

# Design and Implementation of a Formal Computational Ontology Model for Indigenous Agricultural Knowledge Management

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## Abstract

Around the world, policymakers, agricultural experts, researchers, and the general public are increasingly addressing challenges related to the cultivation, quality, availability, preservation, and regulation of Indigenous Vegetables (IVs). This study examined the concepts, cultivation practices, and planting processes of selected indigenous vegetables, and proceeded to design, implement, and validate a formal ontology model. Data were collected through document reviews, interactive discussions, and field observations involving individuals with extensive knowledge of indigenous agriculture in Southwestern Nigeria. The formal ontology model was developed using First-Order Logic and Semantic Networks, integrated with Description Logics (DLs). The model was implemented using Python 3.9.1 and SQL with SQLite3. Validation was conducted using a Proof-of-Concept (PoC) approach to assess the model's accuracy and consistency. Result showed that precision and recall are increased averagely from 83% and 92% of accuracy and completeness respectively, which identify the ontology-based search more efficient than the conventional search about 9 and 64 times more. The study resulted in the creation of the Yorùbá Indigenous Vegetable Ontology (YIVO). The concepts and processes within YIV were analyzed based on the collected data, and consistency checks confirmed that the ontology contained no contradictory assertions. The study concluded that the practical construction and validation of the ontology through conceptual modeling, query retrieval, proof-of-concept testing, and visualization demonstrated that knowledge of Yoruba Indigenous Vegetables can be formalized and effectively represented as computational artifacts

**Key words:** *Ontology, Indigenous, Vegetable, Computational and Model,*

## **1.0 INTRODUCTION**

Agricultural work is inherently complex, requiring farmers to consider multiple factors such as weather, seasonal cycles, market demand, and plant growth stages when planning production. Additionally, the practices and behaviors of both farmers and consumers are evolving, with increasing attention to ecological and economic sustainability. Following World War II, monoculture farming and extensive use of chemical inputs were widely promoted, but these practices led to soil degradation and chemical contamination of crops (Isbell et al., 2017).

In recent years, farmers have increasingly adopted agroecological practices, which design production systems based on the natural functions of agroecosystems. Crop diversity is a central element of this approach. Studies have shown that crop diversity, both spatially and temporally, (i) improves risk management under fluctuating weather and economic conditions, (ii) provides a natural defense against pests and diseases, and (iii) enhances agroecosystem stability and resilience (Paut et al., 2019).

Vegetable farmers often diversify their crops by growing multiple varieties on the same plot throughout the season. Crop diversification and rotation help increase income and yields while improving farm sustainability against pests and adverse climatic events. Effective agricultural planning requires farmers to consider both annual and multi-year production strategies, often relying on their experience from previous cycles (Darnala et al., 2023).

To support farmers in planning and monitoring decisions, Crop Planning and Production Process Ontology (C3PO) has been developed by various researchers. C3PO provides a structured representation of agricultural knowledge and data to facilitate diversified crop production.

## **1.2 Statement of Research Problem**

Knowledge about Indigenous Vegetable (IV) has been mainly observed, practised and communicated without paying adequate attention to how its knowledge can be standardized and formalized. Unfortunately, those works generates an epistemological gap since there is a lack of a technique for characterizing concepts and there are conceptual and terminological ambiguities that are inconsistent with how they are used in the indigenous vegetable worldview

Formalization and standardization are prerequisites to the development of computing artefacts. The need for computing artefacts about IV emerges in the context of the development of software for agricultural decision support system. The necessity for formal representation and digital documentation of this heritage arises in the context of contemporary global Information and Communication Technologies (ICTs). Accordingly, this study aims to develop a formal computational ontology model to manage indigenous agricultural knowledge, specifically focusing on vegetable species and their production.

## **1.3 Objective of the Study**

The specific objectives are;

1. To elicit knowledge of Yorùbá indigenous vegetable production from domain expert;
2. To design an ontology model for the knowledge elicited in (1)
3. To implement the ontology model designed in (2); and
4. To validate the ontology model implemented in (3).

## **2.0 LITERATURE REVIEW**

### **2.1 Introduction**

A comprehensive review of related studies on the design and implementation of ontologies across different aspects and levels of the agricultural

domain is provided. A detailed review of some ontology development methodologies would also be given to situate the research methodology within the related past researches. The background information on Yorùbá agricultural heritage, their representation concepts and classification would be presented.

Vegetables are parts of plants consumed by humans or other animals as food. Traditionally, the term refers broadly to all edible plant matter, including flowers, fruits, stems, leaves, roots, and seeds. In culinary and cultural contexts, the definition can be more selective, often excluding certain fruits, flowers, nuts, and cereal grains, while including savory fruits such as tomatoes and courgettes, flowers like broccoli, and seeds such as pulses (Swedenborg, 2023).

The term “vegetable” first appeared in English in the early 15th century, originating from Old French and initially applied to all plants; this broader meaning is still used in biological contexts (Swedenborg, 2023). It derives from the Medieval Latin *vegetabilis*, meaning “growing, flourishing,” which evolved from a Late Latin sense of “to be enlivening or quickening.” The meaning of “vegetable” as a plant grown for food became established in the 18th century (Ayto, 2013). By 1767, it specifically referred to a “plant cultivated for food, an edible herb or root.” The abbreviated slang term “veggie” emerged in 1955. As an adjective, “vegetable” is used in scientific and technical contexts to describe anything plant-related, whether edible or not—for example, vegetable matter, vegetable kingdom, or vegetable origin (Swedenborg, 2023).

Historically, the wealthy had access to a varied diet including meat, vegetables, and fruits, whereas the poor relied largely on staples such as rice, rye, barley, wheat, millet, or maize. Vegetables supplemented these diets, providing nutritional and culinary variety. For instance, the Aztecs in Central America based their diet on maize and supplemented it with tomatoes, avocados, beans, peppers, pumpkins, squashes, peanuts, and amaranth seeds. In Peru, the Incas

consumed maize in the lowlands and potatoes at higher altitudes, also incorporating quinoa seeds, peppers, tomatoes, and avocados into their diet (Lambert, 2015).

## 2.2 Stage of Vegetable Production

### (i) Cultivation

Vegetables have been an integral part of the human diet for centuries, serving as staple foods in some cases and as complementary foods that add flavor and essential nutrients. While some vegetables are perennials, most are annuals or biennials harvested within a year of planting. Regardless of the cultivation system, the process generally involves preparing the soil by loosening it, removing or burying weeds, and adding organic manures or fertilizers; sowing seeds or planting young seedlings; tending the crop to reduce weed competition, control pests, and provide adequate water; and finally harvesting, sorting, storing, marketing, or consuming the produce fresh (Brickell, 2022).

### (ii) Harvesting

Harvesting separates vegetables from their water and nutrient sources, causing continued moisture loss, particularly evident in leafy greens. For root vegetables, harvesting at full maturity improves storage life, though they can also be left in the ground for gradual harvesting. Careful handling during harvesting is essential to minimize damage and bruising (Dixie, 2015).

### (iii) Storage

Proper post-harvest storage is vital, as a significant proportion of vegetables and perishable foods up to 30–50% in developing countries can be lost due to spoilage from moisture, molds, microorganisms, or pests. Storage may be short-term or long-term. Most vegetables are perishable, with short-term storage allowing marketing flexibility. Leafy vegetables lose moisture and vitamin C quickly during storage, whereas crops like potatoes and onions have longer shelf life, enabling sales at more profitable times. If refrigeration is unavailable,

priority should be given to high-quality produce, maintaining humidity, and keeping the crops shaded (Garg, Prakash & Garg, 2020; Dixie, 2015).

#### **(iv) Preservation**

The goal of vegetable preservation is to extend their usability for consumption or marketing, maintaining maximum palatability and nutritional value. Post-harvest deterioration is primarily due to enzymatic activity and microbial spoilage. Common preservation methods include canning and freezing, which generally maintain nutrient levels comparable to fresh produce, including carotenoids, vitamin E, minerals, and dietary fiber (Rickman, Bruhn & Barrett, 2017). Freezing at below  $-10^{\circ}\text{C}$  preserves vegetables short-term, while  $-18^{\circ}\text{C}$  is needed for long-term storage. After thawing, vegetables should be used immediately to prevent microbial growth (Hui et al., 2023). Traditional sun-drying of crops like tomatoes, mushrooms, and beans faces challenges such as slow drying, contamination, and pest attack, which can be mitigated using solar-powered dryers. Dried produce must be stored in conditions that prevent moisture reabsorption (Garg & Prakash, 2020).

#### **(v) Diseases and Control Methods**

Insect pests are a major cause of global vegetable yield loss, accounting for an estimated 8.7% of production losses. In Nigeria, pest damage significantly limits vegetable production and contributes to poor-quality yields (Aderolu, Omoloye & Okelana, 2013). Vegetable farmers use a variety of chemical and non-chemical methods for pest management, including cultural practices, resistant varieties, synthetic insecticides, botanical pesticides, and conservation of natural enemies. Integrated Pest Management (IPM) promotes the use of environmentally sustainable techniques to keep pest populations below harmful levels, reducing reliance on synthetic chemicals, minimizing environmental pollution, and lowering risks to consumers and farm workers

#### **Benefits of Yorùbá Indigenous Vegetables**

Nigeria is endowed with a wide variety of vegetables, which are not only consumed as food but also valued for their medicinal properties. Several indigenous vegetables in the country have been identified as underutilized by the Nigeria Indigenous Vegetable Project (2015). These vegetables provide an affordable and abundant source of proteins, carbohydrates, minerals, vitamins, and dietary fiber. Examples include Glossy Night Shade (Òdù), Snake Gourd (Tomato eléjò), Garden Egg (Ìgbàgbá), Amaranth (Tètè à tètèdáyé), and Fire Weed (Ebòlò). Despite their nutritional and cultural importance, only a small proportion of these indigenous vegetables are cultivated domestically, while many continue to grow in the wild.

Epidemiological studies indicate that the consumption of vegetables and fruits can protect against oxidative damage, which is linked to a higher risk of cardiovascular diseases, cancer, and other chronic conditions. Antioxidants combat oxidative damage by neutralizing free radicals and reactive oxygen species (ROS). ROS, including hydroxyl ( $\text{OH}^{\cdot}$ ), superoxide ( $\text{O}^{\cdot-}$ ), nitric oxide ( $\text{NO}^{\cdot}$ ), nitrogen dioxide ( $\text{NO}_2^{\cdot}$ ), peroxy ( $\text{ROO}^{\cdot}$ ), as well as non-radicals like hydrogen peroxide and singlet oxygen, contribute to lipid peroxidation, protein oxidation, DNA damage, and cellular degeneration (Hamzah et al., 2013).

Oxidative stress has been implicated in the development of cardiovascular diseases, diabetes, inflammatory disorders, cancer, Alzheimer's and Parkinson's diseases, aging, and possibly dementia (Aruoma, 2013; Amin et al., 2014). Dietary antioxidants from vegetables and fruits help prevent these conditions. Moreover, a diet high in natural antioxidants has been shown to enhance plasma antioxidant capacity and reduce the risk of certain cancers, heart disease, and stroke.

Nigeria consumes over 40 indigenous leafy vegetables, with the southwestern region accounting for 24 of these species (Adebooye et

al., 2013). Local vegetables significantly contribute to the diets of rural and urban populations and are integral to traditional food culture. Different ethnic groups consume a variety of indigenous vegetables for cultural and nutritional reasons, with approximately half of the leafy vegetables in Nigerian diets sourced locally, providing significant micronutrients (Lockett et al., 2020).

**Table 1: Under-utilized Indigenous Vegetable**

During the course of this study, ten (10) under-utilized indigenous vegetables were identified. These include, but are not limited to:

S/No	Yorùbá Name	English Name	Botanical names	Mode of Propagation
1	Ìgbàgbá	Gaeden egg	<i>Solanum mac rocarpon</i>	Seed
2	Ògùmò	Huckleberry	<i>Solanum scabrum</i>	seed
3	Apíròkò	Fluted pumpkin	<i>Telfairia occi dentalis</i>	Seed
4	Tètè à tètèdáyé	Amaranth	<i>Amaranthus virides</i>	Seed
5	Wòròwó	Bologi	<i>Solanecio bia frae</i>	Stem
6	Òdù	Glossy Night Shade	<i>Solanum nigr um</i>	Seed
7	Elégédé	Field pumpkin	<i>Curcubita pepo</i>	Seed
8	Ewúro	Bitter leaf	<i>Vernonia am ygdalina</i>	Stem
9	Tòmátò Eléjò	Snake Guard	<i>Trichosanthe scucumerina</i>	Seed
10	Ebòlò	Fire weed	<i>Crassocephala lumcrepidoides</i>	Seed

### Ontology and Knowledge Management

Ontology, in philosophy, is a branch of metaphysics concerned with the study of reality itself, independent of the subjective perceptions and thoughts of the individual experiencing it (Harriman, 2007). In the context of computer and information sciences, ontology refers to a set of representational primitives used to model a specific domain of knowledge or discourse. These primitives typically include classes (or sets), attributes (or properties), and relationships (or associations among class members). Their

definitions specify both their meanings and the constraints necessary for their logically consistent application (Gruber, 2017). In essence, ontology represents an explicit specification of a conceptualization, where a conceptualization is an abstract and simplified representation of reality.

A concept is an idea or notion formed in the mind. According to Ogden and Richards (2013), effective communication involves three components: concept, symbol, and referent, as illustrated in the “Triangle Meaning” (Figure 1).

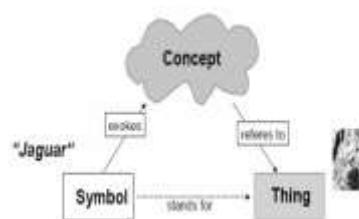


Figure 1: Triangle Meaning of Communication (Source: Ogden and Richards (2013))

### Ontology as a Tool for Knowledge Management

In today’s economy, knowledge has emerged as a critical factor for success. Recognizing its importance, Drucker (1994) asserts that unlike previous economic development periods, knowledge assets now serve as the primary means of production. He further emphasizes that managing information is both a complex and essential task, often serving as a foundation for gaining competitive advantage in organizations. Effective knowledge management enables organizations to learn from past mistakes, improve efficiency, and avoid the constant reinvention of processes. Intellectual capital, therefore, provides a unique source of competitive strength.

The terms data, information, and knowledge are frequently used interchangeably. Data refers to factual elements, often numerical, collected for reference or analysis. Ellis (2013) clarifies that data, when organized meaningfully, becomes information. When information is applied to solve a problem, it transforms into personal knowledge. Converting this knowledge into explicit form

results in an intellectual asset that can be shared and leveraged.

Knowledge itself is generated through thinking, combining information, experience, and insight. Extracting knowledge from information requires human judgment, grounded in context and prior experience. While information exists within a shared sphere of understanding, knowledge is subjective and intrinsically linked to the individual or group generating it (Baumard, 2019).

### 3.0 METHODOLOGY

Based on the above-mentioned literature, the following methods were deployed to accomplish the stated objectives:

(a) Yorùbá indigenous vegetables knowledge was elicited from the domain experts using a combination of observation, interview and documented materials inspection.

(b) Knowledge elicited in (a) was designed by using Formal Concept Analysis with its extension, Relational Concept Analysis.

(c) Ontology designed in (b) was implemented using Python version 3.9.1 and SQL with sqlite3 database for front and backend respectively

(d) The ontology implemented in (c) was validated by both the domain and the ontology experts using criteria such as accuracy and completeness

#### Knowledge Elicitation/Acquisition

Knowledge elicitation is the process of obtaining necessary domain knowledge to build the ontology. The knowledge about the domain used in this study came from a different of sources such as farmers and agricultural experts.

#### Knowledge Analysis and Summarization

This step involves reviewing all previous sources of knowledge, which are then summarized and organized in a structured format. A final verification will be conducted to confirm the

accuracy of data collected from farmers and research institutes. The knowledge on vegetable production will subsequently be analyzed and synthesized.

#### Define the model structure to be used

Ontology provides a data model that represents a set of concepts within a specific domain and illustrates the relationships among those concepts. Therefore, the two primary components of ontology are concepts and relations. An example is the figure 2 showing the conceptual framework of the ontology designed, figure 3 showing the flowchart of the indigenous vegetable model and figure 4 showing the semantic network of the designed model of the vegetable trait ontology structure model shows as indicated by the pictures below:

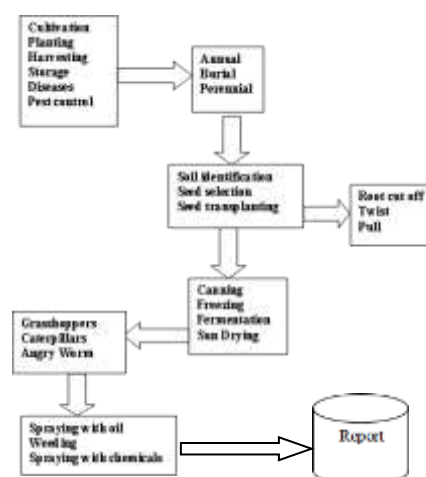


Figure 2: Framework of the Crop Ontology by Adding Vegetable Trait Ontology

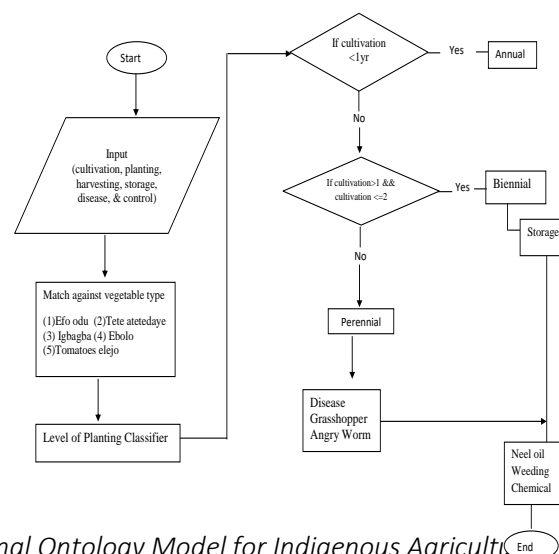


Figure 3: Flowchart of Indigenous Vegetable Ontology Model

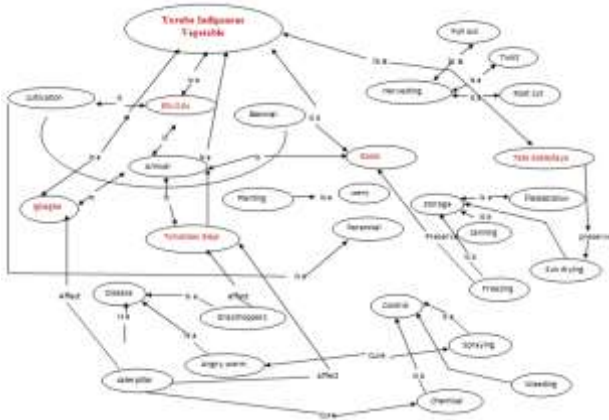


Figure 4: Semantic Network for Yorùbá Indigenous Vegetable

Table 2: Sample Survey Dataset Summary

Yoruba Planting/Amplifier	Cultivation Period			Mode of Planting			Harvesting			Post			Storage			Post Control		
	Annual	Biennial	Perennial	Seedling	Seedling	Seedling	Seedling	Seedling	Seedling	Seedling	Seedling	Seedling	Seedling	Seedling	Seedling	Seedling	Seedling	Seedling
Efo Ebiolo (Fave Wood)	2-3 months			Loamy soil, planting			Twist			Grasshopper/Caterpillar			Freezing			Chemicals/Weeding/Spraying with oil		
Efo Tete (Amaranth)	3-4 months			Loamy soil/broadcasting			Pull Twist Root Cut off			Grasshopper/Caterpillar			Freezing			Chemicals/Weeding/Spraying with oil		
Efo Igbagha (Garden Egg)	2-3 months			Loamy/Sandy soil			Leaf Cut			Grasshopper/Caterpillar/Angry Worm			Freezing			Weeding		
Efo Odu (Glossy Night Shade)	2-3 months			Loamy/Sandy soil			Leaf Cut			Grasshopper/Caterpillar/Angry Worm			Freezing			Weeding/Spraying with oil		
Tomato Elejo (Snake Guard)	3-5 months			Loamy/Sandy soil, transplanting			Seed cut off			Caterpillar/Angry Worm			Freezing/Canning			Weeding		

## Building Yorùbá Indigenous Agricultural Ontology (YIAO)

### Formalization

Formalization can be done either in Description Logics (DLs) or Unified Modelling Language (UML). This study employs Description Logics which provides adequate inference mechanism and high expressive power for hierarchical concept descriptions.

The Description Logics (ALC) is symbolically expressed as;

*Design and Implementation of a Formal Computational Ontology Model for Indigenous Agricultural Knowledge Management*

$$DL = \langle T, \perp, \neg A, C \cap D, C \cup D, \forall r.C, \exists r.C \rangle$$

where:

T - Universal

$\perp$  - Bottom

$\neg A$  - Atomic

$C \cap D$  - Intersect

$C \cup D$  - Union

$\forall r.C$  - Value restriction

$\exists r.C$  - Existential quantification

Data collected was formalized using language concept in automata theory. Examples:

1. “Some Vegetables (Amaranth)(x) are Annual Plant (y), which can grow within one year (z)”

The statement can be symbolized as follows:

$$\exists x, y, z, \text{Amaranth}(x), \text{Annual Plant}(y) \wedge$$

$$\exists z, \text{One Year}(z) \rightarrow \text{grows}(x, z)$$

2. “S’of’o (x) is an indigenous vegetable, which can be grown within (one Year)(y).”

Amaranth is a kind of vegetable that help prevent anaemia because they are high in iron, Vitamins A, B6 and folate”.

The narrative in slide above can be formally represented as:

KB = Vegetable(Amaranth(x)), grows(amaranth(x), Annual Plant(y)), planting(Loamy Soil(y)), affects(grasshopper(y)), ControlBy(Chemical(z)),

$$\forall x, y, z : (\text{Planting}(y) \wedge \text{control}(x, y) \wedge \text{affects}(y, z) \rightarrow \text{ControlBy}(y, x),$$

$$\forall x, y : \text{ControlBy}(y, x) \rightarrow \text{Vegetable}(x) \wedge \text{Grasshopper}(y),$$

$$\forall x : (\text{Amaranth}(x) \rightarrow \neg \text{Vegetables}(z))$$

## 4.0 RESULT AND DISCUSSION

### 4.1 Introduction

The data used for this research was sourced from domain expert (Agricultural Expert and Farmers). The total of 50 survey competency questions was distributed to get the actual fact about the selected Yorùbá indigenous vegetable. The survey questionnaire attribute elicited from domain expert include biological control, vegetable pest, preservation and pest control.

### System Evaluation and Testing

In a preliminary evolution of the ontology model, a few classical test cases were used in the system and the result of the system was accurate when compare with the result of the domain expert. Furthermore, the experiment was conducted using four competency questions with metrics like biological control organism, vegetable disease, chemical fertilizers and pest control. These questions were used to create queries for evaluation by comparing result from keyword-base search (Conventional search “A”) and ontology-based query expansion (ontology search “B”). It was shown from the result that precision and recall are increased averagely from 83% and 92% of accuracy and completeness respectively, which identify the ontology-based search more efficient than the conventional search about 9 and 64 times more.

### Report of Vegetable Ontology Production

The system generates ontology graph base on the information supplied by the user. Once the user submits their response, they can proceed to the next question. By clicking the “Generate Ontology Graph?” button, the user is able to view the semantic network graph, as illustrated in figure 5.

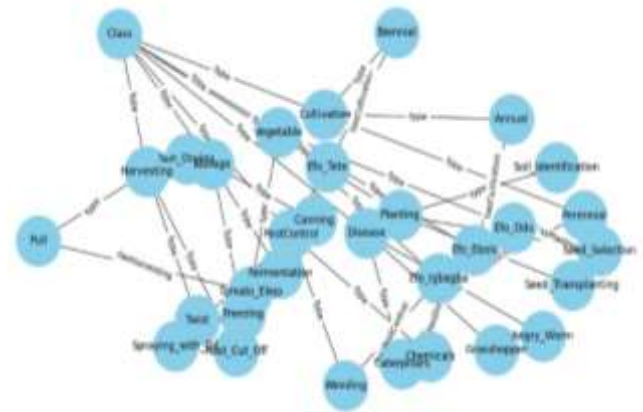


Figure 5: Snapshot of the class hierarchy OntoGraph

### 5.0 CONCLUSION

This study proposed beginning with the development of a well-defined ontology framework, created from scratch with input from domain experts, along with the preparation of rules for future updates using a semi-automated approach. Based on this framework, a prototype of the Yorùbá Indigenous Vegetable Production Ontology was developed. Guidelines and criteria were established to support the construction of other plant production ontologies.

Concepts and relationships were formalized, documented in a datasheet, and reviewed by domain experts. Additionally, a Yorùbá Indigenous Vegetable Agricultural Ontology Visualization tool and an Ontology Tree Editor were developed to provide graphical representations of the ontology and assist editors in managing it. Refinements were performed iteratively, applying transformations validated by experts to enhance the ontology.

The evaluation of the Indigenous Vegetable ontology focused on assessing its effectiveness in answering competency questions. The ontology’s query expansion capabilities were shown to improve information retrieval efficiency and provide answers that traditional retrieval systems without ontology could not achieve.

In conclusion, this study demonstrated that ontologies play a vital role in knowledge

acquisition and management, making the processes of knowledge storage and retrieval significantly more intelligent and effective.

## 6.0 RECOMMENDATIONS

This study recommends that agricultural departments across various parastatals, as well as public and private agricultural organizations, develop web-based expert systems to provide temporary support for individuals requiring immediate assistance when human experts are unavailable due to time or distance constraints. The study also represents advancement in the systematic development and implementation of a theoretically grounded, formal computational ontology for Yorùbá Indigenous Vegetables.

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