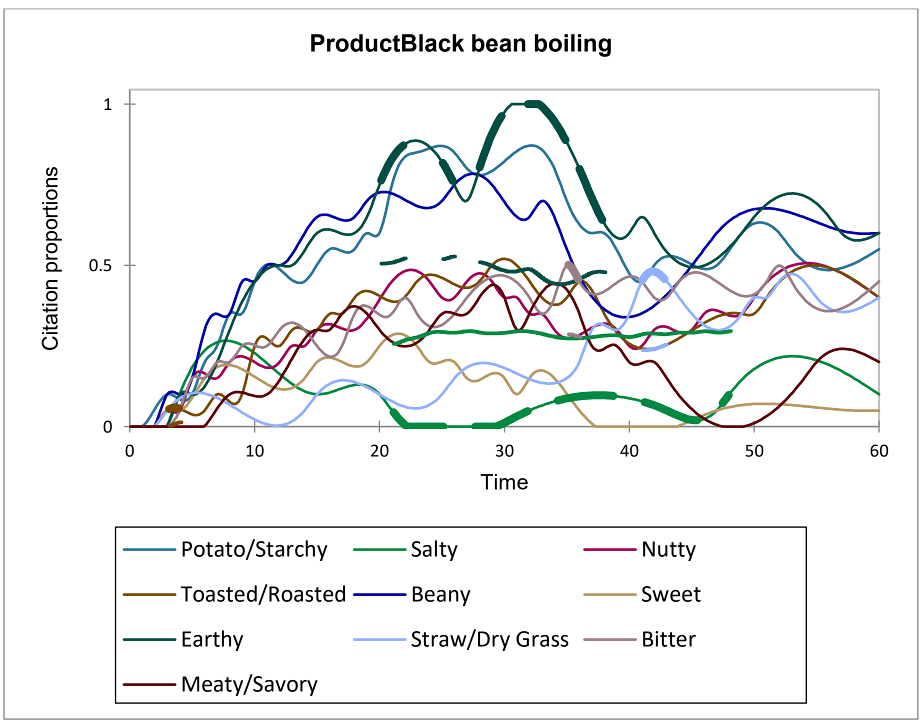
This means that earthy was frequently cited in 20-40 secs time interval while salty was frequently cited 30-50 secs during the evaluation.

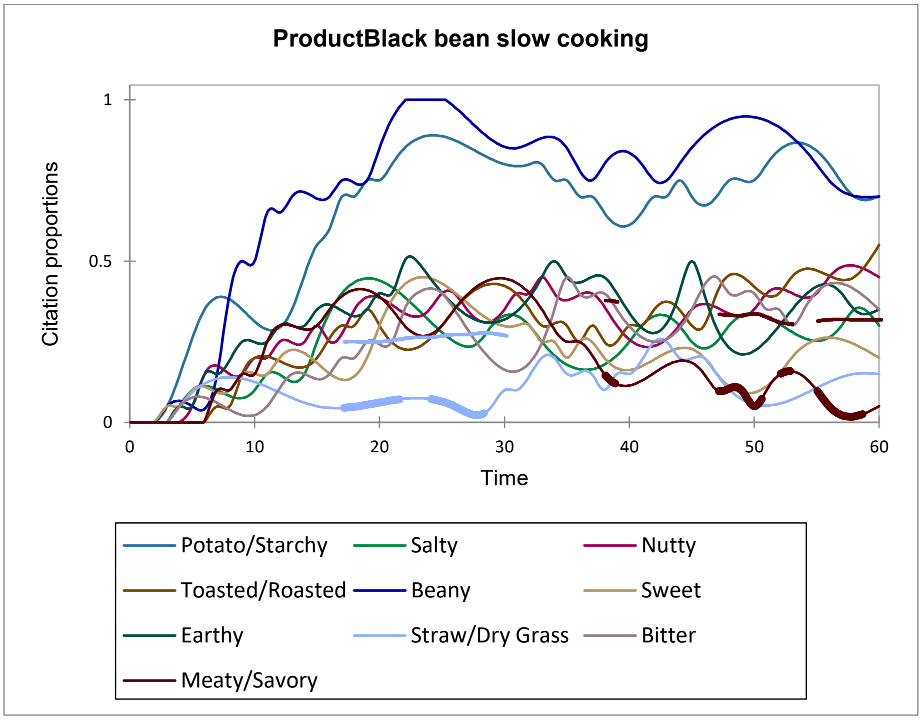
The slow-cooking method showed the highest citation proportions for beany and potato/starchy notes over time, with smoother transitions and fewer abrupt fluctuations than the other cooking methods. According to Chigwedere *et al.,* 2019, slow cooking involves the application of lower temperatures over longer periods, as a result, there is a gradual release of lipid-derived volatiles as compared to other methods which use high temperatures. This likely explains the observed smoother transitions and few sudden fluctuations in the profile. Nutty, earthy, and toasted/roasted attributes were also more consistently cited throughout the evaluation. In contrast, straw/dry grass attributes were cited infrequently.

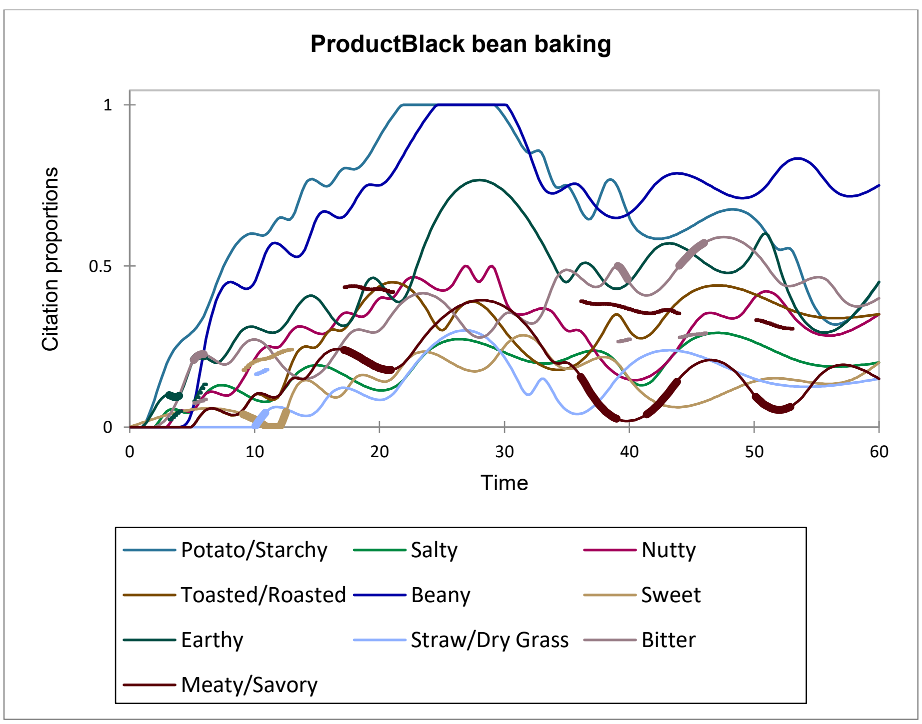
For baked samples, in addition to the dominant beany and starchy attributes, stronger temporal evolution of toasted/roasted, nutty, and meaty/savory notes was observed compared to the other cooking methods. In baking, dry heat is applied which promotes Maillard reaction/browning, caramelization, and lipid oxidation, which may explain the stronger toasted/roasted, nutty, and meaty/savory notes observed over time (*Sun et al.,* 2025). Although beany and starchy attributes remained dominant throughout the evaluation, the evolution of these additional attributes contributed to a more complex and layered flavor profile.

Figure 3.1:TCATA curves for black bean samples across all four cooking methods






ProductBlack bean slow cooking
Citation proportions
1
0.5
0
0
10
20
30
40
50
60
Time
Potato/Starchy
Salty
Nutty
Toasted/Roasted
Beany
Sweet
Earthy
Straw/Dry Grass
Bitter
Meaty/Savory


ProductBlack bean baking
Citation proportions
1
0.5
0
0
10
20
30
40
50
60
Time
Potato/Starchy
Salty
Nutty
Toasted/Roasted
Beany
Sweet
Earthy
Straw/Dry Grass
Bitter
Meaty/Savory

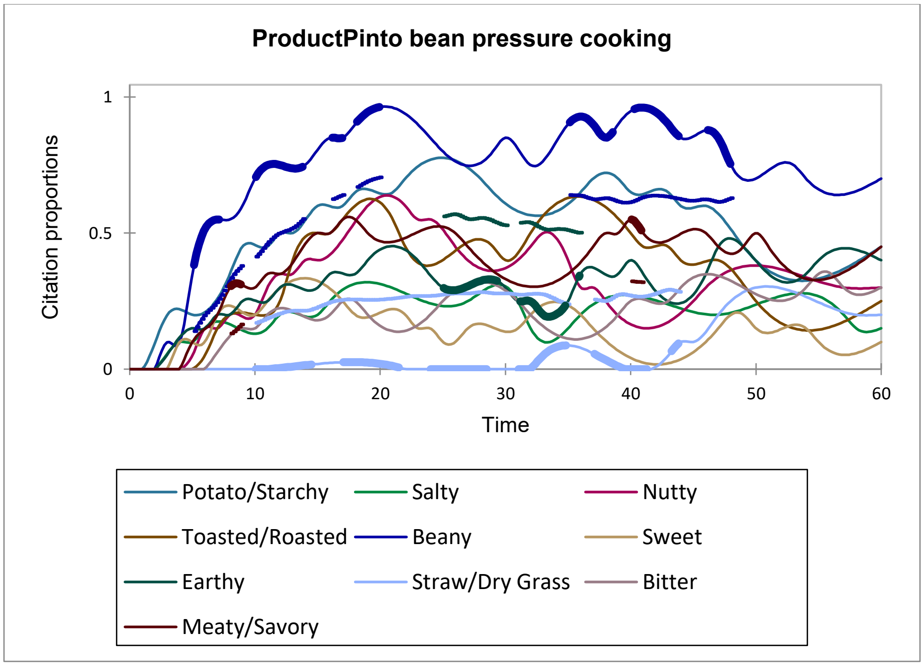
3.5.2. TCATA Results for Pinto Beans

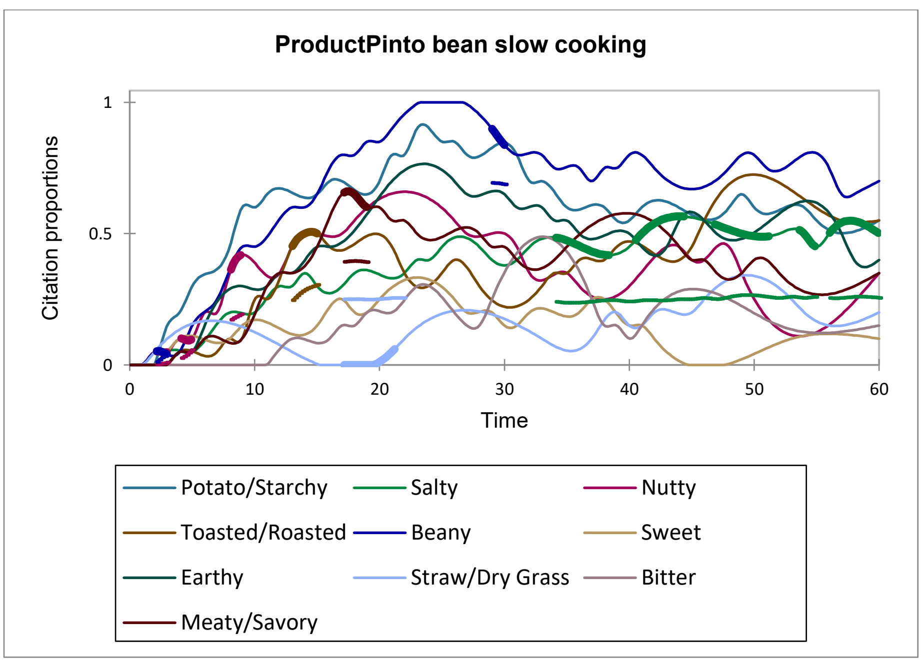
Across all cooking methods, as shown in Figure 3.2, although beany and potato/starchy attributes consistently dominated the sensory profiles of pinto beans, the intensity, stability, and contribution of secondary attributes varied by cooking method. Pressure cooking resulted in a rapid increase and higher citation proportions for beany and starchy notes early in the evaluation, which remained relatively high throughout. Nutty, earthy, and meaty/savory attributes emerged at moderate levels but fluctuated more noticeably over time. The high pressure used in the method likely enhanced starch gelatinization and the early onset of flavor development, which led to the production of savory notes. The least-cited attributes were sweet and straw/dry grass, indicating limited perception and/or short citation durations. The slightly thicker or bolder segments observed on some curves for beany (5-20secs; 35-45 secs) and meaty (25-35 secs) reflect regions where citations were more consistently selected by panelists, highlighting periods of stronger/ stable perception of those attributes throughout the evaluation.

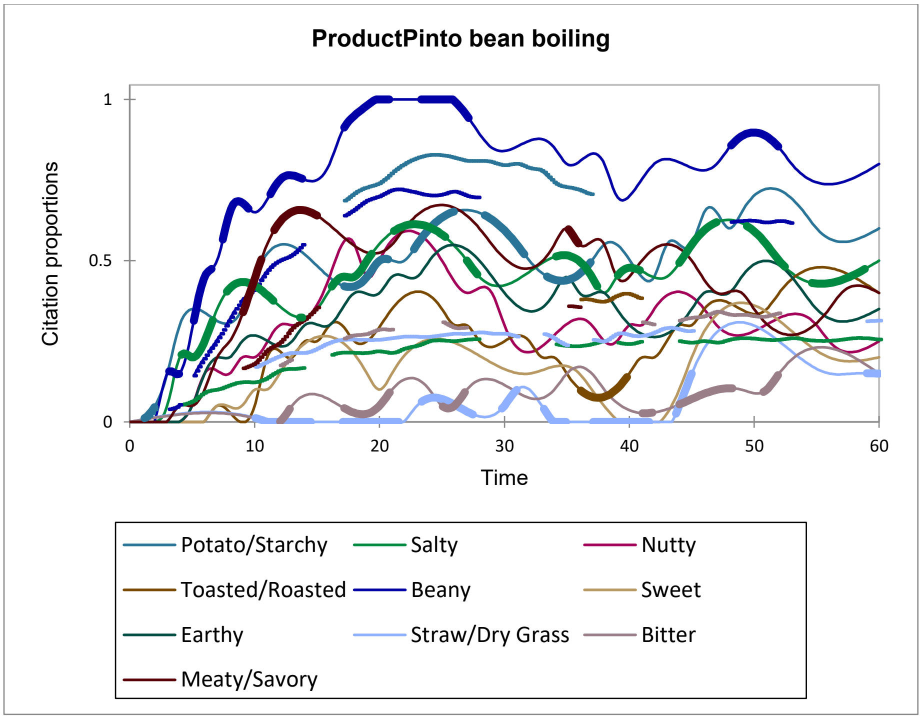
In slow-cooked samples, beany and potato/starchy attributes also reached high citation proportions. Earthy, nutty, and salty attributes remained relatively stable throughout the evaluation, suggesting consistent perception by panelists. At the later stages (35-60secs) of the evaluation meaty was mostly perceived by panelists and was cited frequently as seen in the plot. Boiled samples showed the greatest variability among attributes. While beany and starchy notes remained dominant, earthy, salty, and meaty/savory attributes reached higher citation proportion during the middle portion of the evaluation. Fluctuations among the remaining attributes contributed to a less uniform but more dynamic sensory profile.

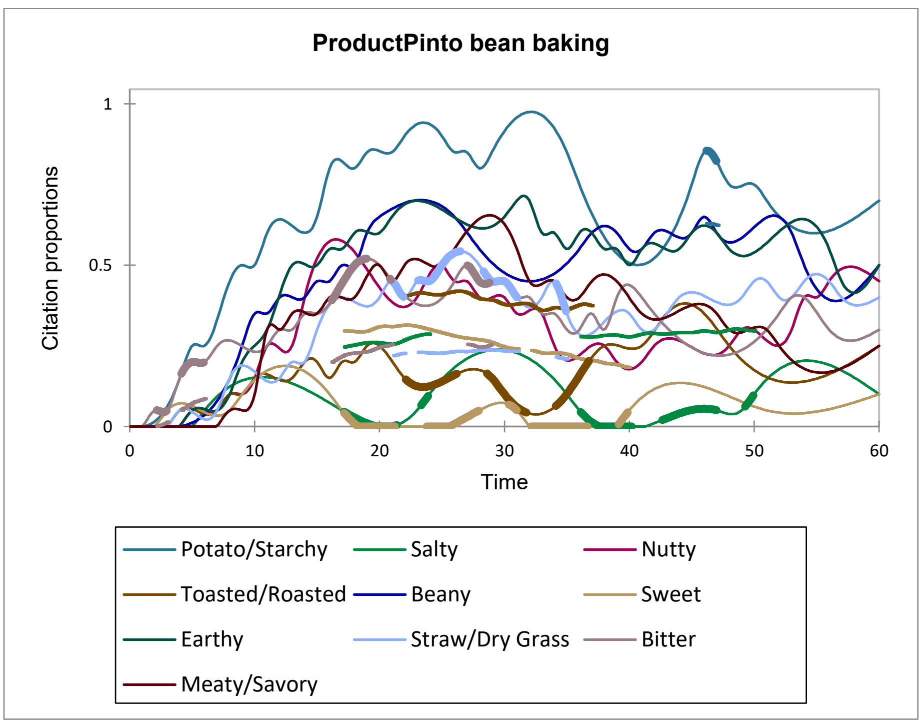
In baked samples, starchy was the most dominant attribute. However, the overall profile was more complex and layered than those produced by other cooking methods. Although earthy, beany, and starchy attributes remain important, toasted/roasted, nutty, and bitter notes were more pronounced. This may be attributed to the effects of dry heat and other browning reactions.

Figure 3.2:TCATA curves of Pinto bean samples across all four cooking methods






ProductPinto bean boiling
Citation proportions
1
0.5
0
0
10
20
30
40
50
60
Time
Potato/Starchy
Salty
Nutty
Toasted/Roasted
Beany
Sweet
Earthy
Straw/Dry Grass
Bitter
Meaty/Savory


ProductPinto bean baking
Citation proportions
1
0.5
0
0
10
20
30
40
50
60
Time
Potato/Starchy
Salty
Nutty
Toasted/Roasted
Beany
Sweet
Earthy
Straw/Dry Grass
Bitter
Meaty/Savory

3.5.3. TCATA Results for Bambara Beans

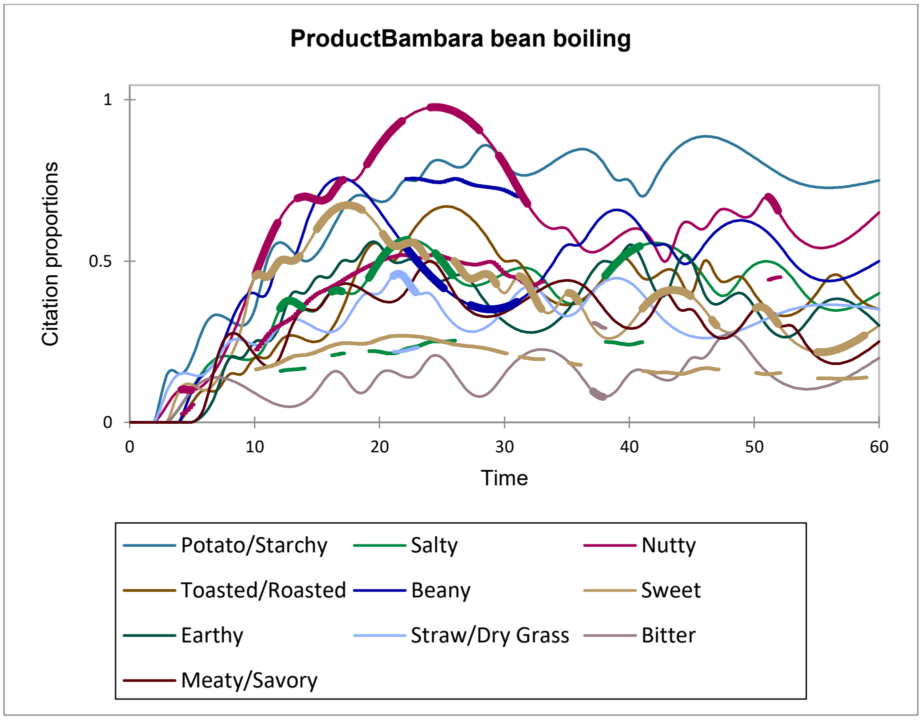
The sensory profiles of Bambara beans shown in Figure 3.3 indicate a clear evolution of attributes depending on the cooking method, with potato/starchy and nutty attributes consistently dominating the overall sensory profile. Across all cooking methods, the curves show noticeably thicker segments for attributes such as sweet, nutty, and straw/dry grass at various points during the evaluation. These thicker segments show periods when most panelists consistently selected those attributes, highlighting periods of stronger or more frequent perception.

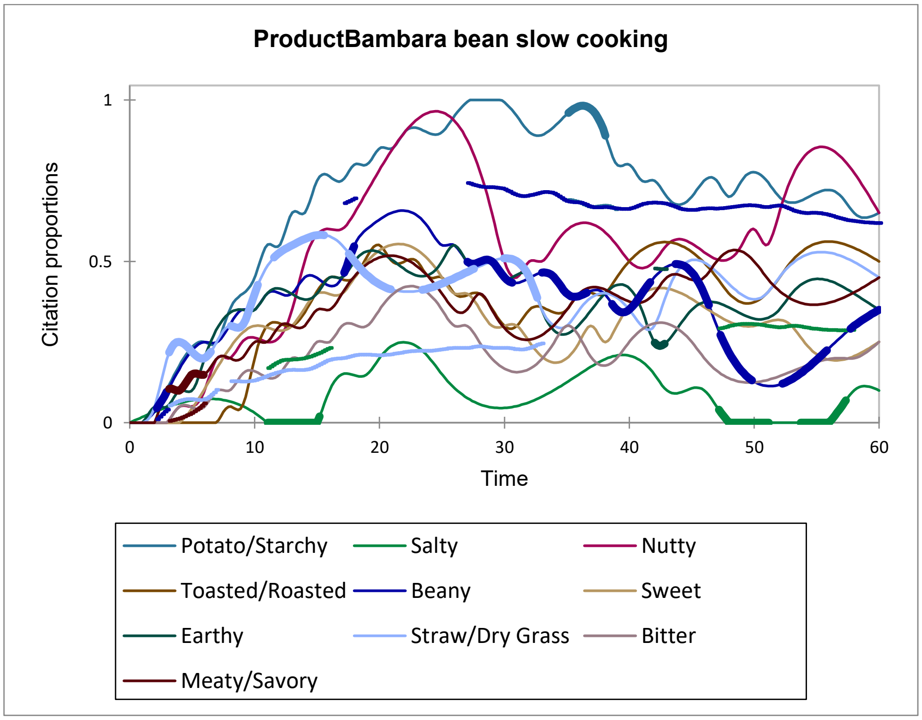
In slow-cooked samples, potato/starchy notes increased steadily and remained at high citation proportions throughout the evaluation period. Nutty notes also increased over time and became the second most dominant attribute after potato/starchy. Earthy and beany attributes became more prominent during the middle and later stages of the evaluation. Other attributes, including sweet, bitter, and meaty/savory were cited at moderate and relatively consistent levels with minimal fluctuations, contributing to a balanced sensory profile.

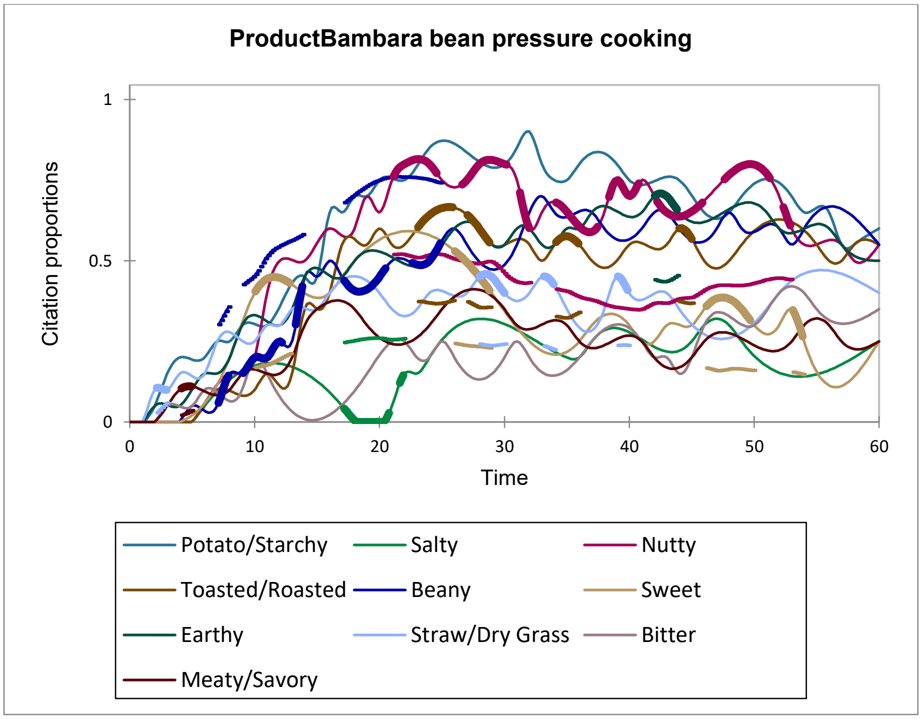
For boiled samples, the nutty attribute showed the highest citation proportions and increased rapidly during the first 30 seconds of the evaluation; however, citation proportions declined during the later stages. Potato/Starchy was the most consistent attribute, maintaining high citation proportions throughout the evaluation. Other attributes, such as beany and sweet, were moderate but relatively stable, suggesting they were perceived consistently throughout the evaluation

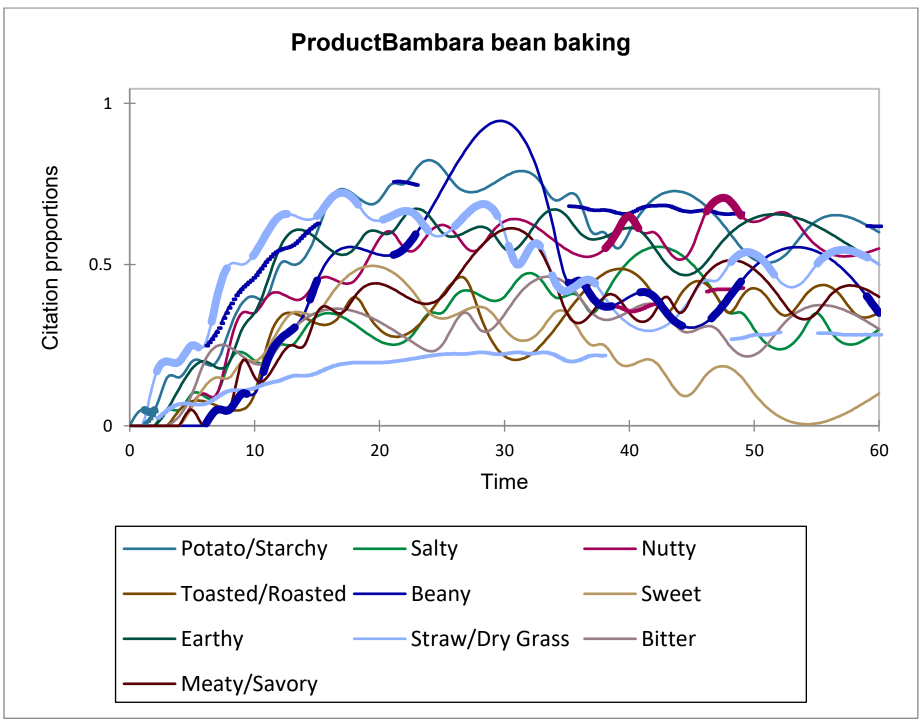
In pressure-cooked samples, beany, nutty and potato/starchy attributes increased rapidly and remained dominant throughout the evaluation. However, toasted/roasted and meaty/savory notes were more pronounced than in slow-cooked samples. Compared to the other cooking methods, baking produced the most complex and layered sensory profile. Although nutty and potato/starchy attributes remained dominant, toasted/roasted, beany and straw/dry grass notes were more pronounced, reflecting the influence of dry heat on the overall sensory profile.

Figure 3.3:TCATA curves of Bambara bean samples across all four cooking methods






ProductBambara bean pressure cooking
Citation proportions
1
0.5
0
0
10
20
30
40
50
60
Time
Potato/Starchy
Salty
Nutty
Toasted/Roasted
Beany
Sweet
Earthy
Straw/Dry Grass
Bitter
Meaty/Savory


ProductBambara bean baking
Citation proportions
1
0.5
0
0
10
20
30
40
50
60
Time
Potato/Starchy
Salty
Nutty
Toasted/Roasted
Beany
Sweet
Earthy
Straw/Dry Grass
Bitter
Meaty/Savory

3.5.4. Correspondence Analysis of Bean Samples

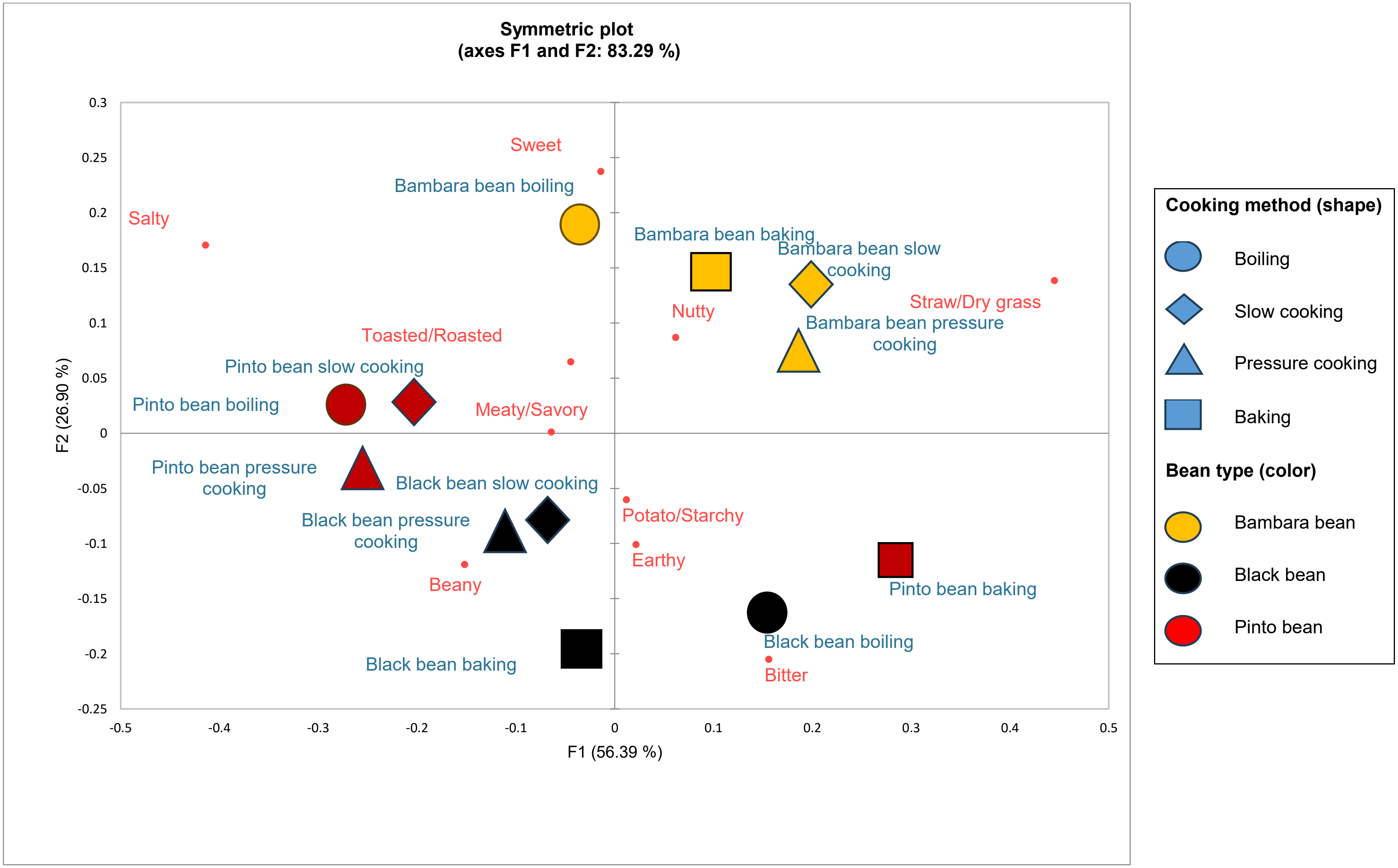
Figure 3.4 presents the correspondence analysis summarizing the relationships between the 12 bean samples and the 10 attributes evaluated using TCATA. The first two dimensions (F1 and F2) explained 83.29% of the total variation. Dimension F1 (56.39%) differentiated samples based on flavor-related attributes, separating beany, earthy, and bitter characteristics from sweet, nutty, and straw/dry-grass notes. Dimension F2 (26.90%) further distinguished samples according to more subtle variations associated with salty, meaty/savory, toasted/roasted, and potato/starchy attributes.

Slow-cooked and baked black bean samples were closely associated with beany, earthy, and bitter attributes, suggesting that these cooking methods enhanced characteristic legume flavors in black beans. In contrast, boiled black beans were positioned closer to the bitter attribute, suggesting a stronger expression of bitterness under this cooking method.

Among pinto bean samples, pressure- and slow-cooked treatments were associated with salty, toasted/roasted, and meaty/savory attributes. Interestingly, the baked Pinto bean sample clustered near the Black bean samples which is an indication of convergence of similar attributes notable of them is bitter. This pattern is common with the effects of dry-heat processing, which can intensify bitter notes. Baking promotes the formation of Maillard reaction intermediates and melanoidins, some of which are associated with bitter or acrid sensory qualities (Martins *et al.,* 2001). According to El Hosry *et al.,* 2025 baking involves limited water activity, which reduces the leaching of soluble bitter compounds and concentrates non-volatile flavor constituents unlike boiling or pressure cooking which are moist-heat methods. In addition, heat processing has been shown to alter flavor-active compounds in beans, sometimes increasing bitter perception and roasted characteristics (Melo *et al.,* 2009). This may explain why pinto bean baking shifted away from the typical meaty/savory characteristics seen in other pinto beans samples. Therefore, the closeness of baked Pinto beans to Black beans samples aligns with findings that dry-heat treatments can amplify bitterness, shifting the flavor profile toward more intense, less preferred attributes.

Most Bambara bean samples clustered within the same region of the upper portion of the plot and showed strong associations with sweet, nutty, and straw/dry-grass attributes. Boiled Bambara beans were positioned closer to the sweet attribute, whereas baked and pressure-cooked Bambara beans were positioned closer to nutty and straw/dry-grass. These results highlight the distinct sensory profile of Bambara beans compared to black and pinto beans.

Figure 3.4:Correspondence Analysis of bean samples evaluated using TCATA across all cooking methods



3.6. Conclusion

Overall, the results demonstrate that both bean type and cooking method influence the temporal evolution and overall sensory profiles of cooked beans. Across all samples, beany and potato/starchy attributes were the dominant flavor characteristics; however, cooking method affected the expression and evolution of secondary attributes, resulting in distinct sensory experiences. Pressure cooking produced more uniform and stable sensory profiles as key attributes such as beany, potato/starchy, nutty, and meaty/savory rose early in the evaluation and remained consistently dominant with minimal fluctuations over time. Boiling generated greater temporal variability as several attributes rose and fell throughout the evaluation rather than remaining stable. For example, boiled black beans showed mid-evaluation spikes in earthy and fluctuations in bitter and nutty notes.

Slow cooking promoted more balanced profiles because several attributes such as beany, potato/starchy, earthy, and salty were at moderate and relatively steady levels throughout the evaluation showing a more even distribution of multiple attributes without sharp peaks or declines unlike pressure cooked samples. Baking produced the most complex profiles, characterized by enhanced toasted/roasted, bitter, and nutty notes that were less pronounced in other cooking methods. Baked pinto beans, in particular, showed stronger roasted and bitter notes than the other pinto samples, making their profile noticeably different.

Correspondence analysis further differentiated samples based on bean type and cooking method. Bambara beans exhibited a distinct sensory profile characterized primarily by sweet and nutty attributes, whereas black and pinto beans were associated with more traditional legume flavor characteristics such as beany, potato/starchy and meaty. Black bean samples were most closely associated with beany, earthy, potato/starchy and bitter attributes, while pinto bean samples were more strongly associated with salty, meaty/savory, and toasted/roasted notes.

These findings demonstrate that cooking method can substantially influence the sensory characteristics of beans and that the magnitude and nature of these effects depend on bean variety. The results provide valuable insights for product developers, food manufacturers, and consumers seeking to optimize flavor characteristics. For example, if the goal is to maintain traditional legume flavors (beany, starchy, earthy), methods such as pressure cooking or slow cooking may be more suitable. However, if the aim is to create more complex roasted flavor profiles, baking can be strategically used.

3.7. References

Ares, G., Antúnez, L., Giménez, A., & Jaeger, S. R. (2015). List length has little impact on consumers' visual attention to CATA questions. *Food Quality and Preference*, *42*, 100–109. https://doi.org/10.1016/j.foodqual.2015.01.015

Ares, G., Jaeger, S. R., Antúnez, L., Vidal, L., Giménez, A., Coste, B., Picallo, A., & Castura, J. C. (2015). Comparison of TCATA and TDS for dynamic sensory characterization of food products. *Food Research International*, *78*, 148–158. https://doi.org/10.1016/j.foodres.2015.10.023

Baker, A. K., Castura, J. C., & Ross, C. F. (2016). Temporal Check-All-That-Apply Characterization of Syrah Wine. *Journal of Food Science*, *81*(6), S1521–S1529. https://doi.org/10.1111/1750-3841.13328

Boinbaser, L., Parente, M. E., Castura, J. C., & Ares, G. (2015). Dynamic sensory characterization of cosmetic creams during application using Temporal Check-All-That-Apply (TCATA) questions. *Food Quality and Preference*, *45*, 33–40. https://doi.org/10.1016/j.foodqual.2015.05.003

Bruzzone, F., Ares, G., & Giménez, A. (2012). Consumers' texture perception of milk desserts. II - comparison with trained assessors' data. *Journal of Texture Studies*, *43*(3), 214–226. https://doi.org/10.1111/j.1745-4603.2011.00332.x

Castura, J. C., Antúnez, L., Giménez, A., & Ares, G. (2016). Temporal Check-All-That-Apply (TCATA): A novel dynamic method for characterizing products. *Food Quality and Preference*, *47*, 79–90. https://doi.org/10.1016/j.foodqual.2015.06.017

Castura, J. C., & Li, M. (2016). Using TDS dyads and other dominance sequences to characterize products and investigate liking changes. *Food Quality and Preference*, *47*, 109–121. https://doi.org/10.1016/j.foodqual.2015.06.019

El Hosry, L., Elias, V., Chamoun, V., Halawi, M., Cayot, P., Nehme, A., & Bou-Maroun, E. (2025). Maillard Reaction: Mechanism, Influencing Parameters, Advantages, Disadvantages, and Food Industrial Applications: A Review. In *Foods* (Vol. 14, Issue 11). Multidisciplinary Digital Publishing Institute (MDPI). https://doi.org/10.3390/foods14111881

Jaeger, S. R., Beresford, M. K., Paisley, A. G., Antúnez, L., Vidal, L., Cadena, R. S., Giménez, A., & Ares, G. (2015). Check-all-that-apply (CATA) questions for sensory product characterization by consumers: Investigations into the number of terms used in CATA questions. *Food Quality and Preference*, *42*, 154–164. https://doi.org/10.1016/j.foodqual.2015.02.003

Martins, S. I. F. S., Jongen, W. M. F., & van Boekel, M. A. J. S. (n.d.). A review of Maillard reaction in food and implications to kinetic modelling.

Melo, T. S., Mancini-Filho, J., & Guerra, N. B. (2009). Thermal processing effects on bean flavor and phenolic-related sensory characteristics. *Food Chemistry, 115*(4), 1543–1548.

Meyners, M., & Castura, J. C. (n.d.). The analysis of temporal check-all-that-apply (TCATA) data.

Pineau, N., de Bouillé, A. G., Lepage, M., Lenfant, F., Schlich, P., Martin, N., & Rytz, A. (2012). Temporal Dominance of Sensations: What is a good attribute list? *Food Quality and Preference*, *26*(2), 159–165. https://doi.org/10.1016/j.foodqual.2012.04.004

Pineau, N., Schlich, P., Cordelle, S., Mathonnière, C., Issanchou, S., Imbert, A., Rogeaux, M., Etiévant, P., & Köster, E. (2009b). Temporal Dominance of Sensations: Construction of the TDS curves and comparison with time-intensity. *Food Quality and Preference*, *20*(6), 450–455. https://doi.org/10.1016/j.foodqual.2009.04.005

Poveromo, A. R., & Hopfer, H. (2019). Temporal check-all-that-apply (TCATA) reveals matrix interaction effects on flavor perception in a model wine matrix. *Foods*, *8*(12). https://doi.org/10.3390/foods8120641

Reinbach, H. C., Giacalone, D., Ribeiro, L. M., Bredie, W. L. P., & Frøst, M. B. (2014). Comparison of three sensory profiling methods based on consumer perception: CATA, CATA with intensity and Napping®. *Food Quality and Preference*, *32*, 160–166. https://doi.org/10.1016/j.foodqual.2013.02.004

Tan, V. W. K., Wee, M. S. M., Tomic, O., & Forde, C. G. (2019). Temporal sweetness and side tastes profiles of 16 sweeteners using temporal check-all-that-apply (TCATA). *Food Research International*, *121*, 39–47. https://doi.org/10.1016/j.foodres.2019.03.019

Visalli, M., & Galmarini, M. V. (2022). Multi-attribute temporal descriptive methods in sensory analysis applied in food science: Protocol for a scoping review. In *PLoS ONE* (Vol. 17, Number 7 July). Public Library of Science. https://doi.org/10.1371/journal.pone.0270969.

Chapter 4 - Integration of Consumer CATA and Semi-Trained Panel TCATA Using Multiple Factor Analysis (MFA)

4.1. Introduction

Multiple Factor Analysis (MFA), also known as multiple factorial analysis, is a multivariate technique developed by French statisticians Brigitte Escofier and Jérôme Pagès (Escofier & Pagès, 1983); Escofier & Pagès, 1988; Escofier & Pagès, 1990). It extends the logic of principal component analysis (PCA) and is designed to handle multiple data tables that measure sets of variables collected on the same observations, or, alternatively, multiple data tables where the same variables are measured on different sets of observations (Abdi *et al.,* 2012). It considers the contribution of all active groups of variables to define the distance between observations. The number of variables in each group may differ, and the nature of the variables can vary from one group to another; however, the variables within each group should share some similarity in nature (Abdi and Williams, 2010d). MFA is carried out in two main stages: First, a separate PCA is performed on each data table, and each table is then normalized by dividing all values by the first singular value from its respective PCA. In the second stage, all normalized tables are combined into a single global matrix, which is then analyzed using a standard (non-normalized) PCA (Abdi *et al.,* 2012). This produces common factor scores for the observations and loadings for the variables.

The goals of MFA are to analyze several data sets measured on the same observations; to provide a set of common factor scores and to project each of the original data sets to analyze communalities and discrepancies (Abdi *et al.,* 2012). MFA is a well-established method for analyzing multiple sets of variables measured on the same observations and has become widely used across various fields, such as sensory and consumer science research, chemometry and process monitoring

(Kvalheim,1988), ecology (Bertrand *et al.,* 2007) , agriculture (Franco *et al.,* 2010), broadcasting (Strohmeier, 2011), geology (Duvert, 2010) , neuroimaging (Kumagai, 2004), medicine and health genetics (B´ecue-Bertaut, 2008b), statistical quality control (Jassey, 2010), economy (Lautre, 2004) and molecular biology (Carlson, 2010). In addition to its broad range of applications, MFA continues to be an active area of methodological development, with ongoing theoretical advancements expanding its capabilities (Abdi *et al.,* 2012).

4.2. Materials and Methods

Chapter 2 of this study involved 76 naïve consumers who evaluated all 12 bean samples using the Check-All-That-Apply (CATA) method, in which participants were provided with a list of pre-established sensory attributes and instructed to select all attributes they perceived during evaluation. Chapter 3 utilized a semi-trained panel of 10 participants who evaluated the same 12 samples using the Temporal Check-All-That-Apply (TCATA) method, which required panelists to track and select attributes over a pre-defined period of time. These two approaches were integrated to provide a more comprehensive understanding of the sensory characteristics of the bean samples. Multiple Factor Analysis (MFA) was conducted to integrate the consumer CATA data and the semi-trained panel TCATA data and evaluate the degree of alignment between consumer perceptions and the more detailed temporal sensory information provided by the semi-trained panel. In this work, the use of MFA allows static CATA data and dynamic TCATA data to be analyzed within a shared multivariate space, making it possible to evaluate the degree of alignment between both panels. Alternative methods such as PCA could summarize each dataset independently, but they cannot integrate the different datasets while preserving their structure. Hence, MFA represents the most appropriate and informative approach for this study.

4.3. Data analysis

Data analysis was conducted using XLSTAT software (Lumivero, Denver, CO, USA). Multiple Factor Analysis (MFA) was applied to the citation frequencies of the attributes common to both the Check-All-That-Apply (CATA) and Temporal Check-All-That-Apply (TCATA) methods (toasted/roasted, salty, sweet, beany, earthy, straw/dry grass, potato/starchy, bitter, meaty/savory, and nutty) to visualize and compare the relationships captured by the two methods.

4.4. Results and Discussion

The MFA biplot below in Figure 4.1 explained 57.62% of the total variance and shows the positioning of the 12 bean samples based on the consumer CATA and semi-trained panel TCATA sensory spaces across cooking methods and bean types. The MFA biplot showed that several sensory attributes were similarly positioned for both datasets, indicating areas of agreement. Attributes such as toasted/roasted, potato/starchy, and nutty clustered closely for both CATA and TCATA, suggesting some agreement between consumers and semi-trained panelists in the perception of these characteristics. Similarly, samples such as pinto and black beans pressure cooking were positioned near savory and starchy attributes, indicating that sensory qualities were similarly associated with these samples across both methods.

The MFA also highlighted meaningful differences; semi-trained panelists identified attributes such as straw/dry grass and bitter more clearly in the TCATA vectors than in the consumer CATA vectors. This was expected because the TCATA panel received some training with attribute references, which may have helped assessors detect more subtle or transient sensory notes that consumers may have overlooked. These differences were more evident for samples such as black bean slow cooking and Bambara bean boiling, which were positioned closer to these TCATA attributes than to their CATA counterparts.

The first dimension (F1 = 35.55%) separated samples primarily based on green/dry attributes versus savory/starchy/roasted attributes. The second dimension (F2 = 22.07%) captured differences related to sweetness, bitterness, and toasted characteristics, further distinguishing baked samples (which showed stronger roasted and toasted notes) from boiled and pressure-cooked samples. The RV coefficient obtained was 0.381 as shown in Table 4.1. The RV coefficient reflects the similarity between the CATA and TCATA datasets. The value obtained indicates low to moderate similarity. This reflects that consumers and semi-trained panelists do not perceive all attributes in the same way. This suggests that consumers may have focused more on dominant, easily recognizable attributes, while semi-trained panelists captured more subtle and time-dependent characteristics.

In the RV coefficient table, the relationship between CATA and MFA was 0.771, suggesting that the MFA representation adequately represented the consumer sensory structure. The RV coefficient between TCATA and MFA was 0.883, indicating stronger alignment between the MFA representation and the semi-trained panel data. Overall, these values indicate that the MFA successfully integrated both datasets, while showing stronger alignment with the TCATA data, likely due to its ability to capture temporal changes in sensory perception.

Figure 4.1:MFA biplot showing results of consumer CATA and semi-trained panel TCATA data across all bean types and cooking methods

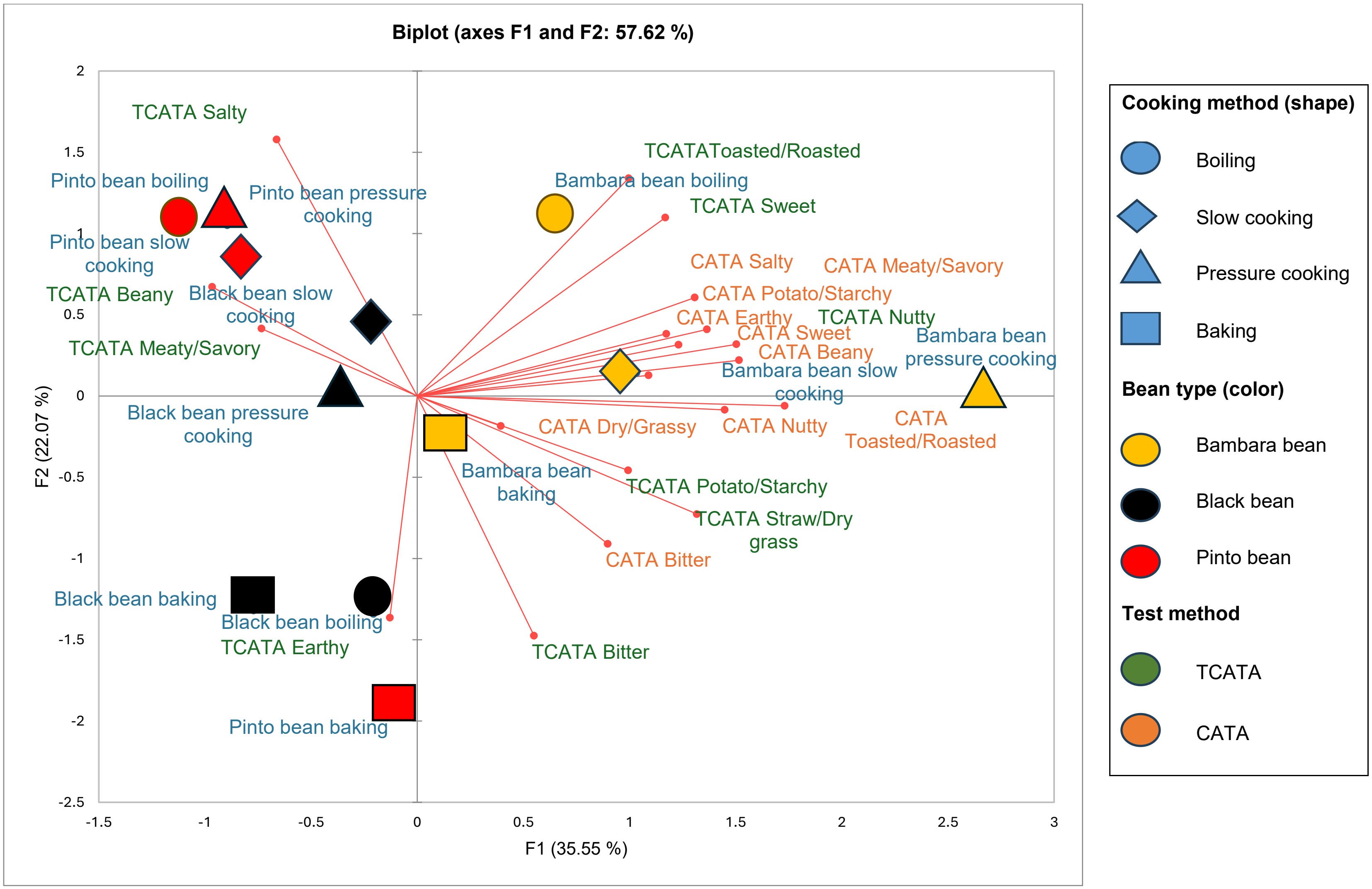


Table 4.1: RV COEFFICIENT indicating relationships between CATA obtained from naïve panelists and TCATA obtained from semi-trained panelists

	CATA	TCATA	MFA
CATA	1.000	0.381	0.771
TCATA	0.381	1.000	0.883
MFA	0.771	0.883	1.000

4.5. General conclusions and Key Findings of the Study

This study explored three different types of dry beans, including black beans, pinto beans, and African Bambara beans, subjected to four cooking methods (boiling, slow cooking, pressure cooking, and baking), and evaluated the effects of these processing methods on sensory profile, consumer acceptance, and consumer perception. Results from Chapter 2 showed that cooking methods strongly influenced the sensory quality and consumer acceptance of beans. This is likely because cooking method influences the aroma, flavor, texture, and particularly beany aroma intensity.

A key pattern observed across the cooking methods was that baking reduced perceived beany aroma the most, followed by boiling, pressure cooking, and slow cooking. Pressure cooking resulted in moderate beany intensity while enhancing flavor and texture liking. Although slow cooking did not reduce beany aroma as effectively as baking or boiling, it still produced high overall liking scores, possibly due to the development of a more balanced and integrated flavor profile resulting from prolonged exposure to mild heat.

Moreover, when the same cooking methods were applied, each bean type exhibited a distinct sensory profile. Black beans showed strong flavor and texture liking under pressure cooking but lower overall liking when baked, despite receiving high appearance scores. Pinto beans were most preferred under pressure cooking and slow cooking, although overall liking scores remained within a moderate range of consumer acceptance. A unique trend was observed for African Bambara beans. Despite lower flavor and texture liking under baking, they achieved their highest overall liking under this cooking method, likely due to the reduction in perceived beany aroma. Under pressure cooking, pinto beans were the most preferred, whereas under boiling, Bambara beans achieved the highest overall liking. Under slow cooking, no differences in overall liking were observed among bean types. This suggests that slow cooking may have minimized sensory differences across bean types. Baking produced the greatest differentiation across bean types.

Findings from Chapter 3 further revealed that temporal sensory profiles differed across cooking methods and bean types. Although beany and potato/starchy were the dominant attributes across all 12 samples throughout the evaluation period, each cooking method produced a distinct sensory profile. Pressure-cooked beans demonstrated a rapid onset of savory and starchy notes, which may contribute to a more favorable sensory profile. Boiled beans showed moderate persistence of beany attributes, accompanied by balanced savory and starchy characteristics. Slow-cooked beans displayed the longest persistence of beany, earthy, and green attributes. Baked beans showed shorter persistence of beany attributes but longer-lasting toasted, roasted, and slightly bitter attributes.

Moreover, while the MFA results supported several key findings from Chapters 2 and 3, they also demonstrated that although consumers and semi-trained panelists differ in the depth of their sensory perceptions, they showed some degree of agreement in the characterization of the samples. The integration of CATA and TCATA provided a more comprehensive understanding of how cooking methods and bean type influence sensory quality. This approach enabled evaluation of the degree of alignment between consumers and the semi-trained panel, providing additional insight into the complementary information obtained from the two sensory methods.

4.6. Overall Industry Applications of study

The findings of this study have several important implications for the food industry, particularly for companies involved in the development of plant-based foods, ready-to-eat legumes, and value-added bean products. First, the study shows that cooking method plays a role in shaping both the sensory profile and consumer acceptance of dry beans. These findings suggest that food scientists or processors can strategically select thermal treatments or processing methods to optimize flavor, texture, and aroma. Methods that reduce beany aroma such as baking and boiling would be valuable for food processors who seek to maximize consumer acceptance of underutilized legumes such as Bambara beans. These methods can help mitigate the strong, grassy, or earthy notes that often limit consumer appeal.

Secondly, the integration of consumer CATA and semi-trained panel TCATA data provides a more comprehensive understanding that can guide product formulation. The MFA results suggest that consumers and semi-trained panelists showed agreement in the perception of major sensory attributes, particularly savory, roasted, and starchy characteristics. This level of agreement suggests that semi-trained panel data may help identify sensory profiles associated with consumer preferences during product development. With this knowledge, companies could streamline product development by using semi-trained panels early in the formulation process.

Furthermore, the temporal insights from Chapter 3 highlight which sensory attributes persist throughout evaluation, and which dissipate more quickly. Products in which beany or green attributes dissipate more quickly during evaluation, such as pressure-cooked or baked beans, may be more acceptable to consumers. This information can guide the design of processing parameters, ingredient additions, or flavor-masking strategies. For example, pressure cooking may be used to create softer textures and enhance savory notes, while baking may be used to generate roasted flavors that help mask inherent beaniness. Lastly, the study provides valuable insights for innovation in plant-based protein markets, where beans are increasingly used as functional ingredients. Understanding how different cooking methods influence sensory attributes can help manufacturers tailor beans for specific applications such as purees, spreads, snacks, or meat alternatives. The strong performance of Bambara beans under certain cooking methods also highlights opportunities for introducing this underutilized legume into mainstream markets, supporting sustainability and agricultural diversification.

4.7. Limitations of the Study

Although this research provides meaningful insights into the sensory and consumer perception of cooked dry beans, several limitations should be acknowledged. First, the study evaluated only three bean varieties and four cooking methods, which may limit the generalizability of the findings to other legumes or processing techniques. Additional bean types, such as navy, kidney, or mung beans, may exhibit different sensory characteristics under similar conditions. Second, the consumer evaluation was conducted with 76 participants from a single geographic region, which may not fully represent broader consumer populations with different cultural backgrounds, dietary habits, or familiarity with beans. Consumer preferences for beany aroma or texture may vary across demographic groups, potentially limiting the application of the results to other regions.

Third, although the semi-trained panel of 10 participants was appropriate for TCATA methodology, it may have limited the depth of attribute detection compared with a fully trained descriptive panel. A larger or more extensively trained panel might have identified additional subtle or emerging sensory characteristics. Fourth, the study relied on laboratory-controlled cooking conditions, which may differ from industrial processing environments. Commercial-scale cooking often involves variations in temperature distribution, pressure, and batch size that could influence sensory outcomes. Finally, while the MFA provided a robust integration of consumer and panel data, the analysis was based on static CATA and dynamic TCATA datasets, which differ in structure and temporal resolution. Although the RV coefficient indicated moderate agreement between the datasets, the inherent differences between the static CATA and dynamic TCATA methodologies may limit the direct comparability of the two sensory approaches.

4.8. References

Abdi, H. & Williams, L.J. (2010d). Correspondence analysis In N.J. Salkind, (Ed.): Encyclopedia of Research Design. Thousand Oaks (CA): Sage. pp. 267–278.

Abdi, H., Williams, L.J. & Valentin D., (2012). Multiple factor analysis: Principal component analysis for multi-table and multi-block data sets. In J. Blasius & M. Greenacre (Eds.), *Multiple correspondence analysis and related methods* (pp. 551–574). CRC Press.

B´ecue-Bertaut, M., Kern, J., Hern´andez-Maldonado, M.-L., Juresa, V., & Vuletic, S. (2008b). Health-risk be haviour in Croatia. Public Health 122, 140–150.

Bertrand, F., Maumy, M., Fussler, L., Kobes, N., Savary, S., & Grossman, J. (2007). Using factor analyses to explore data generated by the National Grapevine Wood Diseases survey. Case Studies in Business, Industry and Government Statistics, 1, 183–202.

Carlson, M. L., Flagstad, L. A., Gillet, F., & Mitchell, E. A. D. (2010). Community development along a proglacial chronosequence: are above-ground and below-ground community structure controlled more by biotic than abiotic factors? Journal of Ecology, 98, 1084–1095.

Duvert, C., Gratiot, N., Evrard, O., Navratil, O., N´emery, J., Prat, C., & Esteves, M. (2010). Drivers of erosion and suspended sediment transport in three headwater catchments of the Mexican Central Highlands. Geomorphology, 123, 243–256.

Escofier, B. & Pag`es, J. (1983). M´ethode pour l'analyse de plusieurs groupes de variables: Application `a la caract´erisation des vins rouges du Val de Loire. Revue de Statistique Appliqu´ee, 31, 43–59. [67]

Escofier, B., & Pag`es, J. (1988). Analyses Factorielles Simples et Multiples: Objectifs, M´ethodes, Interpr´etation. Dunod, Paris.

Escofier, B., & Pag`es, J. (1990b). Multiple factor analysis. Computational Statistics & Data Analysis 18, 121–140.

Franco, J., Crossa, J., & Desphande, S. (2010). Hierarchical Multiple-Factor Analysis for Classifying Genotypes Based on Phenotypic and Genetic Data. Crop Science, 50, 105.

Jassey, V. E. J., Chiapusio, G., Mitchell, E. A. D., Binet, P., Toussaint, M.-L., & Gilbert, D. (2010). Fine-Scale Horizontal and Vertical Micro-distribution Patterns of Testate Amoebae Along a Narrow Fen/Bog Gradient. Microbial Ecology, 61, 374–385.

Kumagai, T. and Utsugi, A. (2004). Removal of artifacts and fluctuations from MEG data by clustering methods. Neurocomputing, 62, 153–160.

Kvalheim, O. M. (1988). Interpretation of direct latent-variable projection methods and their aims and use in the analysis of multicomponent spectroscopic and chromatographic data. Chemometrics and Intelligent Laboratory Systems, 4, 11–25.

Lautre, I.G., Fern´andez, E.A. (2004). A methodology for measuring latent variables based on multiple factor analysis. Computational Statistics & Data Analysis, 45, 505–517.

Strohmeier, D., Jumisko-Pyykk¨o, S., Kunze, K., & Bici, M. O. (2011). The Extended-OPQ Method for User Centered Quality of Experience Evaluation: A Study for Mobile 3D Video Broadcasting over DVB-H. EURASIP Journal on Image and Video Processing, 2011, 1–24.

Appendix A - Screener and Questionnaire used in Consumer study

A.1 Screener

1.What is your gender?
Male
Female

2. Are you currently pregnant or nursing?
Yes
No

3. Which of the following includes your current age?
17 years or under
18-24 years old
25-34 years old
35-44 years old
45-54 years old
55-65 years old
66 years or older

4. When was the last time you, yourself, participated in a market research study or taste test?
In the past month
In the past 2 months
In the past 3 months
In the past 4-6 months
6 months or more ago
I have never participated in a consumer research or marketing research study about a food or beverage

5. Are you currently scheduled to participate in a market research study or taste test at K-State Olathe or any other testing facility?
Yes
No

6. We are interested in talking with people who work in various industries and businesses. Do you, or does anyone in your household, work for any of the following industries? (check all that apply)
Public Utility such as a Gas or Electric Department
A Food/Beverage Manufacturer, Wholesaler, Distributor or Retailer
Mass Media such as Radio or TV Station or a Publisher
A Market Research Company
An Advertising or Public Relations Agency
Grocery Store or Supermarket
Auto Manufacturing/Sales

Credit Card company
Teacher/Professor
None of the above
Allergies

7. Are YOU allergic or sensitive to ANY of the following foods? (check all that apply)
Wheat (gluten)
Soybean
Egg
Milk
Fish
Crustacean shellfish
Dried Beans
Sesame
Tree Nut
Peanut
Other:
I am not allergic to any of the above foods

8. Are you currently experiencing any cold or flu-like symptoms?
Yes
No

9. Which of the following foods/ingredients have you purchased and consumed in the past 3months? (select all that apply)
Potatoes
Grains
Pasta/Noodles
Legumes (Beans/Lentils)
Nuts/Seeds
Fruits
Leafy greens (Spinach/Lettuce)
None of the above

10. Which of the following legumes have you consumed in the past 3months? (select all that apply)
Green Peas/Snap Peas
Lentils
Green Beans
Dry Peas
Chickpeas/Garbanzo Beans
Bambara Beans
Dry Beans
None of the above

11. Which of the following beans (dried or canned) do you consume on a regular basis?
Black Beans
Pinto Beans
Navy Beans
Soybeans (Edamame)
Mung Bean
Lima Beans
Kidney Beans
None of the above

12. How often do you typically eat black and/or pinto beans?
Daily
Several Times a Week
Once a Week
Once a Month
2-3 Times a Month
Rarely
Never

13. Are you willing to try different varieties of beans, some of which may be non-native to the US?
Yes
No

A.2 Questionnaire - Consumer study

1. How much do you like or dislike the overall aroma of this bean?
Dislike Extremely
Dislike Very Much
Dislike Moderately
Dislike Slightly
Neither Like nor Dislike
Like Slightly
Like Moderately
Like Very Much
Like Extremely

2. How intense is the beany aroma of this sample? (Beany aroma refers to a smell similar to beans, peas or soy.)
Not At All Beany
Very Slightly Beany
Slightly Beany
Moderately Beany
Strongly Beany
Very Strongly Beany
Extremely Beany

3.How would you describe the beany aroma of this sample?
Not At All Beany Enough
Somewhat Not Beany Enough
Just-About-Right
Somewhat Too Beany
Much Too Beany

4. How much do you like or dislike the overall appearance of this bean?
Dislike Extremely
Dislike Very Much
Dislike Moderately
Dislike Slightly
Neither Like nor Dislike
Like Slightly
Like Moderately
Like Very Much
Like Extremely

5. How would you describe the color of this bean?
Much Too Light
Somewhat Too Light
Just-About-Right
Somewhat Too Dark
Much Too Dark

6. Considering the aroma, appearance, taste, and texture of this bean sample, how much do you like or dislike the bean sample overall
Dislike Extremely
Dislike Very Much
Dislike Moderately
Dislike Slightly
Neither Like nor Dislike
Like Slightly
Like Moderately
Like Very Much
Like Extremely

7. Using 3 single word descriptors, not statements, what did you like about this sample?
Descriptor 1
Descriptor 2
Descriptor 3

8. Using 3 single word descriptors, not statements, what did you dislike about this sample?
Descriptor 1

Descriptor 2
Descriptor 3

9. How much do you like or dislike the overall flavor of this bean sample?
Dislike Extremely
Dislike Very Much
Dislike Moderately
Dislike Slightly
Neither Like nor Dislike
Like Slightly
Like Moderately
Like very Much
Like Extremely

10. How would you describe the overall flavor of this sample?
Much Too Weak
Somewhat Too Weak
Just-About-Right
Somewhat Too Strong
Much Too Strong

11. How much do you like or dislike the texture of this bean sample?
Dislike Extremely
Dislike Very Much
Dislike Moderately
Dislike Slightly
Neither Like nor Dislike
Like Slightly
Like Moderately
Like Very Much
Like Extremely

12. How would you describe the texture of this sample?
Much Too Soft
Somewhat Too Soft
Just-About-Right
Somewhat Too Firm
Much Too Firm

13. How would you describe the saltiness of this sample?
Not At All Salty Enough
Somewhat Not Salty Enough
Just-About-Right
Somewhat Too Salty
Much Too Salty

14. How would you describe the sweetness of this sample?
Not At All Sweet Enough
Somewhat Not Sweet Enough
Just-About-Right
Somewhat Too Sweet
Much Too Sweet

15. How would you describe the bitterness of this sample?
Not At All Bitter Enough
Somewhat Not Bitter Enough
Just-About-Right
Somewhat Too Bitter
Much Too Bitter

16. How does this sample meet your expectations for cooked beans
Much Worse Than Expected
Somewhat Worse than Expected
Met Expectations
Somewhat Better Than Expected
Much Better than Expected

17. Thinking about its flavor (taste and aromatics), please select the attributes listed below that you identified while eating. (select all that apply)" Choose n
Toasted / Roasted
Green / Vegetable-Like
Stale
Nutty
Musty
Fermented / Sour
Potato / Starchy
Salty
Dry / Grassy
Beany
Bitter
Meaty / Savory
Earthy
Bland
Sweet
Metallic
Fruity
Other (Please specify)

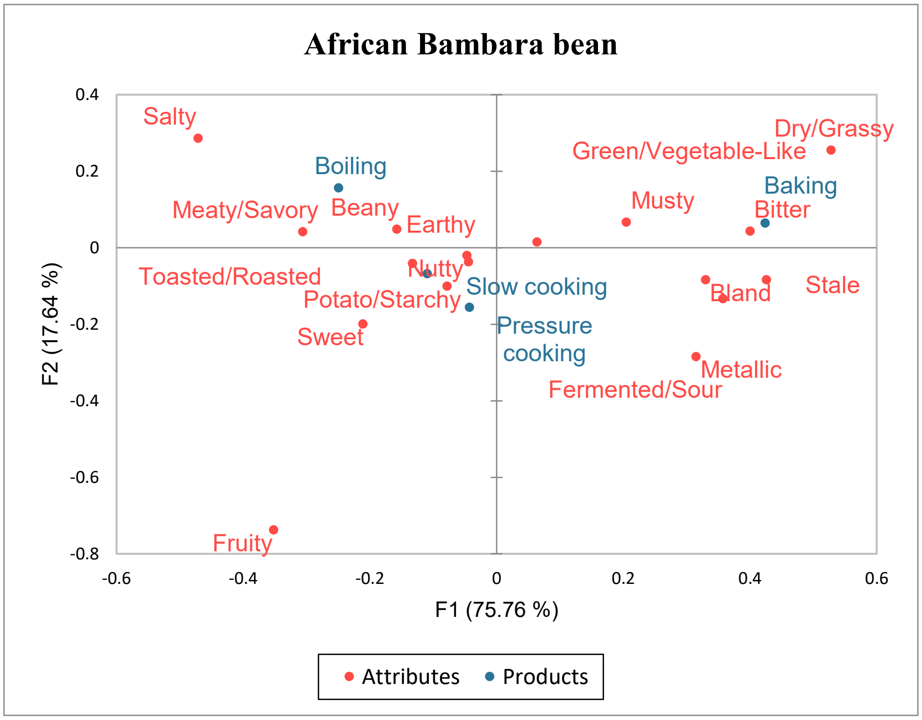
16. How often do you typically consume beans (dry/cooked, canned or pureed) in a meal or as the main entree, at home or in a restaurant?
More than once a week
Once a week

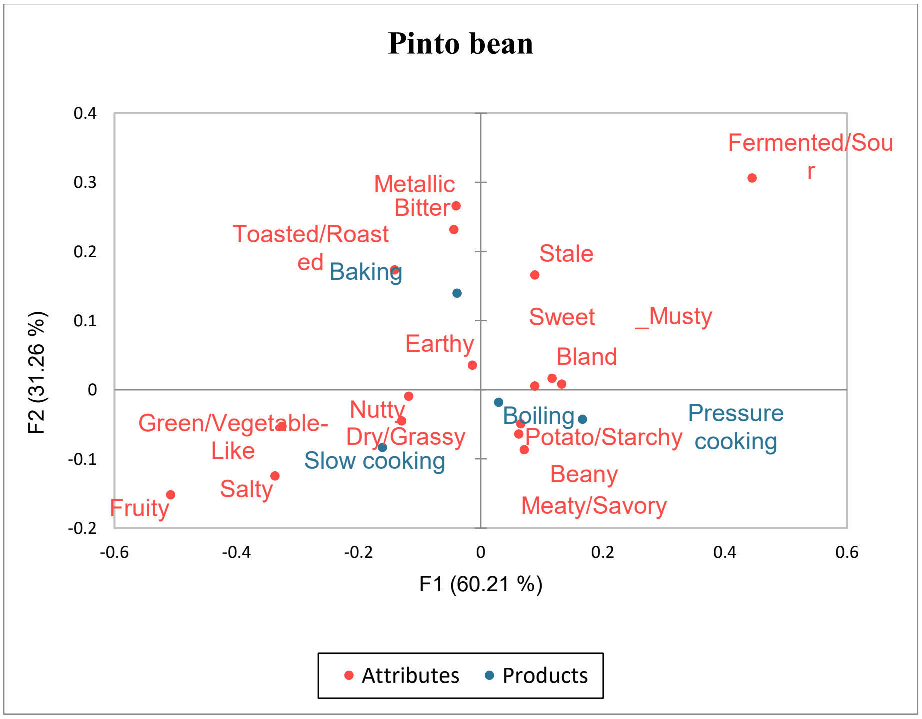
2 to 3 times a month
Once a month
1 to 2 times a year
Less than once a year
Never

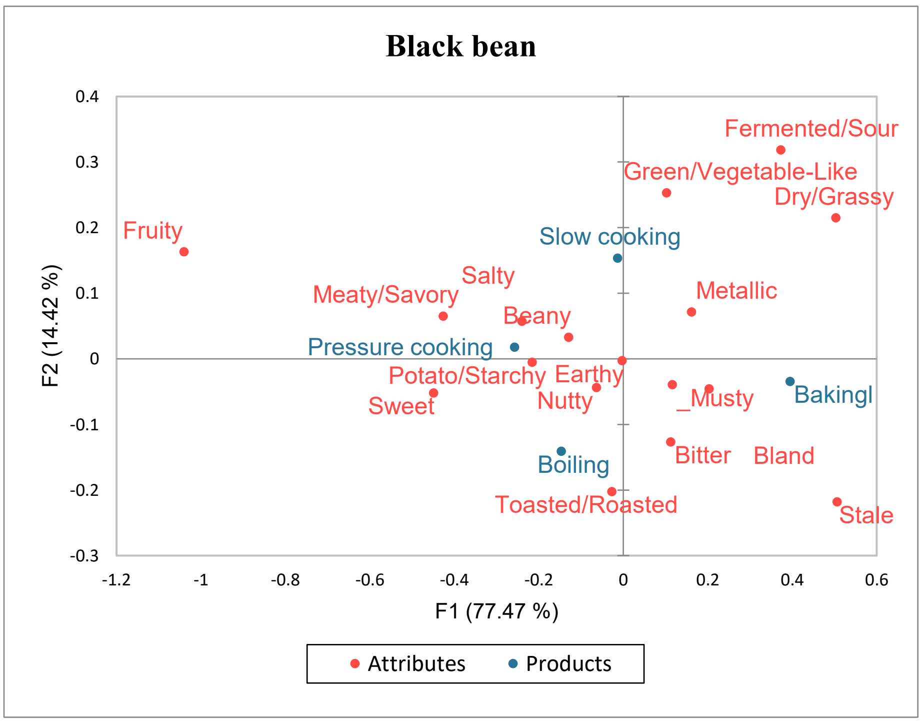
18. Which of the cooking methods do you typically use when cooking dry beans? (Check all that apply)
Steaming
Boiling
Frying
Roasting
Slow-Cooking
Pressure Cooking
Fermenting
Baking
Smoking
Toasting
Braising
Other (Please specify)

19. What is your gender?
Male
Female
20. Which of the following categories best describes your current age?
18-25
26-35
36-45
46-55
56-65

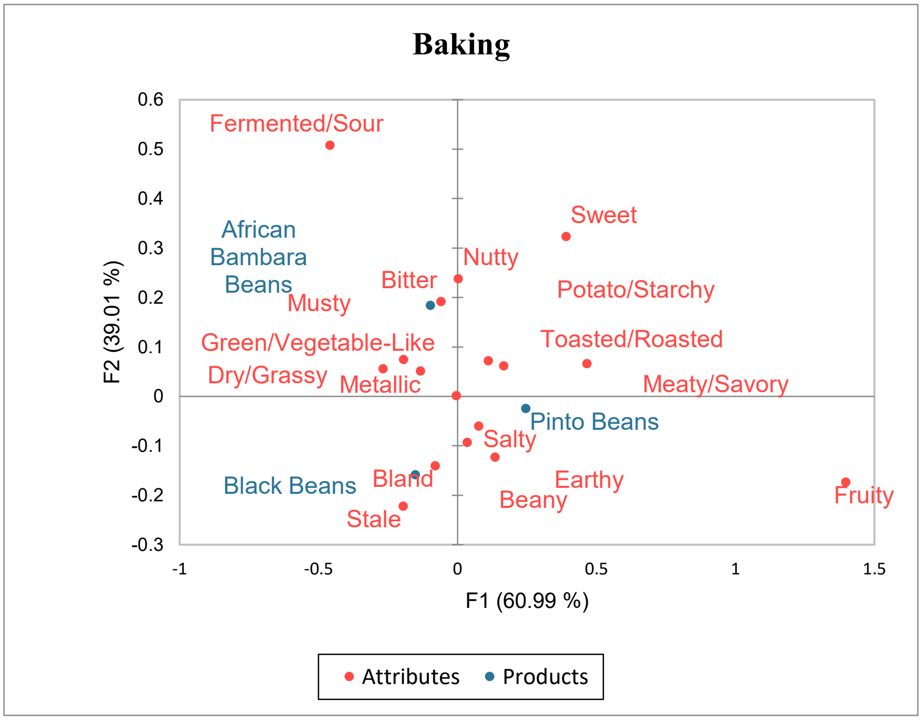
Appendix B - Check-All-That-Apply (CATA) analysis for sensory attribute variations within bean samples

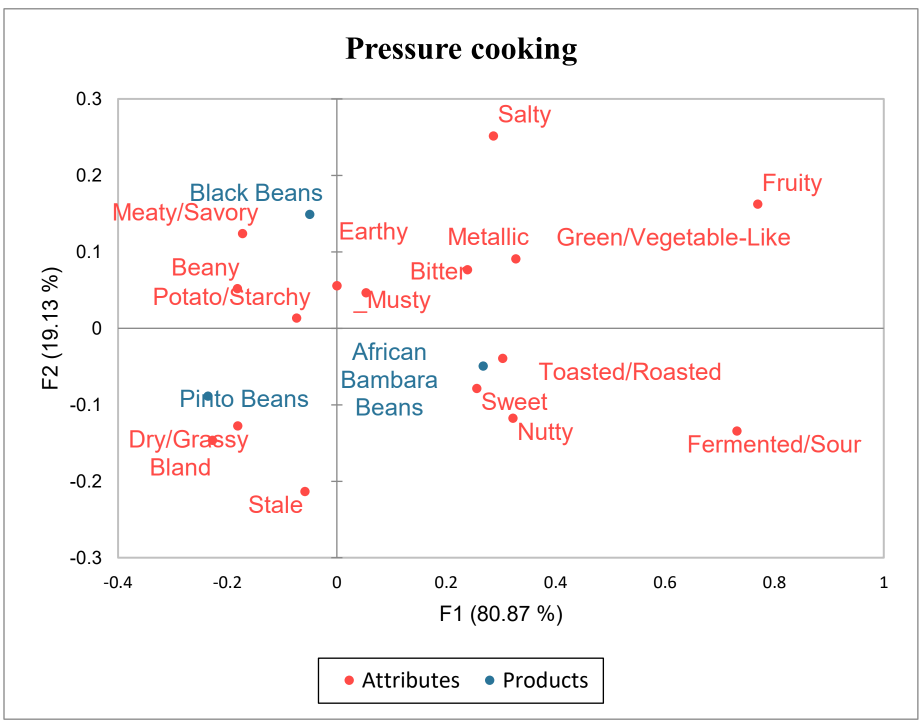


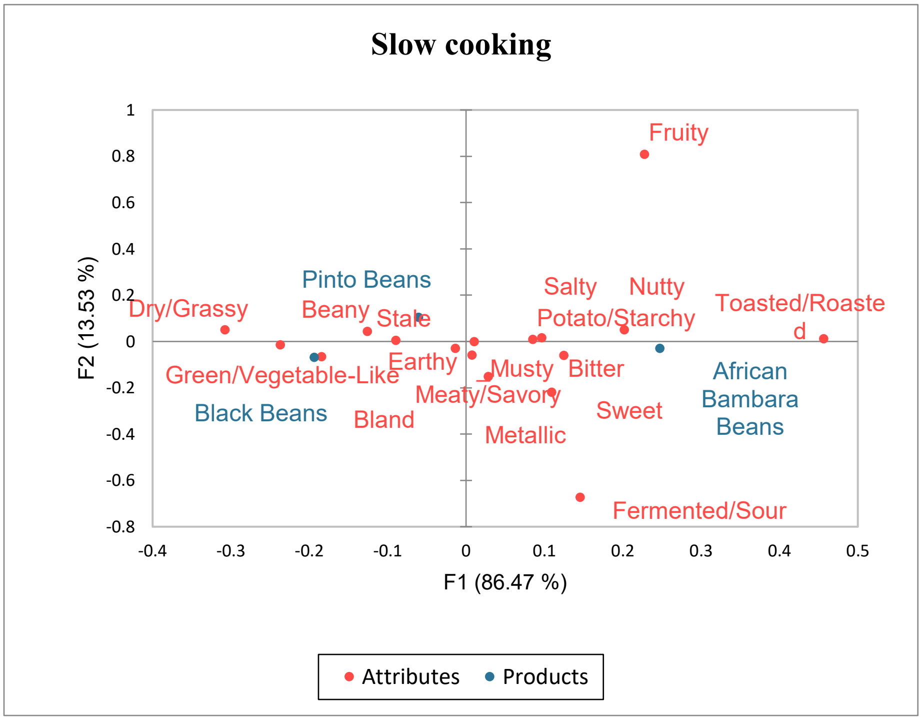

Pinto bean
F2 (31.26 %)
F1 (60.21 %)
Fermented/Sour
Metallic
Bitter
Toasted/Roasted
Baking
Stale
Sweet
_Musty
Earthy
Bland
Nutty
Green/Vegetable-Like
Dry/Grassy
Boiling
Pressure cooking
Potato/Starchy
Slow cooking
Beany
Salty
Meaty/Savory
Fruity
Attributes
Products

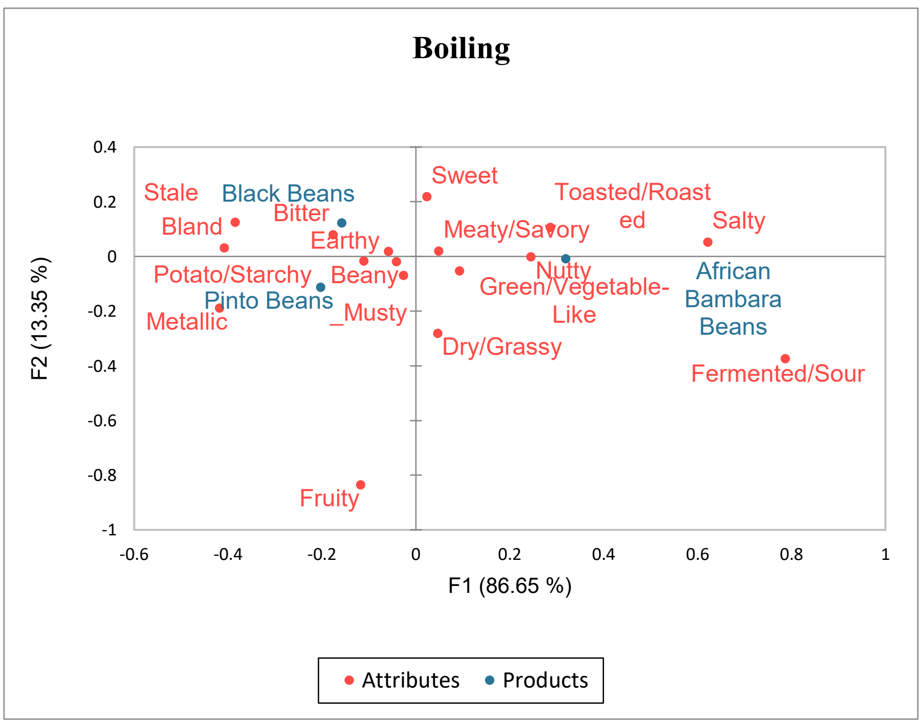

Black bean
F2 (14.42 %)
F1 (77.47 %)
Fermented/Sour
Green/Vegetable-Like
Dry/Grassy
Fruity
Slow cooking
Salty
Metallic
Meaty/Savory
Beany
Pressure cooking
Potato/Starchy
Earthy
Nutty
_Musty
Bakingl
Sweet
Boiling
Bitter
Bland
Toasted/Roasted
Stale
Attributes
Products

Appendix C - Check-All-That-Apply (CATA) analysis for sensory attribute variations across bean samples






Slow cooking
F2 (13.53 %)
F1 (86.47 %)
Fruity
Pinto Beans
Beany
Stale
Dry/Grassy
Salty
Nutty
Potato/Starchy
Toasted/Roasted
Green/Vegetable-Like
Earthy
Musty
Bitter
African Bambara Beans
Meaty/Savory
Black Beans
Bland
Sweet
Metallic
Fermented/Sour
Attributes
Products


Boiling
F2 (13.35 %)
F1 (86.65 %)
Sweet
Stale
Black Beans
Toasted/Roasted
Bitter
Bland
Meaty/Savory
Salty
Earthy
Potato/Starchy
Beany
Nutty
African Bambara Beans
Green/Vegetable-Like
Pinto Beans
Metallic
Musty
Dry/Grassy
Fermented/Sour
Fruity
Attributes
Products

]

Appendix D - Penalty analysis of the Just-About-Right (JAR) scores for the beany aroma intensity of bean samples

Sample	JAR Levels	% of Consumers	Mean Drops	Penalty	P-value	Significant
Black bean Pressure cooking	Too little	5.26%	-0.207			
	JAR	76.32%				
	Too much	18.42%	1.150			
Black bean Slow cooking	Too little	34.21%	0.971	0.33	0.05	
	JAR	42.11%				
	Too much	23.68%	1.403	0.33	0.01	yes
Black bean Boiling	Too little	21.05%	0.398	0.08		
	JAR	46.05%				
	Too much	32.89%	1.086	0.36	0.01	yes
Black bean Baking	Too little	34.21%	0.272	0.09		
	JAR	39.47%				
	Too much	26.32%	0.683	0.18		
Pinto bean Pressure cooking	Too little	19.74%	1.511			
	JAR	59.21%				
	Too much	21.05%	1.974	0.42	0.00	yes
Pinto bean Slow cooking	Too little	15.79%	2.417			
	JAR	68.42%				
	Too much	15.79%	1.833			
Pinto bean Boiling	Too little	13.16%	1.020			
	JAR	65.79%				
	Too much	21.05%	1.520	0.32	0.001	yes
Pinto bean Baking	Too little	9.21%	1.380			
	JAR	69.74%				
	Too much	21.05%	0.719	0.15		
African Bambara bean Pressure cooking	Too little	23.68%	0.757	0.18		
	JAR	50.00%				
	Too much	26.32%	0.918	0.24	0.02	yes
African Bambara bean Slow cooking	Too little	15.79%	1.069			
	JAR	61.84%				
	Too much	22.37%	1.025	0.23	0.011	yes
African Bambara bean Boiling	Too little	23.68%	0.902	0.21		
	JAR	46.05%				
	Too much	30.26%	1.718	0.52	0.003	yes

African Bambara bean Baking	Too little	22.37%	1.552	0.35	0.002	yes
	JAR	51.32%				
	Too much	26.32%	1.146	0.30	0.013	

*Note: JAR ≥ 70% of consumers, *Minimal penalty < 0.50, *High penalty ≥ 0.50, significant (p>0.05)*

Appendix E - Questionnaire for TCATA

Instruction

Click Green START Arrow and CHEW & SWALLOW button when you place the sample in your mouth and start chewing. Begin selecting and deselecting attributes as you perceive them. SWALLOW. While SWALLOWING, DO NOT deselect any attributes that are still highlighted from CHEWING. Click AFTERTASTE then select and deselect attributes as you perceive them left in your mouth after swallowing.
DO NOT click the red stop button, continue selecting and deselecting attributes as you perceive them until the timer ends. You may stop deselecting when you no longer detect an aftertaste - just DON'T click the RED Button.

1 Nutty
2 Sweet
3 Earthy
4 Meaty/Savory
5 Beany
6 Potato/Starchy
7 Straw/ Dry Grass
8 Toasted/Roasted
9 Bitter
10 Salty

Thank you for completing this test! Please click FINISHED and SIGN