ConsomON, an ontology for structuring knowledge and modeling consumer food behavior.

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Abstract

The transition to a more sustainable food system has become a strategic priority due to pressing environmental, social, and health challenges. This shift requires not only changes in production and distribution but also a deep transformation in consumer eating habits. Understanding the complexity of these behaviors is essential to identify effective strategies and interventions. However, studying consumer behavior involves multiple disciplines—sensory and consumer science, social sciences, nutrition, psychology, economics—each with its own methods and terminology, making integration difficult. Ontologies offer a solution by providing a shared conceptual framework to analyze and model consumer dynamics. Existing food-related ontologies, such as FoodWiki, FoodOn, and TransformON, are primarily product- or process-oriented. While useful, they do not adequately address the interaction between consumers, food, and context. To fill this gap, the ConsomON ontology was developed to model the biological, cognitive, and behavioral processes involved in food choices, from exposure to stimuli to final purchase and consumption decisions. ConsomON has been built using the Linked Open Terms methodology, combining top-down and bottom-up approaches. The top-down method draws on literature, expert input, and existing models like PO² and I-ADOPT, focusing on high-level concepts for consistency. The bottom-up approach uses detailed, domain-specific data from two questionnaires—one structured (Food Choice Questionnaire) and one open-ended—used as a case study to develop the "consumer motivation" hierarchy of attributes. The PO²Manager software suite was used to build and implement the ontology. Ultimately, ConsomON aims to standardize vocabulary and structure data on food consumer behavior, fostering interdisciplinary collaboration and enabling data-driven approaches such as meta-analyses, AI-based tools, and holistic models of food choice processes.

Keywords

Knowledge engineering, FAIR data, Food consumption modeling, Consumer perception and preference

1. Introduction

A move towards a more sustainable food system has become a strategic priority for public policies, economic stakeholders and scientific research because of the environmental, social and health challenges that we face today. This transition requires not only the transformation of production and distribution systems, but also a profound change in consumer eating habits. Understanding the complexity of these behaviors is crucial to identifying the levers that can encourage the adoption of a more sustainable diet, and to designing targeted, effective interventions [1].

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To this end, research should adopt a systemic approach that considers all the factors influencing people's decision-making dynamics and behavior [2]. However, the study of these factors involves various disciplines, including the social sciences, sensory and consumer sciences, nutrition, psychology, economics and so on. Studies rely on different methodologies and terminologies, and this heterogeneity makes it challenging to integrate knowledge and data. An ontology provides a shared conceptual model and semantic foundation for analyzing, modeling and predicting consumer dynamics, making it a relevant approach to overcoming this fragmentation.

Most ontologies developed in the food sector are product-centric or process-oriented. Examples include FoodWiki [3], an ontology with SWRL rules for safe food consumption system, the Food Ontology [4] from the British Broadcasting Corporation's Ontologies for describing recipes, ingredients, menus and diets, or most recently FoodOn [5], an ontology of the Open Biological and Biomedical Ontology Foundry (OBO Foundry) that describes different facets of food and interconnects agricultural and livestock practices related to food production, culinary or industrial processing, and biomedical sciences. Similarly, the PO2/TransformON domain ontology has been recently developed to describe transformation processes and characterization of products derived from biomass, including food and bioproducts [6]. It is a process-centered ontology reusing World Wide Web consortium (W3C) standards and is also compatible to FoodON and other OBO Foundry ontologies [7,8]. The vocabulary is based on the European FoodEx2 classification, which is maintained by the European Food Safety Agency (EFSA) [9]. It incorporates a terminology of 9000 concepts related to substances, process steps, devices, operating procedures and process parameters, which are described with Simple Knowledge Organization System (SKOS) data model [10].

Another notable initiative in the field of food consumer sciences is the European COMFOCUS consortium (https://comfocus.eu/), which proposed an ontology to support the management and integration of data compliant with the FAIR principles of research, accessibility, interoperability, and reusability [11]. Built upon the C-OAR-SE framework (C-OAR-SE meaning 'Construct definition, Object classification, Attribute classification, Rater identification, Scale formation and Enumeration' described in [12]), the COMFOCUS ontology is based on a limited set of standardized protocols and questionnaires, and it does not systematically identify the concepts underlying various measurements in research. Furthermore, it does not enable us to conceptualize the relationships between these measures or model the processes that explain food choices.

This highlighted the need for a consumption-centered ontology focusing on the interaction between consumers, food, and context. In Section 2, we present the method used in building the ConsomON ontology. In section 3, we present the implemented model of ConsomON and in Section 4 we discuss future directions of this work.

2. Methodology for ontology building

The Linked Open Terms (LOT) methodology [13] was used for ontology building. The steps from specification to implementation involve different stakeholders: the ontology developer, domain experts, and future users. Here, we present the results of the first specification stage, which involves gathering the requirements for the ontology. The specification step includes defining use cases by detailing the application's aim, domain, scope, stakeholders (the users and systems interacting with the ontology), and data characteristics (describing the types, sources, and structure of data). We followed a top-down and bottom-up approach for ontology building. We used the PO² software suite [14-16] to both build the ontology and implement the case study.

2.1. Aim and scope of ConsomON

The application aim of ConsomON is to support the description of processes related to consumer food choices and consumption data, along with the integration of associated data collected across various disciplines and methods.

The domain of the ontology encompasses the researchers conducted within the Human Nutrition and Food Safety INRAE division (https://www.inrae.fr/en/divisions/human-nutrition). The division's research aims to respond to the major societal issues relating to human nutrition (determinants of food behavior and choice, food/health relationship, food toxicology, nutritional safety and environmental impact). In a first round, the scope was restrained to psychological and perceptual dimensions involved in food choices, with a specific focus on motivations, values, contextual influences, and behavioral intentions. This restriction allowed us to target the most immediate and measurable drivers of consumption, ensuring conceptual clarity while laying a solid foundation before expanding the ontology to other dimensions. For this use case, only self-reported data were considered, including structured quantitative data from closed-ended questionnaires (e.g., derived from Likert scales on motivations), and unstructured textual data (verbatim) in response to open-ended questions (e.g., sentence completion related to food choices). In a second round, heterogeneous sources and data types will be included, such as, behavioral data (food supply and consumption purchase data), instrumental data (heart rate, electrodermal activity, etc.) and implicit data (response times, emotions scores derived from facial emotion analysis, etc.).

The stakeholders involved include ontology developers working on the semantic structuring of the data, domain experts in sensory and consumer sciences, researchers and data analysts working with structured datasets for interdisciplinary researches.

An additional prerequisite for ConsomON is that it must be complementary to, and therefore compatible with TransformON, to enable data integration across food-related domains, from food processing to consumer behavior. To this end, the Process and Observation Ontology (PO^2) core model was used to develop ConsomON and ensure consistency with TransformON. The PO^2 v2.4 core model [6] reuses W3C standard ontologies such as SOSA or 'Sensor, Observation, Sample, and Actuator' ontology (https://www.w3.org/TR/vocab-ssn/), OWL-time or 'Time Ontology in OWL' (https://www.w3.org/TR/owl-time/), the PROV-O or 'Provenance Ontology'(https://www.w3.org/TR/prov-o/), and the QUDT, or 'Quantity, Unit, Dimension and Type' collection of ontologies (https://qudt.org/) representing the physical quantity and unit measurement systems. The PO^2model is also close to the OBO process model as it includes the distinction between the "unplanned" physical, chemical or biological processes defined in Basic Formal Ontology (BFO) as occurents and the "planned process" introduced in the Ontology for Biomedical Investigations (OBI) that involves plan specifications [17]. The Process part of the PO^2core model is used to describe the sequential sequence of steps or events that take place during the process being described. The Observation part is used to describe the quantitative or qualitative variables in a way that is compatible with the I-ADOPT model [18], a framework which address the interoperability of observational data endorsed by the Research Data Alliance (https://www.rd-alliance.org/).

2.2. Top-down approach

The top-down approach is based on a literature review, expert knowledge gathered from researchers in the field, and the PO^2 core model, which allows generic processes to be represented in OWL2.

First, the specification phase involved defining concepts that make it possible to represent consumers' food behavior, taking into account biological, cognitive and behavioral processes. These processes range from exposure to food stimuli to the ultimate consumption decision. A literature survey was conducted to explore the diversity of conceptual models addressing food choices. A total of 21 models of food behavior were examined, from social psychology, cognitive psychology neurosciences and marketing, with a particular focus on motivations, values, contextual influences, and behavioral intentions regarding food choices.

2.3. Bottom-up approach

The bottom-up approach is based on a case study involving two distinct Food Choice Questionnaires (FCQ) used to measure consumer motivations towards food [19]. One questionnaire is based on predefined criteria, and uses scales, while the other invites participants to express themselves in natural language using sentence completion. In contrast to the top-down approach, the bottom-up approach provides very detailed, domain-specific concepts thanks to the collected verbatims.

2.3.1. Food Choice Questionnaire based on scales

A total of 300 participants completed a single item FCQ adapted from [20]. They responded on 5-point Likert scale ranging from "Totally disagree" to "Fully agree" to 14 questions, each beginning with the stem "*It is important to me that the foods I consume on a daily basis...*" followed by one of the following statements: *are healthy; help me regulate my mood (manage stress, lift my spirits); are practical (easy to buy, store, and prepare); provide me with pleasant sensations (texture, appearance, smell, taste); are natural; are affordable; help me control my weight; are environmentally friendly; respect animal welfare; respect producers (working conditions, fair pay); are familiar to me; promote moments of sharing or conviviality; are the same as those consumed by people around me; are in line with current recommendations or trends.*

2.3.2. Food Choice Questionnaire based on free comments

Two weeks later, the same participants completed open-ended questions using a sentence-completion format (up to six responses per question) based on the following stems:

1. *For me, it is important that my diet is...*
2. *In general, I choose foods/dishes/products that...*
3. *If I hesitate between several foods/dishes/products, I tend to favor those that...*
4. *I sometimes make exceptions when...*
5. *Beyond the food itself, my food choices may be influenced by...*
6. *In the future, in the way I consume foods/dishes/products, I intend to...*

3. Results and discussion

3.1. Conceptual model for Food Choice

First, the conceptual model was constructed, in order to have a global graphic representation of the ontology's domain (i.e., consumer behavior). Existing models offer valuable insights into food behavior, but they do not always explicitly link these observations to concepts. Many also lack empirical validation, as they do not systematically measure variables or conduct experiments to support their frameworks. Additionally, the broad analysis of global consumer behavior incorporates socio-demographic and cultural variations, making generalization challenging. While some models integrate cognitive and emotional factors, others focus on environmental and social influences without fully incorporating psychological mechanisms. A cutting-edge conceptual model [21] conceived after a literature review of 59 models distinguished three main components more clearly:

• Food: includes internal factors (sensory characteristics, appearance) and external factors (labels, packaging, accessibility, social norms).

• Consumer: divided into personal internal state (physiological needs, biological characteristics, psychology, habits) and cognitive factors (knowledge, preferences, anticipated consequences).

• Context: defined under "socio-cultural factors", but remains fragmented, with elements like social context of choice and physical environment, sometimes grouped under external food factors.

This model provides a structured representation of factor influencing food choice, though some ambiguities persist in classifying certain concepts. Despite this, it remains a strong foundation for modeling food behavior. To strengthen the connection between food behavior models and psychological processes, several socio-cognitive theories have been reviewed and integrated in the conceptual model of ConsomON. To represent these different theories in our model and categorize them, we based our approach on a three-stage behavioral modulation framework [22]. This division between cognition, affect, and conation, is commonly used in psychology, and has already been applied in consumer studies, particularly in social media research [23].

Finally, The C-OAR-SE framework, the basis for the COMFOCUS ontology, was also taken into consideration. The C-OAR-SE metamodel, proposed in the field of marketing, defines phenomena (or “constructs”) in terms of objects, attributes, and raters. Raters are individuals (people or consumers) who express themselves (attributes) about something (objects) in a particular micro-context [12]. Objects reflect what the attributes refer to, in different contexts (e.g., individual objects or pairs of objects, or part of an assortment) and in different arrangements. Objects can be real (physically materialized) or abstract (recalled, imagined, displayed as pictures, etc.). They can be singular, a collection of elements, or have multiple nested components. Attributes reflect the dimension of judgment or description of something (the object of interest). The formation of a scale (Scale Evaluation) then consists of assembling the parts of object elements with the parts of corresponding attribute elements.

Figure 1 shows the conceptual model used to model food behavior in ConsomON. It consists of six stages. The first one is exposure, which refers to the interaction (voluntary or involuntary) between a consumer, a food, and a context. The food and context can be real or abstract. Exposure can relate to a specific food, a category of foods, or foods in general.

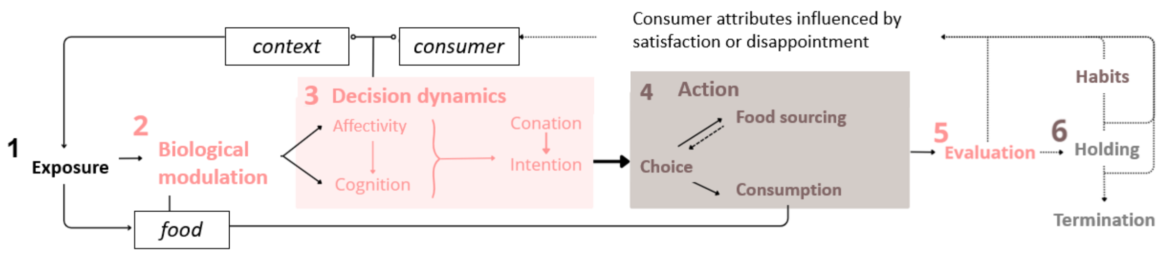

Figure 1: Conceptual framework of the food behavior modeling proposed for ConsomON (note that this is a preliminary version subject to change). The stages in pink are not directly observable. The stages in grey are part of the decision-making process with a feedback loop after the evaluation stage. The text boxes represent the components coming into play in the process.

The biological modulation stage encompasses all processes that can be influenced as a result of exposure and consumption. It involves the acquisition and transmission of information via sensory stimulation, as well as the regulation of physiological state. In the longer term, this modulation can lead to metabolic adaptation. This is followed by the decision-making process, which is structured in three sub-steps: affectivity, cognition, and conation. Affectivity and cognition contribute to the formation of an intention, which is then reinforced or modulated by conation—a process that encompasses motivations and influences, encouraging or inhibiting the next step: action.

Taking action results in food choices that relate either to consumption, i.e., eating the food, or to food sourcing, defined as all actions related to acquiring food, such as shopping, ordering at a restaurant, selecting products from a vending machine or picking mushrooms in the forest. A subsequent choice leading to consumption may then occur.

The choice evaluation stage corresponds to a metacognitive process. It involves comparing initial expectations with actual experience. This comparison creates a feedback loop that can affect subsequent decision-making. This mechanism can change certain consumer attributes, such as beliefs or perceptions (at the cognitive level), and generate feelings of satisfaction or disappointment.

Finally, the maintenance stage occurs when satisfaction is regularly achieved, or when the initial intention is particularly strong. Repeating one or more choices through feedback can alter the level of self-determination of motivations. This process can lead to the formation of a habit, which can then reshape the decision-making dynamic. Conversely, if the choices are not maintained, the termination stage occurs, marking the end of these behaviors.

3.2. Food Choice model implementation

Figure 2 shows the transposition of the theoretical conceptual model built from the literature analysis using the Process and Observation Ontology model and the PO²Manager software. This Java-based application includes a graphical user interface (GUI) designed to facilitate data entry in accordance with the PO² model (Data Manager part) and an ontology editor that enables the design and maintenance of domain ontologies built upon the PO² core model in OWL2 (Vocabulary Manager part).

The left-hand side of Figure 2 shows the tree view which allows the users to create the different concepts involved in a process, such as unit operations with their input and output components. The right-hand side of Figure 2 shows a process itinerary (shown as black nodes organized as sequences of steps) and input or output components (shown as red noes) in an interactive graph where the steps are linked together sequentially. Additionally, observations can be linked to the steps at which they were carried out (these steps are indicated by a green semicircle in the graph). The po2:Observation contains data tables with metadata for material and method descriptions as well as administrative information about the experiment (additional view not shown in the figure). PO²Manager also includes the vocabulary used to define the class instances according to the selected domain ontology (here, ConsomON), as shown at the bottom of the Figure 2 screenshot. The user can switch from the Data Manager part to the Vocabulary Manager part to access the concept definition and the ontology hierarchy view. Finally, the ontology and annotated datasets are made available through an online triple store.

According to the PO² model, the Consumer and the Food are the entities on which observations will be made, in a given Context, and are defined as po2:Component. A wide variety of contextual effects related to variables concerning the physical, social, and temporal environment, the intrinsic properties of foods, and variables characterizing the individual have been listed in the literature [24]. Context can be represented as a collection of po2: Attributes, which constitute the variables. Similarly, intrinsic or extrinsic characteristics related to Consumer or Food will be collected and hierarchized to form sub-classes of po2:Attribute. The po2:Scale class enables us to distinguish between different process target scales: i) food as a whole, ii) food categories, and iii) specific foods, and different observation target scales: i) anticipated (just before the observation), ii) immediate (at the time of observation), iii) memorized (recall from previous experience), or iv) projected (related to future choices).

The PO² core model uses the sosa:System concept, which allows us to define either an 'actuator' (an element or agent that 'performs the action', e.g., a consumer) or a 'sensor' (an element or agent that measures or observes, e.g., an ethologist). This model bears strong similarities to the C-OAR-SE model and the COMFOCUS ontology covering aspects such as individual raters, measures (attributes), food entities (targets), and specific contexts of data collection (micro-contexts).

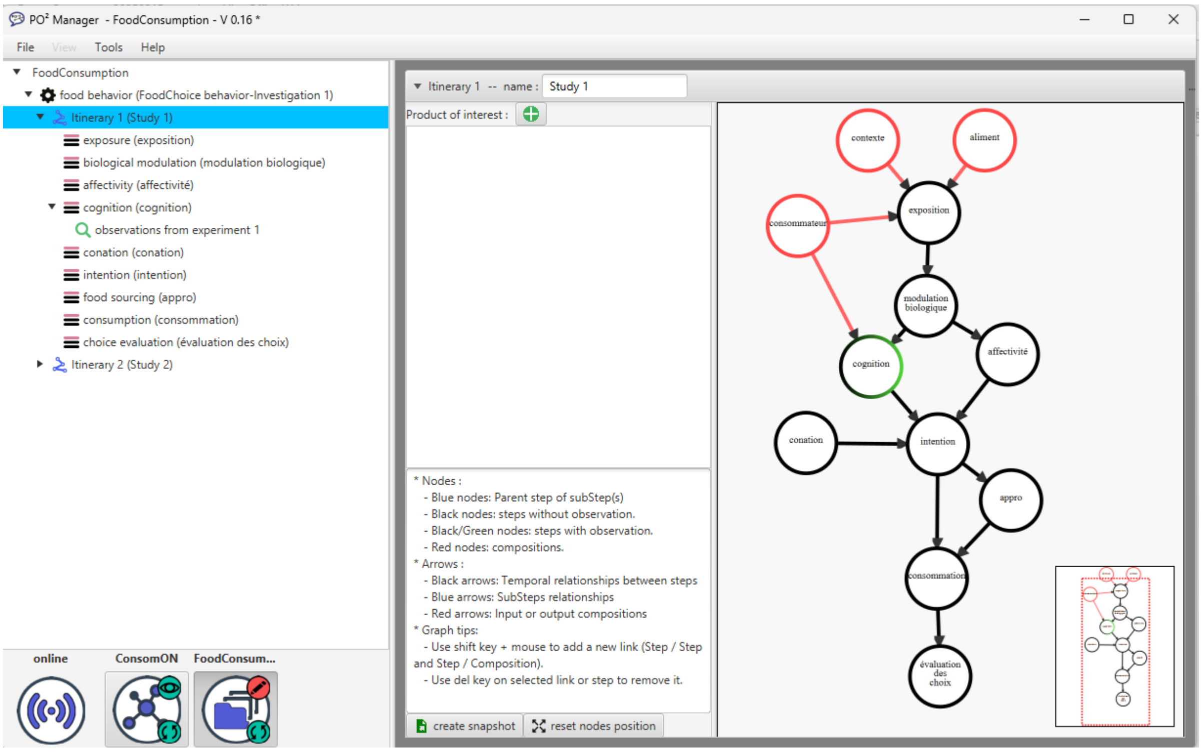

Figure 2: PO²Manager screenshot displaying a Food Consumption process implementation (note that this is a preliminary version subject to change). A red node is an input or output component (po2:Component), a black node is a step of the process (po2:Step), and a back/green node is a step that contains data tables (sosa:ObservationCollection).

3.3. Use case implementation

To specialize the hierarchy of PO² core concepts by using a bottom-up approach, we evaluated motivations through a case study in which consumers assessed their own motivational attributes. The questionnaire items of the single item FCQ were directly associated with the corresponding motivational attributes. By contrast, in the natural language questionnaire, the participants' responses were encoded using natural language processing techniques to extract lemmas associated with the motivational attributes of the FCQ, and new attributes were created when it was not possible, contributing to enrich the ontology.

Figure 3 shows the current vocabulary included in ConsomON. The hierarchies specialize the seven core concepts of the PO² model, namely po2:Process, po2:Component, po2:Scale, po2:Step, po2:Material (*i.e.*, sosa:System), po2:Method (*i.e.*, sosa:Procedure), po2:Attribute (*i.e.*, ssn/sosa:Property). Each owl:Class is represented by a skos:Concept, which allows us to manage multilingual labeling, synonymy, and textual notes and definition. Thanks to the use of the shared model PO², ConsomON will import the food hierarchy of TransformON, including the skos:exactMatch relations to the FoodEx2 groups, recently defined in a thesaurus in the SKOS format [25]. Alignment with FoodON food material hierarchy is also underway.

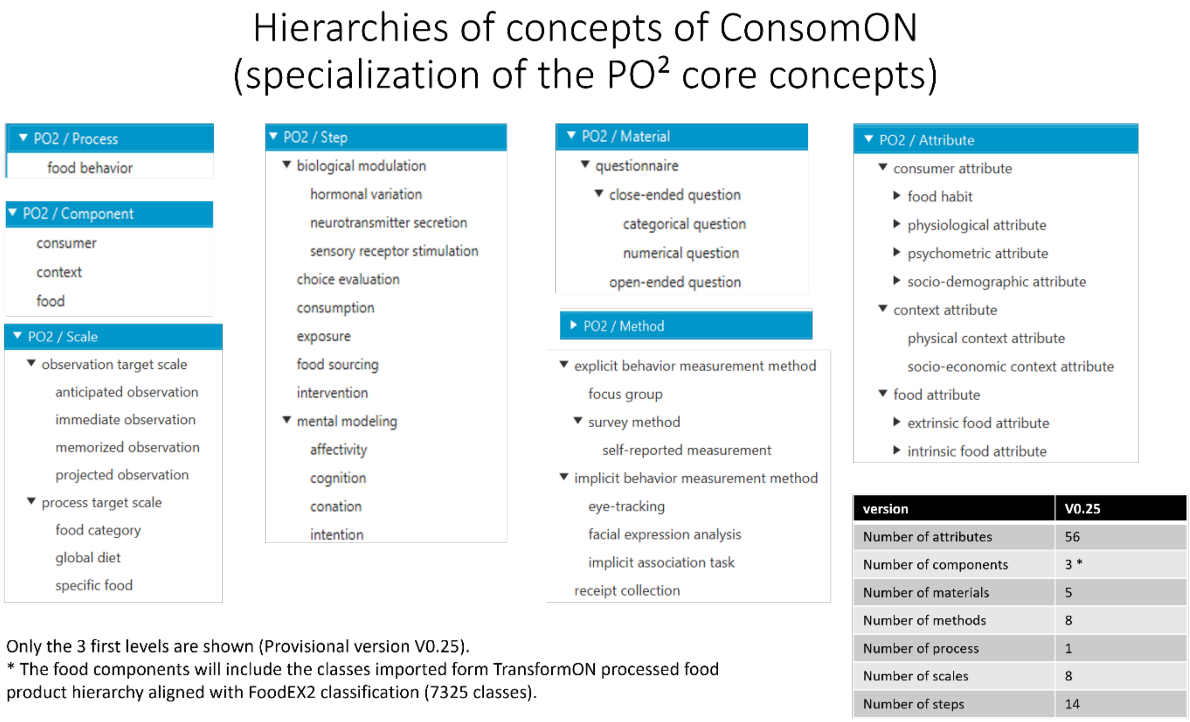

Figure 3: The hierarchies of concepts of ConsomON v0.25 specializing the seven 'core' concepts of the Process and Observation (PO²) generic model. Each skos:Concept represents an owl:Class.

3.4. Discussion

This paper describes a tentative modeling of food behavior based on a literature survey and an experimental study using two versions of the Food Choice Questionnaire. This is an initial proposal to structure data relating to the expression of motivations for consumption. The PO² model appears to be a good representation of the ConsomON conceptual model, as it enables us to visualize the various stages of food choice behavior and the entities involved in this process, namely the Consumer, Food, and Context. However, it still needs to be validated in more complex use cases. This will be done as part of the ConsoTexplorer project, which aims to explore consumers' representations, expectations, perceptions, and intentions through the development of a conversational agent and natural language processing techniques.

Although the proposed model bears some similarities to that of COMFOCUS, our approach differs fundamentally in terms of design. The COMFOCUS approach identified methods considered to be 'gold standards' and represented behaviors through values measured according to these methods. In the ConsomON ontology, however, we have focused on concepts related to consumption rather than the methods used to evaluate them. In practice, consumer science research methods are often adapted to meet the specific needs of studies, and many variations of methods exist to measure the same concepts, as illustrated by the presented case study.

Rather than bringing together a large number of experts from various disciplines at the specification stage, we have opted for an iterative and modular approach to ontology. We favor building and consolidating the ontology brick by brick, drawing on concrete case studies from projects at an early stage. This approach promotes reflexivity by encouraging reflection on both the data acquisition framework and the ontology's development. By adopting an agile approach, we aim to integrate ontology into software development projects designed to collect data on consumer food behaviors. This will facilitate the adoption of FAIR by-design practices. ConsomON will therefore be at the centre of the foodXPTools digital platform (https://foodxptools.hub.inrae.fr/) — a tool dedicated to studying food behaviors and intended for the various stakeholders of the multidisciplinary research infrastructure CALIS (https://calis.ir.inrae.fr/).

Ultimately, ConsomON aims to become a tool that helps structure data related to food consumer behavior. The ability to reuse the food branch of TransformON enhances interoperability. By offering a standardized vocabulary, ConsomON will foster communication and interdisciplinarity. This will facilitate the implementation of "data-driven" approaches, such as validating knowledge through meta-analysis, developing new data collection and analysis tools based on artificial intelligence, and constructing holistic models that integrate the various stages involved in making and maintaining food choices.

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Declaration on Generative AI

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