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An OWL-Based Ontology Model of Food Production and Distribution in Indonesian

Joko Purwanto [1)*], **Muhammad Abdul Muin** [2)], **Adlan Nugroho** [3)], **Kukuh Muhammad** [4)]
[1,2)] Software Engineering Technology Cilacap State Polytechnic,
[3, 4)] Informatic Engineering, Polytechnic State Cilacap
[1)]jokopurwanto@pnc,ac.id, [2)]abdulmuin@pnc.ac.id, [3)]adlannugroho@pnc.ac.id [4)]kukuhmuhammad@pnc.ac.id

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Abstract: Food security in Indonesia is influenced by the dynamics of production, distribution, and availability between regions. However, many existing information systems still rely on conventional data structures without semantic integration, which limits interoperability and hinders interregional analysis. To address this gap, this study developed an ontology model based on the Web Ontology Language (OWL) that formally represents the relationships between food production, commodity characteristics, distribution flows, food insecurity conditions, and geographical context. The ontology was built using Protégé through stages of literature review, official data collection from BPS, FAO, and the Ministry of Agriculture, conceptual model design, implementation, and evaluation. Conceptual validation was conducted through Focus Group Discussions (FGD) with food supply chain experts to ensure the suitability of the ontology structure and the actual conditions of the national food system. The technical evaluation involved consistency testing using the Pellet reasoner and Competency Question (CQ) testing through SPARQL queries to assess the ontology's ability to respond to essential information needs. The resulting ontology consists of five core classes (FoodProduction, FoodItem, FoodDistribution, FoodSecurityStatus, and GeographicRegion) which collectively represent the semantic structure of Indonesia's food supply chain. The evaluation results show that the ontology is structurally consistent and capable of producing outputs that are in line with CQ, including the retrieval of production-distribution information and the initial identification of commodity surpluses and deficits based on instance data. These findings indicate that the developed ontology provides a coherent semantic foundation for modeling food systems and has strong potential to support the development of knowledge-based food security management applications.

Keywords: Ontology; Food production; Food distribution; Food security; OWL

INTRODUCTION

Food security is a strategic issue that requires a technology-based approach to manage food production and distribution efficiently (Alshammari et al., 2022; FAO, 2023; Maharani & Puspasari, 2024; Putri Elfriede, 2022; Shen et al., 2022). Food security has become a global challenge with increasing population and climate change (FAO, 2022a, 2022b; United Nations, 2022) In Indonesia, there is a problem of overproduction in one region and shortages in another, indicating an imbalance in food distribution (Ruauw, 2015; Sarikaya, 2017; Suryana, 2014).

Conceptually, food security is a condition in which countries and individuals have adequate access to food, both in terms of quantity and quality, that is safe, diverse, nutritious, equitable, and affordable without conflicting with the religion, beliefs, and culture of the community, in order to support a healthy, active, and productive life in a sustainable manner (Indonesia, 2012). The stability and sustainability of food security are based on three main pillars, namely: (1) sufficient and evenly distributed food availability; (2) an effective and efficient food distribution system; and (3) diverse, nutritious, and balanced food consumption patterns. Food security is an issue of sustainable development, the environment, and trade, so that the implementation of sustainable food security development is related to all sectors of national development (Adrianus, 2019).

However, the food information systems currently in use are still oriented towards conventional data without a semantic model capable of understanding the complex interrelationships between production and distribution factors. Various government agencies manage data in different formats, resulting in fragmentation, inconsistency of terms, low interoperability, and limitations in cross-source data integration (Kollia et al., 2021; Masliani et al.,

*name of corresponding author

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2024; Pujilestari, 2024). These limitations have an impact on suboptimal analysis processes, making it difficult to make accurate and comprehensive data-driven decisions.

The ontology-based knowledge representation approach offers a promising alternative to overcome these challenges. Ontologies provide a formal structure that can be understood by machines to define entities in a domain, the relationships between entities, and the various constraints inherent in them (Purwanto et al., 2017; Putra et al., 2016). This semantic approach has been widely used to support interoperability, data integration, and rule-based reasoning mechanisms in various complex domains, including agriculture and food systems. By organizing knowledge into explicit conceptual structures, ontologies facilitate the alignment of heterogeneous data from various sources and enable smarter and more automated analysis processes.

A number of previous studies have applied ontological approaches in the context of agriculture, food processes, and supply chains. (Dooley et al., 2024) developed food process ontology requirements to model planned and unplanned processes in food systems, but the model did not include spatial aspects and cross-regional food distribution. In addition to Dooley, several other studies have also developed ontology models in relevant domains. (Defiyanti et al., 2022) developed OntVarRice to formalize knowledge about superior rice varieties in Indonesia, but this model focuses on production aspects and does not yet integrate distribution or food security. (Malik et al., 2021) developed FertOnt to formally model knowledge about fertilizers, but this ontology stands as a domain knowledge model without any connection to the food supply chain or distribution mechanisms. These studies show that existing ontology models are still partial and do not provide an integrated semantic representation that links production, commodity characteristics, distribution, and spatial conditions.

This study attempts to fill this gap by developing an OWL-based ontology model to represent the relationship between food production, distribution, commodities, geographical regions, and food security status in the Indonesian context. This ontology is designed not only as a knowledge representation structure, but also as a basis for rule-based reasoning and semantic queries to detect production-distribution imbalances and identify potential food insecurity. In addition, the development of this ontology involves a conceptual validation process by food supply chain experts and software and data engineering experts to ensure the model's suitability for field practices and national food security analysis needs.

LITERATURE REVIEW

Various studies have examined aspects of food production, distribution, and security using technological and semantic modeling approaches. emphasizes the importance of stock analysis in distribution systems to maintain a balance between food availability and demand in various regions. The study reveals the influence of storage capacity, consumption patterns, and logistical efficiency on supply stability. This historical data approach provides an important basis for understanding how distribution can be optimized to prevent food surpluses and shortages.

In the context of integrated information systems, (Gunawan et al., 2024) developed a model for real-time monitoring of food production, distribution, and consumption through a centralized data system. The study shows increased transparency and accelerated response to potential food insecurity. (Muliani et al., 2022) added a spatial perspective through mapping the dimensions of food security using Web GIS and the TOPSIS method. Spatial data integration has proven to be important in analyzing distribution patterns, accessibility, and regional food vulnerability levels. Meanwhile, (Syaifullah, 2013) shows that rice distribution inequality in East Java can trigger food instability even though regional production is sufficient, emphasizing that distribution is a critical component of food security.

The formulation of a multidimensional food security strategy is discussed by (Salasa, 2021), which covers aspects of production, distribution, access, and price stability. This approach emphasizes that food security cannot be observed from a single perspective, but requires the integration of various interrelated factors.

In the context of semantic technology, (Dooley et al., 2024) developed an OWL-based food process ontology that models the flow of production, processing, distribution, and consumption in a single integrated framework. The model provides a comprehensive end-to-end representation of the food process, but does not yet include food insecurity indicators or reasoning capabilities to detect supply imbalances.

On the distribution side, (Ameri et al., 2023) introduced the Supply Chain Traceability (SCT) Ontology, which was developed based on the Industrial Ontologies Foundry (IOF) and Basic Formal Ontology (BFO), giving it a strong formal structure and high interoperability. The SCT Ontology models important logistics events such as Custody Change Events, Sampling Events, and Observation Events, which are highly relevant for tracking food quality and safety throughout the supply chain.

On the production side, (Malik et al., 2021) developed FertOnt, which models knowledge about fertilizers, nutrient types, and application recommendations to produce optimal yields. In addition, (Defiyanti et al., 2022) developed OntVarRice, which represents knowledge about superior rice varieties in Indonesia, including pest resistance, yield potential, and other agronomic characteristics. Both ontologies emphasize the importance of a production knowledge base as part of national food security stability.

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On the other hand, (Dooley et al., 2024) discuss the need to develop a generic, standardized food process ontology that is compatible with the Open Biological and Biomedical Ontology (OBO) Foundry ecosystem. This research emphasizes the importance of modeling planned processes (e.g., mixing, freezing, boiling, shipping) and unplanned processes (e.g., natural fermentation) in the "farm-to-fork" food chain. Their approach prioritizes the use of Basic Formal Ontology (BFO) and Relation Ontology (RO) to maintain semantic coherence and reduce property complexity. This process ontology is not only relevant to the manufacturing industry and food laboratories, but also supports the needs of epidemiology (food outbreak tracking), nutritional analysis, and digital twin systems. The existence of a time dimension (time ontology)—such as start, end, and duration—is a crucial element in modeling the dynamics of food processes.

From a methodological perspective, the research by (Purwanto et al., 2017) and (Putra et al., 2016) provides important contributions in the application of OWL, ontology modeling techniques, and evaluation using reasoners and OntoQA. These studies show that formal ontology approaches can be effectively applied to complex domains and support the process of evaluating knowledge structures. Although not in the food domain, these studies strengthen the methodological foundations related to formal ontology development, ontology quality evaluation, and the use of reasoners to ensure model consistency—aspects that are also important parts of this study.

Table 1. Comparison of Previous Research and the Position of This Research

Research / Ontology	**Main Focus**	**Dimensions Covered**	**Strengths**	**Limitations / Remaining Gaps**	**Relevance to This Research**
(FM, 2009)	Food stock analysis based on historical data	Distribution, availability	Provides an important basis for understanding regional surpluses/deficits	Does not model knowledge structure; no semantics; no production–region integration	Reinforces the importance of food distribution aspects
(Gunawan et al., 2024)	Real-time monitoring of production–distribution–consumption	Production, distribution, consumption	High transparency and rapid response to vulnerabilities	Conventional data model; no reasoning; no ontology	Supports the urgency of data integration
(Muliani et al., 2022)	Spatial analysis of food security	GIS, multi-criteria, region	Strong spatial visualization	Does not model conceptual relationships; not integrative	Relevant to spatial aspects of the region
(Syaifullah, 2013)	Inequality in rice distribution	Production, consumption, distribution	Empirical evidence of food imbalance	Does not model commodities/semantic relations	Reinforces the importance of distribution representation
(Salasa, 2021)	Construction of national food security	Production, access, distribution, price stability	Multidimensional framework	No semantic model; does not support reasoning	Relevant for validating dimensions of security
(Dooley et al., 2024)	Ontology of the food process from production to consumption	Processes, food entities	End-to-end model based on OWL	No vulnerability indicators; no rule reasoning	Provides a basis for modeling the food chain's process
(Ameri et al., 2023)	Traceability and logistics	Distribution, logistics events, quality	Based on BFO & IOF; high interoperability	Does not model production knowledge; does not include vulnerability indicators	Relevant for distribution & traceability design
(Malik et al., 2021)	Fertilizer and agricultural	Production, agronomy	Details of critical input knowledge	Not related to distribution/vulnerability	Strengthening the production side

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	input knowledge				
(Defiyanti et al., 2022)	Superior Indonesian rice varieties	Production, agronomy	Strong in agronomy and CQ	Not connected to distribution/logistics	Supports commodity production structure
(Purwanto et al., 2017)	OWL-based digital library ontology	Methodology, ontology evaluation	Provides a basis for reasoner & OntoQA evaluation	Different domains, but rich in methodology	Strengthening the OWL approach and evaluation
This research	Indonesian food ontology based on production–distribution–on of regions + reasoning	Production, distribution, region, resilience indicators	Comprehensive integration + SWRL + SPARQL + reasoning	Has not yet combined top-level ontology (e.g., BFO) → area of further development of	Filling the gap in ontology-based food domain integration

METHOD

This study uses a semantic-based ontology development approach utilizing Ontology Web Language (OWL) through Protégé software. Ontology was chosen because it is capable of representing complex relationships between entities in the food supply chain and provides a reasoning mechanism to generate new knowledge that supports food security management (Ameri et al., 2023; Dooley et al., 2024; Kollia et al., 2021). The development process was carried out in five stages: literature study, data collection, model design, implementation and design of inference rules, and reasoning-based testing and competency questions.

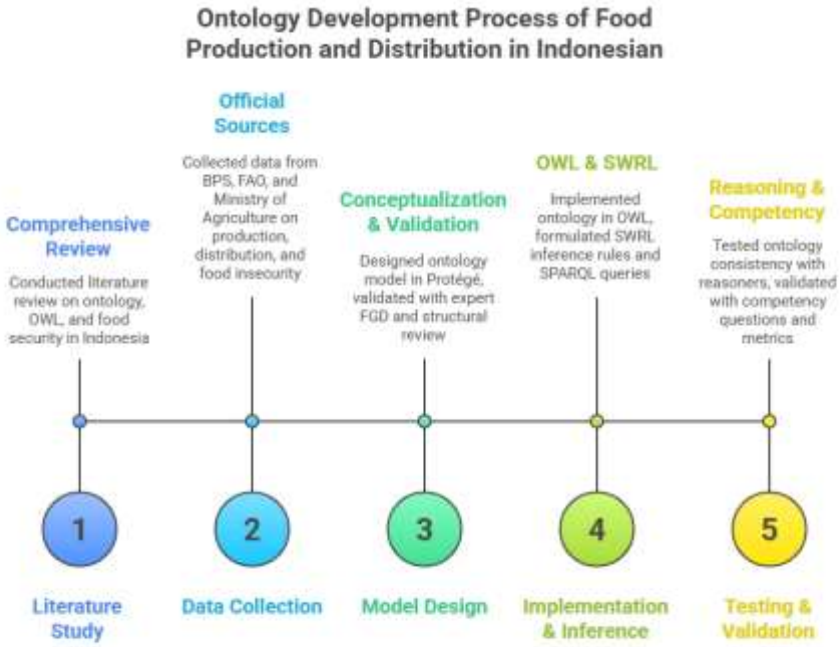

Figure 1. Stages of Designing the Food Production and Distribution Ontology Model

Referring to Figure 1 above, ghe first stage is a literature study to gain a comprehensive understanding of ontology, OWL, and strategic issues of food security in Indonesia. The literature reviewed includes food stock analysis (FM, 2009), spatial mapping of food security (Muliani et al., 2022), strategic dimensions of food security (Salasa, 2021), and interregional distribution analysis (Syaifullah, 2013). In addition, specific ontology studies such as Supply Chain Traceability (SCT) Ontology (Ameri et al., 2023), OntVarRice (Defiyanti et al., 2022), and FertOnt (Malik et al., 2021) were used to identify methodological gaps. The review results show that there is no

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ontology model that comprehensively represents production, distribution, and food insecurity indicators in a single formal scheme.

The second stage is data collection through official sources such as the Central Statistics Agency (BPS), the Food and Agriculture Organization (FAO, 2022a, 2022b, 2023), and the Ministry of Agriculture. The data collected includes production volume, distribution patterns, commodity types, areas of origin and distribution destinations, and food insecurity indicators. This data is used as the basis for forming classes, property objects, property data, and individuals in ontology.

The third stage was the design of an ontology model in the Protégé environment. Based on empirical data and literature findings, a conceptual representation was developed that included key entities such as FoodProduction, FoodItem, FoodDistribution, GeographicRegion, and FoodSecurityStatus. The design was conceptually validated through a Focus Group Discussion (FGD) with a food supply chain expert from a state university. The FGD was conducted using semi-structured discussions with concept checking instruments, so that experts could explain the components of the supply chain, the structure of the flow of goods, and the important attributes of production and distribution. The expert's input was used to clarify the origin–destination modeling, distribution channels, and institutions involved in food distribution. Once the model reached approximately 80% completion, a structural review was conducted by software and data engineering experts to ensure the integrity of relationships, the accuracy of class hierarchies, and the consistency of semantic definitions. The model was revised based on the input provided until the ontology structure reached a stable level.

The fourth stage is the formal implementation of ontology in OWL and the formulation of SWRL-based inference rules and SPARQL. Ontology is executed in Protégé and inference rules are added to detect imbalances in production and distribution. One of the SWRL rules used is as follows:

```
FoodProduction(?p) ^ ProductionVolume(?p, ?pv) ^
FoodDistribution(?d) ^ DistributionVolume(?d, ?dv) ^
produces(?p, ?item) ^ distributes(?d, ?item) ^
located_in(?p, ?r1) ^ hasDestinationRegion(?d, ?r2) ^
swrlb:lessThan(?pv, ?dv)
→ ImbalanceRegion(?r2)
```

This rule maps the destination distribution area (`?r2`) as `ImbalanceRegion` when the distribution volume exceeds the production volume of the source area. In addition to SWRL, SPARQL queries are designed for quantitative analysis of production–distribution differences, one of which is:

```
PREFIX ont: <http://www.example.org/ontopangan#>
SELECT ?region ?commodity
       (SUM(?prodVol) AS ?Produced)
       (SUM(?distVol) AS ?Distributed)
       (IF(SUM(?prodVol) > SUM(?distVol), "Surplus", "Deficit") AS ?Status)
WHERE {
  OPTIONAL {
    ?prod a ont:FoodProduction ;
          ont:located_in ?region ;
          ont:produces ?commodity ;
          ont:ProductionVolume ?prodVol .
    FILTER regex(str(?prodVol), "^[0-9.]+$")
  }
  OPTIONAL {
    ?dist a ont:FoodDistribution ;
          ont:hasDestinationRegion ?region ;
          ont:distributes ?commodity ;
          ont:DistributionVolume ?distVol .
    FILTER regex(str(?distVol), "^[0-9.]+$")
  }
}
GROUP BY ?region ?commodity
ORDER BY ?region
```

This query is used to identify regions experiencing commodity deficits based on individual data.

The fifth stage is testing and validation based on reasoning and competency questions (CQ). Consistency testing is performed using the HermiT and Pellet reasoners to ensure there are no semantic conflicts in the definitions of classes, relations, or individuals. Next, functional testing is carried out based on CQ scenarios, which include key questions such as: (1) commodities produced per region, (2) distribution objectives per commodity,

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(3) comparison of production and distribution volumes, (4) identification of deficit regions, and (5) determination of food insecurity indicators. Each CQ is answered through the execution of SPARQL queries, and the reasoning results are evaluated for their suitability with empirical data. In addition, Ontology Metrics are used to assess the completeness of the model structure through the number of classes, object properties, data properties, and individuals. The combination of reasoning consistency, successful answering of CQs, and model metric completeness is used as the basis for ontology validity.

RESULT

This study resulted in an ontology design that represents the interconnection between production, distribution, and food security conditions. This ontology was constructed with five main classes, namely FoodProduction, FoodItem, FoodDistribution, FoodSecurityStatus, and GeographicRegion. Each class is equipped with specific attributes that describe the characteristics of the food domain, as well as relationships that connect entities in accordance with the actual conditions of the food supply chain.

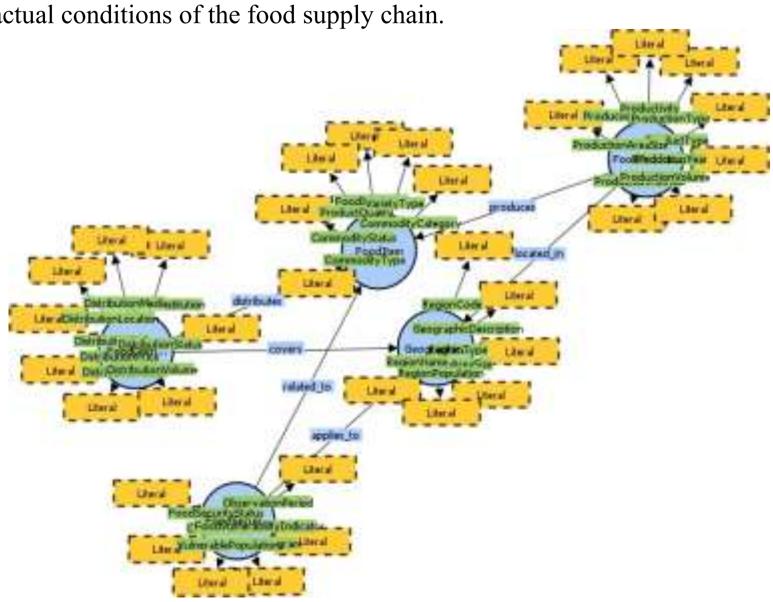

Figure 2. Food Production and Distribution Ontology Model

Referring to Figure 2 above, the FoodProduction class is designed to represent aspects of food production, including attributes such as commodity type, volume, production area, methods used, land area, productivity, and production season. This information allows the model to describe variations in production capacity and agricultural practices in the field. Meanwhile, the FoodItem class is used to describe the characteristics of the food commodities produced. The attributes defined include commodity name, category, quality, product type, variety, and availability status. Thus, the model can distinguish between commodities based on their properties and quality.

The next class is FoodDistribution, which emphasizes the mechanism of food distribution from producers to consumers. The attributes used include distribution channels, location, institutions involved, volume, delivery media, price, period, and distribution status. The existence of this class enables analysis of distribution channels, distribution efficiency, and price dynamics between regions. Furthermore, the FoodSecurityStatus class represents the food security conditions in a region. The attributes used include the observation area, vulnerability indicators, food security status, observation period, contributing factors, number of vulnerable people, and intervention programs. With this information, the model is able to comprehensively describe food insecurity conditions while linking them to contributing factors and mitigation efforts.

The GeographicRegion class acts as a link between all data and spatial context. Attributes include region name, region code, region type, area size, population, and geographical description. With this geographical dimension, all data on production, distribution, and food security status can be traced spatially and linked to specific administrative regions.

In addition to attributes, this ontology also includes relationships between classes. The relationship FoodProduction produces → FoodItem indicates that production results in specific food commodities. The relationship FoodProduction located_in → GeographicRegion indicates the location of production in a region. The relationships FoodDistribution distributes → FoodItem and FoodDistribution covers → GeographicRegion explain the connection between food commodities and distribution channels and their coverage areas. Meanwhile, the relationship FoodSecurityStatus applies_to → GeographicRegion confirms that food security status applies to

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a specific region, with the possibility of an optional relationship FoodSecurityStatus related_to → FoodItem that links security status to specific commodities.

This structure allows the ontology model to describe the overall relationship between production, distribution, and food security. The FoodProduction and FoodItem classes focus on upstream aspects such as commodities and production, while FoodDistribution maps downstream aspects such as food distribution. The FoodSecurityStatus class connects all these activities with food security conditions, and GeographicRegion ensures the spatial relevance of all information. With this design, the model can be used to analyze imbalances between production and distribution, identify food-insecure areas, and support data-driven decision making.

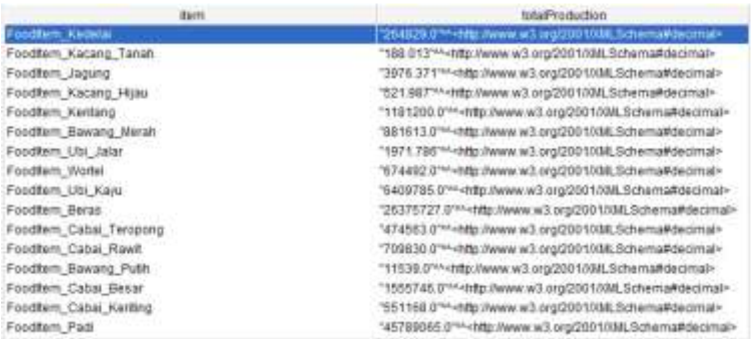
To ensure the accuracy of the structure built, a consistency test was conducted using the Pellet reasoner and the debugger feature in the Protégé software. The test results show that all classes, attributes, and relations designed are consistent without any hierarchy or definition conflicts. Figure 3 shows the results of this consistency test, which also reinforces the validity of the ontology design as a formal representation of the food supply chain.

Figure 3. Consistency Test of the Food Production and Distribution Ontology Model

The evaluation of the food security ontology was conducted through three main approaches: rule-based reasoning, competency questions (CQ) testing using SPARQL, and structural metrics analysis of the ontology. All three were used to ensure that the ontology not only had a sound conceptual structure but was also capable of valid inferences and functionally answering domain questions. All tests were conducted on 3,535 individuals representing food production entities, distribution entities, administrative regions, and food security conditions in Indonesia.

SWRL rule-based reasoning demonstrates that the ontology model is capable of automatically identifying regions experiencing food surpluses and deficits. The defined surplus-distribution rules produce consistent inferences across instance data. For example, in West Java, the reasoner classifies commodities such as paddy, rice, cayenne pepper, large chili pepper, carrots, potatoes, and cassava as SurplusFoodItem because the production value of these commodities far exceeds the incoming distribution. Conversely, regions such as DKI Jakarta, Maluku, Lampung, East Kalimantan, Central Sulawesi, and South Sumatra are identified as DeficitRegions for certain commodities, particularly shallots and rice. These inferences emerge based on an automatic comparison between ProductionVolume and DistributionVolume values , without manual intervention from the researcher, thus demonstrating consistent reasoning capabilities.

The ontology's ability to answer competency questions was tested through four CQs. SPARQL results for CQ1 indicate that West Java is one of the regions with the highest food production levels in Indonesia. Commodities produced include 16 food items, with rice reaching 45.8 million tons and rice around 26.3 million tons. In addition, horticultural commodities such as large chilies (1.55 million tons), carrots (674 thousand tons), and shallots (881 thousand tons) also dominate production. The following figure 4 presents some of the CQ1 results for commodities with the highest volumes.



item	totalProduction
FoodItem_Kedelai	"264829.0"^^<http://www.w3.org/2001/XMLSchema#decimal>
FoodItem_Kacang_Tanah	"188.013"^^<http://www.w3.org/2001/XMLSchema#decimal>
FoodItem_Jagung	"3976.371"^^<http://www.w3.org/2001/XMLSchema#decimal>
FoodItem_Kacang_Hijau	"521.987"^^<http://www.w3.org/2001/XMLSchema#decimal>
FoodItem_Kentang	"1181200.0"^^<http://www.w3.org/2001/XMLSchema#decimal>
FoodItem_Bawang_Merah	"881613.0"^^<http://www.w3.org/2001/XMLSchema#decimal>
FoodItem_Ubi_Jalar	"1971.786"^^<http://www.w3.org/2001/XMLSchema#decimal>
FoodItem_Wortel	"674492.0"^^<http://www.w3.org/2001/XMLSchema#decimal>
FoodItem_Ubi_Kayu	"6409785.0"^^<http://www.w3.org/2001/XMLSchema#decimal>
FoodItem_Beras	"26375727.0"^^<http://www.w3.org/2001/XMLSchema#decimal>
FoodItem_Cabai_Teropong	"474563.0"^^<http://www.w3.org/2001/XMLSchema#decimal>
FoodItem_Cabai_Rawit	"709830.0"^^<http://www.w3.org/2001/XMLSchema#decimal>
FoodItem_Bawang_Putih	"11539.0"^^<http://www.w3.org/2001/XMLSchema#decimal>
FoodItem_Cabai_Besar	"1555746.0"^^<http://www.w3.org/2001/XMLSchema#decimal>
FoodItem_Cabai_Keriting	"551168.0"^^<http://www.w3.org/2001/XMLSchema#decimal>
FoodItem_Padi	"45789065.0"^^<http://www.w3.org/2001/XMLSchema#decimal>

Figure 4. Query Results CQ1 – Food Production in West Java

The CQ2 test illustrates the pattern of food commodity inflows into West Java through distribution channels. The results show nine commodities entering, including rice (198,850 tons), large red chilies (142,440 tons), soybeans (50,000 tons), and cooking oil (34,095 tons). These inflows indicate that although West Java is a major

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food producer, the province still receives a limited supply of certain commodities. The following figure 5 displays some of the CQ2 results.

item	totalDistribution
FoodItem_Cabai_Merah_Besar	"142440.0"^^<http://www.w3.org/2001/XMLSchema#decimal>
FoodItem_Beras	"198850.0"^^<http://www.w3.org/2001/XMLSchema#decimal>
FoodItem_Cabai_Merah_Keriting	"6175.0"^^<http://www.w3.org/2001/XMLSchema#decimal>
FoodItem_Bawang_Putih	"950.0"^^<http://www.w3.org/2001/XMLSchema#decimal>
FoodItem_Minyak_Goreng	"34095.0"^^<http://www.w3.org/2001/XMLSchema#decimal>
FoodItem_Bawang_Merah	"1750.0"^^<http://www.w3.org/2001/XMLSchema#decimal>
FoodItem_Komoditas_Lainnya	"3700.0"^^<http://www.w3.org/2001/XMLSchema#decimal>
FoodItem_Telur_Ayam_Ras	"2340.0"^^<http://www.w3.org/2001/XMLSchema#decimal>
FoodItem_Gula	"680.0"^^<http://www.w3.org/2001/XMLSchema#decimal>
FoodItem_Kedelai	"50000.0"^^<http://www.w3.org/2001/XMLSchema#decimal>

Figure 5. Query Results CQ2 – Distribution of Entrances to West Java

The CQ3 results show the difference between production and distribution for each commodity. Consistently, all commodities produced in West Java show a positive difference. Therefore, the province does not experience a deficit in any of the commodities analyzed. The largest surplus was found in rice, with a difference of 45.7 million tons, followed by rice (26.1 million tons), cassava (6.4 million tons), and large chili peppers (1.55 million tons). This pattern confirms the reasoning results that identified West Java as a food surplus region.

The CQ4 results mapped regions experiencing food deficits based on a comparison of incoming distribution and local production. SPARQL identified several deficit areas, particularly for shallots and rice. DKI Jakarta showed a shallot deficit of 18,484 tons and a rice deficit of 2,490 tons. Similar trends occurred in East Kalimantan, Lampung, and South Sumatra for shallots, and in Maluku and Central Sulawesi for rice. This information demonstrates how ontology can be used to support data-driven decision-making at the national or regional level.

In addition to CQ testing, the ontology's ability to support scenario simulations was tested through two case studies. The first scenario simulated a rice surplus at the national level. Through reasoning, the ontology identified surplus regions such as West Java, Central Java, East Java, and South Sulawesi. Conversely, regions such as East Nusa Tenggara, Maluku, and West Papua were detected as deficit regions. The second scenario evaluated the condition of shallots, which showed deficits in several regions such as DKI Jakarta, East Kalimantan, Lampung, and South Sumatra. These two simulations demonstrated the ontology's ability to function as a predictive analysis tool that supports food availability mapping.

To assess the ontology structure, a metrics analysis was performed using the Ontology Metrics feature in Protégé. The ontology consists of 37,512 axioms, including 32,272 logical axioms, 3,597 declaration axioms, 5 classes, 6 object properties, 36 data properties, 18 annotation properties, and a total of 3,535 individuals. The large number of logical axioms indicates a sufficient level of semantic richness, while the large number of individuals ensures that reasoning and CQ tests are conducted in an environment that reflects real data. Thus, the metrics indicate that the ontology has sufficient complexity to support the representation of the food domain, while remaining efficient for reasoning.

Overall, the evaluation results indicate that the developed ontology is capable of meeting the needs of food supply chain knowledge representation, generating accurate inferences, and comprehensively answering domain questions. The integration of reasoning, SPARQL, and metric analysis provides a comprehensive picture of the ontology's performance, both structurally and functionally.

DISCUSSIONS

The results of the study indicate that the developed ontology is capable of representing the systemic relationship between food production, interregional distribution, and food security conditions in an integrated manner. This representation not only includes quantitative attributes such as production volume and distribution, but also links them to spatial dimensions through the GeographicRegion class and vulnerability indicators through the FoodSecurityStatus class. This capability enables reasoning-based analysis to identify surpluses, deficits, and distribution patterns that have the potential to cause food imbalances, as demonstrated by scenario simulation results using SPARQL and SWRL rules.

Compared to the research of (Dooley et al., 2024), which comprehensively modeled food process flows but was still limited to process representation without a numerical inference mechanism, this ontology offers the added value of integrating production-distribution data that can be analyzed quantitatively. This approach broadens the modeling scope by linking process information with quantitative data relevant for decision-making. Furthermore, this research complements the contribution of the SCT Ontology by (Ameri et al., 2023), which emphasized distribution traceability through an event - based approach. The SCT Ontology provides a conceptual foundation for tracking changes in product ownership and quality during distribution, but does not include production aspects or food security indicators. The model developed in this research bridges these two domains by unifying the dimensions of upstream production and downstream distribution within a single, coherent ontological framework.

*name of corresponding author

On the upstream side, this ontology also extends domain-specific approaches such as OntVarRice (Defiyanti et al., 2022) and FertOnt (Malik et al., 2021), which model agronomic factors such as crop varieties and fertilization. While both studies provide a detailed knowledge framework for production factors, neither provides a mechanism for linking this agronomic information to interregional distribution dynamics. The integration offered in this study allows for a more holistic analysis, for example, of how production characteristics in a region impact distribution flows and potential food insecurity.

Competency questions (CQ)-based scenario testing demonstrated the ontology's ability to answer fundamental questions in food management. CQ1 and CQ2 successfully displayed production and distribution volumes for each commodity in a specific region. CQ3 demonstrated the ontology's ability to calculate the difference between production and distribution, thereby automatically detecting surpluses and deficits. CQ4 was even able to identify regions with significant deficits, such as Jakarta, Lampung, Maluku, Central Sulawesi, and East Kalimantan. These results confirm that the ontology's structure enables reasoning relevant to the analytical needs of the food sector.

In practice, this model has the potential to be used as a key component in decision support systems for government agencies, such as Bappenas, the Ministry of Agriculture, and local governments. Ontology-based representation enables cross-data source integration, interoperability, and the expansion of knowledge structures without requiring changes to the overall storage architecture. Compared with relational database models, ontologies offer advantages in semantic flexibility and automated inference capabilities to discover relationships not explicitly stated in the data. This is particularly relevant in the context of a dynamic and multidimensional national food system.

However, this study has several limitations that require attention. First, the data coverage is still at the provincial level, thus not reflecting sub-regional variations that may be more relevant for local food vulnerability analysis. Second, the indicators used for the FoodSecurityStatus class are still limited and do not cover all pillars of food security, particularly access and stability. Third, the complexity of SWRL rules will increase if the data coverage is expanded to more regions and commodities, necessitating a modularization strategy or integration with an external rule engine. Fourth, the production and distribution data used are still static and do not reflect seasonal or annual dynamics that could potentially influence inference results.

Nevertheless, the findings of this study indicate that the developed ontology is capable of capturing key relationships within the Indonesian food system and providing a reasoning-based analytical mechanism relevant to national food planning needs. With further development through integration of Web GIS-based spatial data, the addition of vulnerability indicators, and real-time data updates from government information systems, this model has the potential to develop into an adaptive and comprehensive semantic platform to support food security policies.

CONCLUSION

This research has successfully developed an ontology model based on Web Ontology Language (OWL) to represent relationships between entities in the food production and distribution system in Indonesia. The ontology consists of five main classes (FoodProduction, FoodItem, FoodDistribution, FoodSecurityStatus, and GeographicRegion) connected through object relationships designed to reflect the actual conditions in the food supply chain. Testing results using reasoners and scenario simulations based on competency questions indicate that this model is semantically consistent, capable of handling analytical queries, and can identify production-distribution imbalances and regions experiencing food deficits. Thus, this ontology has the potential to become the foundation of an adaptive, knowledge-based food security management system and can support more structured and data-driven decision-making.

Despite its significant contribution, this research still has several limitations that require attention. First, the instance data used is still limited to a specific level of aggregation and does not cover more detailed spatial variations. Second, the indicators in the FoodSecurityStatus class do not fully represent all pillars of food security, particularly the access and stability aspects, which require additional data integration. Third, this model has not been implemented in an operational system and therefore cannot be evaluated in terms of user performance or cross-platform integration. Furthermore, the complexity of SWRL rules is expected to increase as data coverage and regions expand, necessitating a modularization strategy or integration with an external rule engine .

As a further development direction, this ontology model has the potential to be expanded through the integration of real-time and spatial data based on Web GIS to support more precise food insecurity analysis. It is also necessary to add more comprehensive food security indicators, including dimensions of consumption, access, and price stability. Implementing the ontology into a Semantic Web-based food security information system is also an important step in assessing the effectiveness and scalability of the model in an operational context. With further development, this ontology is expected to become a core component of a national food security management platform that is more integrated and responsive to the dynamics of changing food conditions.

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