Development and Quality Evaluation of Hazelnut Ontology

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Abstract: In recent years, several projects that are supported by information and communications technologies (ICT) have been developed in the agricultural domain to promote more precise agricultural activities. Agriculture domain has a great deal of stakeholders. These stakeholders need more sophisticated data and appropriate intelligence to perform precise agricultural activities. It is essential to provide publishing domain-specific vocabularies while gathering data from heterogeneous sources and performing to merge them. When the importance of hazelnut agricultural product is taken into consideration, gathering much more detailed data regarding it and publishing this data for stakeholders of the relevant domain to use are indispensable. There is, therefore, a definite need for developing an ontology regarding hazelnut. In this research, we propose an ontology for hazelnut and examine a variety of ontology evaluation tools and methodologies to assess the ontology developed. In particular, we use a number of the metrics to evaluate the quality of proposed ontology and discuss the implications of proposed hazelnut ontology and its quality for both researchers and practitioners.

Keywords: Ontology Quality Evaluation, Hazelnut Ontology Quality, Ontology Quality, Precise agriculture

1. Introduction

In recent years, several projects that are supported by information and communications technologies (ICT) have been developed in the agricultural domain to manage agricultural practices. Each agricultural practice is performed by a lot of stakeholders, including farmers, domain experts, traders, and regulation agencies. These stakeholders need more sophisticated data and much more appropriate intelligence to perform the relevant agricultural practices. The data regarding any agricultural domain are based upon the activities of stakeholders. ICT applications are valuable resources in the agriculture domain to handle data gathered from various data sources such as farmers, sensors, government, researchers, analysts, and the market. ICT applications support gathering, processing, storing, publishing the agricultural data in an efficient way. Hazelnut is one of the valuable agriculture domains that can benefit from implementing ICT applications. ICT applications might help farmers deal with a number of challenges. For instance, recording and reporting the data with respect to age productivity, morbidity of trees, and the number of trees in orchards. Furthermore, ICT applications provide analyzing observation data for soil fertility and detecting location of orchards (southern slopes or northern slopes). They provide storing, publishing and reporting the following data gathered from hazelnut farmers as well: the pruning period of hazelnut trees, fertilization techniques used for hazelnut, types of sprayers used in hazelnut orchards, and irrigation methods. Internet of Things (IoT) tools which have particular sensors might improve agricultural practices by gathering data regarding the environmental effects on plant breeding like ICT applications. Sensors which are typically the main components of IOT applications might detect and measure a variety of data with respect to hazelnut. For instance, slope of hazelnut orchards, weather temperature, velocity of wind, rainfall, soil moisture, soil Ph, frost (date of most recent frost, minimum temperature, duration of temperature below 0°C), relative humidity (diurnal and seasonal range), light intensity, and leaf anatomy might be detected and measured using IOT applications. They might also be monitored by implementing ICT applications. When the data heterogeneity in the agriculture domain is taken into account, it is essential to provide publishing

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domain-specific vocabularies while gathering data from heterogeneous sources and merging them. Considering this variety of data sources and users interested in domain-specific information regarding hazelnut, one needs to have an ontology that fulfills the quality requirements. Ontologies enable us to share a common understanding of the structure of information among people or software agents, to reuse domain knowledge, to make domain assumptions explicit, to separate domain knowledge from the operational knowledge, and to analyze domain knowledge [1].

Evaluating the quality of ontologies which are used in such critical processes plays a vital role for applying them to the semantic systems in a reliable way. The usage of ontologies with lack of quality requirements might cause complicated issues such as misunderstandings among people and software agents, publishing wrong metadata, and gathering, storing, and processing inappropriate data in the relevant domain. A variety of tools and methodologies are used while evaluating the ontologies to eliminate these problems. The aim of this research is to develop an ontology regarding hazelnut for sustainable farming, and to evaluate the proposed ontology by using different tools and methodologies. Furthermore, the proposed ontology might be used as the main component of semantic annotation layer within the scope of multi-layer agricultural open data processing model [6].

This research makes noteworthy contributions to the current literature in two ways. First, we review the research conducted on existing agricultural ontologies; then we propose an ontology for hazelnut. Second, we examine a variety of ontology evaluation tools and methodologies to validate the ontology developed. Then, we select three tools and one methodology which are accessible and cover many quality criteria to evaluate the proposed ontology. Lastly, the findings based on the metrics to evaluate the quality of proposed ontology are examined, and their implications for both researchers and practitioners are discussed as well.

The paper has been divided into four parts. The first part unfolds the research problem underlying requirements of development and evaluation of Hazelnut Ontology. The second part provides a research background that constitutes foundational terms associated with a hazelnut ontology. In the model and findings part of the study, hazelnut ontology is introduced, quality evaluation tools and methodologies are examined, and the quality of hazelnut ontology is evaluated. In addition, model and finding part describes the methodology used to develop Hazelnut Ontology. The conclusion and prospective future works are discussed in the last part of the study.

2. Research Background

Given the fact that agricultural data are gathered from various data sources, in different kinds of formats, and by using different metadata, it is complicated to use the relevant data in an efficient way. Eliminating heterogeneity of data sources in the agricultural domain is possible by using semantic web technologies. Semantic web targets ensure significant contents' format, which could be processed by both humans and machines [7]. RDF (Resource Description Framework) and OWL (Web Ontology Language) are two major technologies used by semantic web to accomplish the aforementioned objective. RDF which is a standard data and modelling specification used to encode metadata and digital information; OWL that builds on and extends RDF and RDFS by adding more vocabulary terms for describing sets of things called classes, facts about those classes, relationships between classes or instances, and characteristics of those relationships are two common data languages in semantic web [8]. It is important to emphasize that OWL is the common, well-known, and standard language to create ontologies. Moreover, it has three sublanguages to meet different requirements; OWL Full, OWL DL, and OWL Lite. Hazelnut Ontology, which is created to represent the metadata regarding hazelnut, to carry out the interoperability between heterogeneous agricultural data sources and shall be elaborated later on within "Model and Findings" part of this paper is developed by using OWL.

An ontology is an explicit specification of a conceptualization which means an abstract, simplified view of the world that we wish to represent for some purpose [3]. Conceptualization consists of a set of objects, concepts, and other entities about which knowledge is expressed, and of relationships that hold among them [4]. Nowadays, ontologies are not only an explicit and theoretical specification of a shared conceptualization or a common and abstract understanding of a domain, but they are also implied in projects as conceptual models that allow communication among people and heterogeneous and widely spread application systems; content-based access on corporate knowledge memories, knowledge bases, archives; agent understanding through interaction, communication, and negotiation of meanings; and understanding and agreement upon a piece of information structure [5]. There exist diverse ontologies concerning agriculture domain such as AGROVOC which was published initially in the early of the 1980s by the Food and Agriculture Organization (FAO) of the United Nations. Furthermore, it is the most popular and well-known agricultural thesaurus all over the world. Today, AGROVOC is available as an SKOS-XL (Simple Knowledge Organization System eXtension for Labels) concept scheme, also published as a Linked Data (LD) set composed of 35,000+ concepts available in up to 29 languages [9]. SKOS (Simple Knowledge Organization System) was developed by the Institute for Learning & Research Technology to provide a means for representing knowledge organization systems (including controlled vocabularies, thesauri, taxonomies, and folksonomies) in a distributed and linkable way [10]. SKOS-XL defines an extension for the SKOS, providing additional support for describing and linking lexical entities [11]. Another prominent representative of agricultural ontology is Crop Ontology (CO). The CO is designed to provide a structured, controlled vocabulary for the phenotype of important crops for food and agriculture, and is collectively developed by various Crop Communities, associated with the centers of the Consultative Group on International Agricultural Research (CGIAR) [12]. It is the creation of the Generation Challenge Programme (GCP, http://www.generationcp.org/), which understood from its inception the importance of controlled vocabularies and ontologies for the digital annotation of data. [13]. CO has generally two resources OBO (Open Biological and Biomedical Ontology) ontologies and trait dictionaries. These resources are collected under five various groups, which are General Germplasm Ontology, Phonotype and Trait Ontology, Structural and Functional Genomic Ontology, Location and Environmental Ontology, and Plant Anatomy & Development Ontology. Some of the trait dictionaries and ontologies of CO were examined and analyzed to see whether they are suitable for hazelnut domain or not by the guidance of domain experts. However, the arguments proposed by domain experts have proved that any ontology is not appropriate for hazelnut. Even though there exist various agricultural ontologies created by many authors apart from these popular ones, when taking into consideration agricultural products' descriptors such as passport, management, characterization, evaluation, environment and site, they are not favorable to use them for hazelnut domain.

Before creating Hazelnut Ontology, it was considered that whether the trait dictionaries and phenotypes published by CO, are suitable for hazelnut or not. However, the traits which are examined by these ontologies do not meet the all requirements of stakeholders in hazelnut domain. Table 1 represents all the trait dictionaries and phenotypes published by CO. As Table 1 shows, CO considers traits and variables into nine different groups and almost each of trait dictionaries include all these groups. However, while creating Hazelnut Ontology the following categories are used *Passport*, *Management*, *Environment and Site*, *Characterization*, and *Evaluation*. These categories are broader top categories used by Bioversity for defining genetic resource. They also include the nine groups illustrated on Table 1 as well and meet the following needs of stakeholders [2];

– to be able to learn the basic information which is used to manage hazelnut generally
– to be able to learn and access the parameters which should be observed when the hazelnut is originally collected
– to be able to describe the environmental and site-specific parameters
– to be able to enable an easy and quick discrimination between phenotypes
– to be able to define and evaluate the hazelnut descriptors such as yield, agronomic performance, stress susceptibilities and biochemical and cytological traits

Considering the stakeholders' more sophisticated needs which are mentioned above, it was inevitable to create a comprehensive ontology. So, we decided to create Hazelnut Ontology, and introduce it in the Model and Findings part of this paper.

Table 1

Trait dictionaries and phenotypes published by CO

Phenotype and Trait Ontology	Number of Variables / Traits	Abiotic stress	Agronomical	Biochemical	Biotic stress	Morphological	Phenological	Physiological	Quality	Fertility	Other Traits
Bambra grounnut	134 variables	√	√	√	√	√	√	√	√	X	
Banana	370 variables	X	√	√	√	√	√	√	√	X	
Barley	148 variables	√	√	X	√	√	√	√	√	X	
Barley Trait POLAPGEN Ontology	148 traits	X	√	√	X	√	X	X	X	X	
Beet Ontology	385 variables	√	√	X	√	√	X	√	√	√	
Brachiaria	82 variables	√	√	√	√	√	X	√	√	X	
Brassica	155 variables	√	√	√	√	√	√	X	√	X	
Cassava f	245 variables	X	√	X	√	√	X	√	√	X	
Castor bean	75 variables	√	√	X	√	√	√	X	√	X	
Chickpea	89 variables	√	√	X	√	√	X	√	√	X	
Common Bean	184 traits	X	√	√	√	√	√	√	√	X	
Cotton	282 variables	√	√	√	√	√	√	√	√	X	Processing
Cowpea	204 variables	√	√	X	√	√	√	X	√	X	
Fababean	94 variables	√	√	X	√	√	√	√	√	X	
Groundnut	101 variables	X	√	X	√	√	X	√	√	X	
Lentil	68 variables	√	√	X	√	√	√	√	√	X	
Maize	352 variables	√	√	X	√	√	√	√	√	X	
Mungbean	89 variables	√	√	X	√	√	√	√	√	X	
Oat	228 variables	√	√	√	√	√	√	√	√	X	
Pearl millet	52 variables	X	√	X	√	√	√	X	X	√	
Pigeonpea	73 variables	√	√	X	√	√	√	√	√	X	

Potato	197 variables	√	√	X	√	√	X	X	√	X	Crop research
Rice	405 variables	√	√	√	√	√	√	√	√	√	
Sorghum	179 variables	X	√	X	√	√	√	X	√	X	
SoyBase Soybean Trait Ontology	678 terms	√		√	√	√			√	√	
Soybean	90 variables	√	√	√	√	√	√	X	X	X	
Sugar Kelp trait	46 variables	X	√	√	X	√	√	√	X	X	
Sunflower	353 variables	√	X	√	√	X	√	√	√	X	
Sweet Potato	303 variables	√	√	√	√	√	X	√	√	X	Crop research and Harvest
Vitis	273 variables	√	√	√	√	√	√	X	X	X	Technological
Wheat	498 variables	√	√	X	√	√	√	√	√	X	
Woody Plant Ontology	384 variables	√	√	√	√	√	√	√	√	√	
Yam	191 variables	X	√	X	√	√	√	√	√	X	

3. Model and Findings

3.1. Introducing Hazelnut Ontology

Agriculture is a vital sector due to the contribution to employment, exportation, and domestic income; providing raw materials sources for industry. According to Statistical Yearbook of the Food and Agriculture Organization for the United Nations, more than 3 billion people–almost half of the world's population–live in rural areas; and roughly 2.5 billion of these rural people derive their livelihoods from agriculture [42]. One of the much significant agricultural products is hazelnut as well in the world. Hazelnut is produced almost one billion tons per year dominantly in Turkey, Italy, the USA, Azerbaijan, Georgia, and Spain. In the world, there are many stakeholders directly or indirectly related to hazelnut such as farmers, researchers, analysts, domain experts and exporters. When the importance of hazelnut agricultural product is taken into consideration, gathering much more detailed data regarding it and publishing this data for stakeholders of the relevant domain to use are indispensable. There is, therefore, a definite need for developing an ontology regarding hazelnut. The main purpose of developing Hazelnut Ontology is to share a common vocabulary. On the other hand, Hazelnut Ontology is acknowledged that it is going to help provide an international format to standardize general understanding with respect to hazelnut. Another purpose of creating an ontology regarding hazelnut provides a generally accepted common language for hazelnut. It is a generally complicated process to gather data concerning a specific domain. This ontology is created to help stakeholders while deciding which attributes should be defined within the gathered data as well. Hazelnut Ontology is created to contribute to facilitating data storage, data retrieval, and data exchange in a rapid, reliable, and proper way by publishing accurate metadata with different types of services.

While developing Hazelnut Ontology we have examined three types of approaches such as top-down, bottom-up, and middle-out. According to the top-down approach, the initial work for building ontology is to begin the process by modelling top level concepts [14]. The bottom-up approach assumes that the documents include concepts and conceptual structures of the domain as well as the needed terminology to express them [14]. In the middle-out approach, the process of building the ontology started with the most important concepts first, and defining higher level concepts in terms of these, as the higher-level categories naturally arise [15]. Relevance of these approaches to ontology development is to identify the concepts as follows: from the most concrete to the most abstract (bottom-up), from the most abstract to the most concrete (top-down), or from the most relevant to the most abstract and most concrete (middle-out) [16]. We will examine a number of methodologies adopting the approaches for the purpose of assessing the Hazelnut Ontology in detail.

DOLCE (Descriptive Ontology for Linguistic and Cognitive Engineering), which is a foundational ontologies library, acts as a starting point for comparing and elucidating the relationships with other future modules of the library, and also clarifying the hidden assumptions underlying existing ontologies or linguistic resources [17]. On-To-Knowledge project known as OTK Methodology develops, explores sophisticated methods and tools for Knowledge Management, provides infrastructure for the Semantic Web, and is a process-oriented methodology for introducing and maintaining ontology-based knowledge management solutions in enterprises [18]. METHONTOLOGY is a popular and well-structured methodology used for building ontologies from scratch. METHONTOLOGY guides in how to carry out the whole ontology development through the specification, the conceptualization, the formalization, the implementation and the maintenance of the ontology; and it also identifies management activities (schedule, control, and quality assurance) and support activities (knowledge acquisition, integration, evaluation, documentation, and configuration management) [19]. TOVE (Toronto Virtual Enterprise) project aims to build ontologies that model both commercial and public enterprises. Also the goals of TOVE are to create a shared representation (aka ontology) of the enterprise which each agent in the distributed enterprise can jointly understand and use; to define the meaning of each description (aka semantics); to implement the semantics in a set of axioms that will enable TOVE to automatically deduce the answer to many common sense questions about the enterprise; and to define a symbology for depicting a concept in a graphical context [20]. DILIGENT (Distributed, Loosely-controlled and Evolving Engineering of Ontologies) methodology provides a process template suitable for distributed engineering of knowledge structures that is planned to extend towards a fully worked out and repeatedly tested methodology in the long run; and it comprises five main activities of ontology engineering: building, local adaptation, analysis, revision, and local update

[21]. Business Object Ontology is used in [22] to propose an integrated support methodology for constructing business models, including employing new business models, transplanting existing business activities to computers, and decision making support in employing a new environment of computers. A Natural Language Interface Generator (GISE), which is designed to provide a natural language access to a variety of Expert Systems, generates natural language interfaces that can support dialogues around the ontology [23]. It uses three steps for developing of natural language interfaces and ontologies. There are many more methodologies such as Enterprise Model Approach, KBSI IDEF5, Ontolingua, CommonKADS and KACTUS, Plinus, Onions, Mikrokosmos, MENELAS, PHYSSYS, and lastly SENSUS for building ontologies [24]. However, we shall not give the definitions of these methodologies in this paper.

The methodology of Ontology Development 101 was created considering an iterative approach for building ontologies and has seven steps. It has been preferred to make use of developing Hazelnut Ontology using the Protégé tool within the scope of this research. These steps are as follows: determining the domain and scope of the ontology, considering to reuse existing ontologies, enumerating important terms in the ontology, defining the classes and the class hierarchy, defining the properties of classes—slots, defining the facets of the slots, and creating instances [1]. The main purpose of this study is to develop an agricultural domain ontology and evaluate the quality of this ontology. That's why, for the first step of the relevant methodology, agriculture has been determined as the domain of creating ontology. Furthermore, this study aims to contribute to Hazelnut Farming area of research by developing an ontology. As the existing ontologies are not appropriate for hazelnut agricultural product, we could not make use of these existing ontologies while developing the ontology. The most comprehensive document to determine the metadata regarding hazelnut is "Descriptors for Hazelnut". Therefore, this document is used to enumerate important terms in the ontology. According to this document, Bioversity International (formerly known as IPGRI), which is an independent international scientific organization, uses the following five types of descriptors: passport, management, environment and site, characterization and evaluation descriptors [2]. These descriptors are classes of the ontology, and also, they designate the class hierarchy with the sub descriptors. Meanwhile, it should be noted that each descriptor has several sub descriptors. Some of these sub descriptors are classes of the ontology, but the others are the properties of classes-slot. The definitions and number of sub descriptors of each main descriptor are demonstrated on Table 2.

Table 2

Definitions, Number of Sub Descriptors and Use of the Descriptors

Descriptor	Definition	Number of Sub Descriptor
Passport	• Provides basic information used for the general information of the accession • Describes parameters when the accession is originally collected	• Two main descriptors – First descriptor has 14 sub descriptors – Second descriptor has 23 sub descriptors.
Management	• Provides the basis for the management of accession • Assists their multiplication and regeneration	• One main descriptor and this has 12 sub descriptors.
Environment and Site	• Describes the environmental and site-specific parameters	• Two main descriptors – First descriptor has 15 sub descriptors – Second descriptor has 1 main descriptor, and this has 22 sub descriptors.
Characterization	• Enables an easy and quick discrimination between phenotypes	• One main descriptor and this has 10 sub descriptors
Evaluation	• Includes characters such as yield, agronomic performance, stress susceptibilities, and biochemical and cytological traits	• Seven main descriptors and these descriptors

The descriptors demonstrated on Table 2 are in a hierarchical structure that means subclass-superclass relationships within the ontology, so while creating Hazelnut Ontology, this hierarchy should be considered. Table 2 presents an overview of the major descriptors of hazelnut. However, there are many descriptors regarding these major descriptors within the document. The most general concept of Hazelnut Ontology is Descriptor; and it has five types of general top-level concepts: Passport, Characterization, Environment and Site, Evaluation and Management. The other concepts that belonged to top level concepts are described as middle level; and the concepts related to middle level ones are named the bottom level concepts. Figure 1 demonstrates three different levels of the hazelnut ontology: top level, middle level and bottom level.

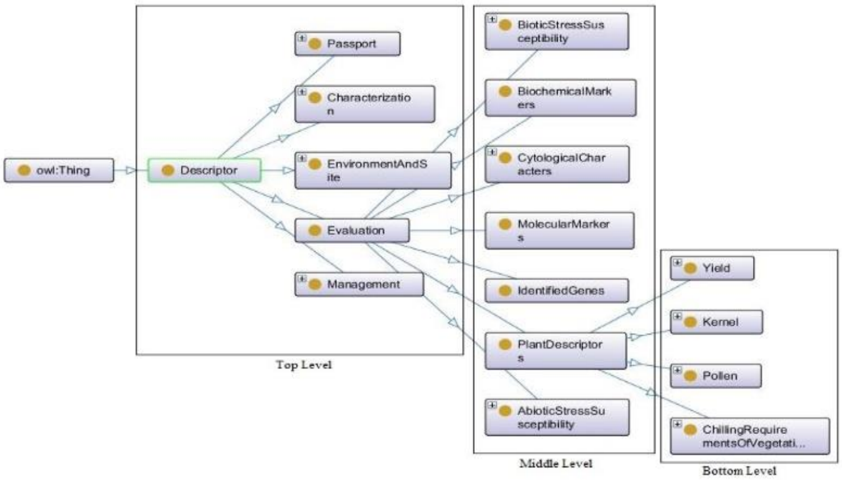

Fig. 1. Hazelnut Ontology Classes in Different Levels

Ontology creation is based on iterative design, and complicated and evolutionary process. There is no doubt that many domain experts shall contribute to Hazelnut Ontology. This part of the paper begins by laying out introducing the Hazelnut Ontology and looks at why we need to create it. The next part is concerned with the tools and methodologies used to evaluate the quality for ontologies and analyzing the meanings of the results calculated by these tools and methodologies.

3.2. Ontology Quality Evaluation Methods and Tools

We begin by taking a closer look at frameworks, methodologies and tools to evaluate the quality of Hazelnut Ontology.

Andrew Burton-Jones et al. proposed a metrics suite to assess the quality of domain ontologies [25]. Their metrics suite consists of four metrics to evaluate the ontology quality which is the overall metric of the suite. The first metric of the suite is *syntactic quality*. Syntactic quality has two attributes: lawfulness and richness. The second metric of the suite is *semantic quality* which has three attributes: interpretability, consistency, and clarity. The third metric is *pragmatic quality* which has three attributes: comprehensiveness, accuracy, and relevance. The last metric is social quality, and it has two attributes: authority and history.

The second quality model we focused on is based on the hierarchical model, which is one of the software quality model types. The model proposed by Hong Zhu et al. divided the quality attributes into three aspects: contents which have quality attributes with a focus on the content of the ontology; presentation that has quality attributes related to the way in which the ontology presents the domain knowledge; and usage that has quality attributes which manifest themselves when the ontology is used [26].

Another quality model we examined is developed for assessing the quality of a biodiversity ontology. The model is an operationalization of the information quality (IQ) assessment framework which combines conceptual and empirical approaches to identify an IQ problem structure and the requirements for an information object and grounding IQ metrics [27]. The relevant model has twelve dimensions (accuracy/validity, cohesiveness, complexity, semantic consistency, structural consistency, currency, redundancy, naturalness, precision/completeness, verifiability, volatility, and authority) and metrics related to these dimensions. Each of metrics has a type of cost as automatic or semiautomatic. OntoQA (Metric-based Ontology Quality Analysis), which is proposed by Samir Tartir et al., has metrics as schema and instance. The schema metrics (relationship richness, attribute richness, inheritance richness) are related to the designation of an ontology. Instance metrics, which is divided into two metrics; namely, knowledgebase metrics (class richness, average richness, cohesion) and class metrics (importance, fullness, inheritance richness, relationship richness, connectivity, readability), are related to placement of instance data and distribution of the data [28]. The method proposed by Gomez-Pérez prevents the inconsistency, incompleteness, and redundancy errors by using the criteria consistency, completeness, conciseness, expandability, and sensitiveness [29]. Protégé which is a project at Stanford University is an important tool to create, visualize and query the ontologies [30]. This tool is also used to evaluate the ontologies by summarizing the ontology metrics, which are categorized into metrics, class axioms, object property axioms, data property axioms and annotation axioms. OntoClean methodology validates the ontological adequacy of taxonomic relationships and uses the broad concepts regarding ontologies like essence, identity, and unity which characterize relevant aspects of the intended meaning of the properties, classes, and relations that build an ontology [31]. OntoMetric method based on a multilevel framework is also called a taxonomy of 160 characteristics. It provides a way to choose and compare existing ontologies. While investigating the appropriate ontology for relevant projects, it is necessary to emphasize that some viewpoints called dimensions should be considered. These dimensions include the content of the ontology and the organization of their contents; the language in which it is implemented; the methodology that has been followed to develop it; the software tools used to build and edit the ontology; and the costs when the ontology will be necessary in a certain project [32]. AKTiveRank, which uses a variety of metrics such as class match, density, semantic similarity, and betweenness to evaluate the ontologies considering the strength of representation of the concepts, is an experimental system [33]. Gangemi et al. present a method to evaluate and validate the ontologies using three dimensions (structural measures, functional measures, and usability-profiling measures), which are based on a metaontology called O2 complemented with an ontology of ontology validation called oQual [34]. OQuaRE considers three concepts (evaluation support, evaluation process, and metrics), and five characteristics (reliability, operability, maintainability, compatibility, transferability and functional adequacy) while evaluating the ontologies [35]. OOPS! (OntOlogy Pitfall Scanner!) is a tool that identifies pitfalls within the ontologies [36]. TOMM (Tool for Ontology Modularity Metrics) is a software tool that is used to apply structural criteria, logical criteria, relational criteria, information hiding criteria, and richness criteria to ontology modules (axiom abstraction, vocabulary abstraction, high-level abstraction, weighted abstraction, and feature expressiveness) created by NOMSA modularization tool [37].

3.3. Evaluation of Hazelnut Ontology

As Hazelnut Ontology is a typical instance of an agricultural ontology, it is a kind of trait dictionary because it reflects detailed descriptors with respect to hazelnut agricultural product in five different groups. The document “Descriptors for Hazelnut” that we used to create Hazelnut Ontology is the only one, and the most comprehensive scientific study all over the world. Although this document provides much information with respect to the hazelnut agricultural product, the created ontology using this document should have been evaluated by using a variety of metrics. The quality of Hazelnut Ontology has been evaluated in terms of quality with the scope of this research using three tools and one-question-based methodology. In accordance with McDaniel and Storey, who created a timeline of domain ontology evaluation initiatives, the first study for evaluating ontology quality started with Gomèz-Pèrez’s study named Initial Criteria; and the studies in this area continued with Bioinformatics created by Bodenreider [40]. Protégé, OntoMetric, and TOMM tools, which cover many evaluation metrics, are used to evaluate Hazelnut Ontology within the scope of this study. These tools are available and open access for ontology creators. Ontology creators could evaluate their ontologies in terms of completeness, adaptability, conciseness, consistency, and clarity by using a questioning method. This kind of evaluation could be performed using FOCA methodology, which provides questioning ontologies in terms of five different goals. Figure 2, representing the tools and methodologies, is used to evaluate Hazelnut Ontology. The results calculated by using these tools and methodology are examined and discussed in this section of the paper.

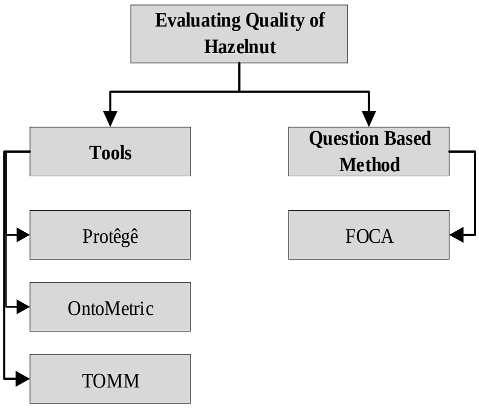

Fig. 2. Tools and methods used to evaluate Hazelnut Ontology

Protégé which is used to create Hazelnut Ontology is the first tool we used to evaluate the quality of Hazelnut Ontology as well. The method of Protégé for evaluating ontology is to indicate the count of the essential components of ontologies such as metrics, class axioms, object property axioms, individual axioms, and annotation axioms. When one looks at Table 2, one can see that each metric (class axioms, object property axioms, individual axioms, and annotation axioms) have sub-metrics as well. The major components of OWL ontologies are axioms. Axioms as a metric in Protégé indicate the total count of logical and non-logical axioms. An OWL Ontology might have different kinds of axioms such as declarations, facts, keys, datatype definitions, and axioms concerning classes, objects, data properties, annotations. Class means a set of individuals known as instances in OWL Ontologies. Object properties specify the associations between two individuals. Data properties enable us to assign specific values to the individuals. Annotations are used to assign additional information regarding individuals, classes, object properties, and datatype properties.

The class axioms consist of two different ones; sub class of and disjoint classes. There might be a hierarchical relationship between two classes in ontologies. For instance, Descriptor is the super-class in Hazelnut Ontology. Evaluation is the sub-class of Descriptor. If two classes are disjoint, that means an individual cannot be an instance of these two classes at the same time.

There are four different object property axioms in Protégé: sub object property of, functional object property, object property domain, and object property range. Object sub property axioms are similar to subclass axioms. The properties might be functional; and when a property is functional, that property is used to associate only one individual with another individual. Properties are used to associate objects from the domain to objects from the range. Individual axioms consist of class assertion, object property assertion, data property assertion, and different individuals. Class assertions provide a way to express which individual is an instance of which class. Object property assertions enable us to bind an individual with another individual by a specific circumstance. Data property assertions are expressions of connecting an individual to a literal.

The last metric is annotation axiom which has only one sub-metric such as annotation assertions. It is used to add meaningful, explanatory, and human-readable expressions and comments to individuals and IRIs.

Table 3

Metrics and Axioms of Hazelnut Ontology / Protégé

Metrics	Axiom	2189
	Logical axiom count	1359
	Declaration axioms count	721
	Class count	300
	Object property count	44
	Data property count	18
	Individual count	359
	Annotation Property count	2
Class axioms	Sub Class Of	372
	Disjoint Classes	6
Object property axioms	Sub object property of	2
	Functional object property	9
	Object property domain	1
	Object property range	1
Individual axioms	Class assertion	579
	Object property assertion	245
	Data property assertion	143
	Different Individuals	1
Annotation axioms	Annotation assertion	109

OntoMetric which is a web-based tool created by University of Rostock. It is the second tool we used to evaluate the Hazelnut Ontology. The calculation results of OntoMetric tool in different categories for Hazelnut Ontology are represented on Table 4, Table 5, Table 6, and Table 7. However, calculation results of class metrics have not been represented in this section of the paper because Hazelnut Ontology has 300 classes; and each class has nine calculation results. This means 2700 table of calculation results should take place in this section of the paper. So, these results were not included in this part of the paper. OntoMetric tool evaluates an ontology by calculating diverse metrics for instance base, schema, class, knowledgebase and graph. Base metrics stand for the number of integral parts of ontology such as classes, axioms, object properties, individuals, etc. The calculation results of base metrics measured by OntoMetric tool are likewise with Protégé. That’s why, it is appropriate to explain only schema, knowledge base, and graph metrics in this part of the paper.

Table 4

Base metrics' calculation results / Onto Metric Tool

Base Metrics	
Axioms:	2189
Logical axioms count:	1359
Class count:	300
Total classes count:	300
Object property count:	44
Total object properties count:	44
Data property count:	18
Total data properties count:	18
Properties count:	62
Individual count:	359
Total individuals count:	359
DL expressivity:	ALCHOF(D)

Schema metrics should be taken into account while making decisions regarding how well ontology design models the domain knowledge. Schema metrics consist of a sort of metrics used to designate the richness, width, depth and inheritance of an ontology schema design. The most essential and significant metrics of schema category are the following: attribute richness, inheritance richness, relationship richness, attribute-class ratio, equivalence ratio, axiom class ratio, inverse relations ratio, and class relation ratio. Calculation results of schema metrics could be seen on Table 5. An ontology with many attributes depicts the relevant domain in an appropriate format. Attribute richness is calculated as the number attributes for all classes divided by the number of classes. It is a well-known fact that classes and their subclasses are essential components used for expressing the knowledge well within the ontologies. The metric inheritance richness is a way to indicate the grouping structure of classes within the ontology and identified as the average number of subclasses per class. Relationship richness examines the varieties of relations within the ontologies; and is calculated as the number of non-inheritance relationships, divided by the total number of relationships. Attribute-class ratio metric is used to specify the association between the classes that have attributes and all classes in the ontology. It is calculated as the number of classes containing attributes divided by the number of classes. Equivalence ratio enables us to calculate the rate between similar classes and all classes. It is computed as the number of the same classes divided by the number of all classes. Axiom class ratio specifies the ratio between axioms and classes; and is calculated as the number of axioms divided by the number of classes. Inverse relations ratio calculates the ratio between the inverse relations and all relations; and is computed as the summation of inverse object properties count and inverse functional data properties count divided by the summation of all object properties count and all functional data properties count. Class relation ratio calculates the ratio between classes and relations.

Table 5

Schema metrics' calculation results / Onto Metric Tool

Schema metrics	
Attribute richness:	0.06
Inheritance richness:	4.529411765
Relationship richness:	0.118483
Attribute class ratio:	0
Equivalence ratio:	0
Axiom/class ratio:	7.296667
Inverse relations ratio:	0
Class/relation ratio:	0.7109

Ontology quality can be measured considering the data that took part within the ontology as it points to how well the ontology is designed, and how much the ontology represents the real-world. Average population and class richness are two different metrics calculated by OntoMetric tool. Average population is computed as the number of instances of the knowledge base divided by the number of classes defined in the ontology schema. Class richness enables comparisons between the counts of classes which have instances and total number of classes. It is computed as the percentage of the number of classes with instances divided by the total number of classes.

Table 6

Knowledge base metrics' calculation results / Onto Metric Tool

Knowledgebase metrics	
Average population:	1.196667
Class richness:	0.31

Graph metrics are used to calculate the structure of ontologies. As can be seen from Table 7, which represents the calculation results of the graph metrics, OntoMetric tool calculates seven diverse graph metrics such as cardinality, depth, breadth, fan-outness, tangledness, total number of paths, and average number of paths. Absolute root cardinality specifies the count of root nodes. The count of leaf nodes mean absolute leaf cardinality and the number of sibling nodes is absolute sibling cardinality. The depth metric that consists of absolute, average, and maximal is associated with cardinality of the paths. The breadth metric is represented by three different metrics such as absolute, average, and maximal expresses the cardinality of levels. Ratio of leaf and ratio of siblings are two fan-outness (how graph nodes distribute) metrics calculated by OntoMetric tool. Tangledness is the measurement of the multi-hierarchical nodes in the graph. The total number of paths is the summation of distinct paths, which exist in the graph. They are placed between a root node and a leaf node. The metric average number of paths is computed as the total number of distinct paths divided by the number of graphs.

Table 7

Graph metrics' calculation results / Onto Metric Tool

Graph metrics	
Absolute root cardinality:	1
Absolute leaf cardinality:	232
Absolute sibling cardinality:	300
Absolute depth:	1456
Average depth:	4.696774
Maximal depth:	7
Absolute breadth:	310
Average breadth:	4.428571
Maximal breadth:	37
Ratio of leaf fan-outness:	0.773333
Ratio of sibling fan-outness:	1
Tangledness:	0.226667
Total number of paths:	310
Average number of paths:	44.285714

TOMM is the last tool we used to evaluate Hazelnut Ontology. Table 8 represents the calculation results of TOMM. It computes similar metrics with other tools we used. However, it calculates three new metrics such as atomic size, appropriateness, and intra-module distance. Atomic size means average size of a group of interdependent axioms [37]. Appropriateness is a way mapping module sizes to values which are between 0 and 1 by defining an appropriate function considering the defect density correlation [38]. The intra-module distance means the number of relations in the shortest path between two entities [39].

Table 8

TOMM's calculation results

Metrics for Hazelnut Ontology	
No. of classes in module	300
No. of object property in module	44
No. of data property in module	18
No. of individual in module	359
Size of module	721
Atomic size of module	4.801664355
No. of axioms in module	2189
Appropriateness of module	1.0
Intra-module distance	289450.0
Cohesion of module	0.063114325
Attribute richness of module	0.213333333
Inheritance richness of module	4.529411765

Attribute richness metric was computed by OntoMetric and TOMM tools. The following results were obtained from these tools: 0.06, 0.21, respectively. The distinction of these values is due to the formula used by OntoMetric and TOMM tools. Although many tools use only the functional attributes to calculate attribute richness metric, OntoMetric uses all attributes declared in the ontology, and also handles the datatype as attributes. According to these calculation results, Hazelnut Ontology has not got enough attributes (slots). From the results, it is apparent that Hazelnut Ontology should be examined in terms of ontology design's quality and the quantities of information related to instance data. Another metric calculated by OntoMetric and TOMM tools is inheritance richness. This metric is calculated as approximately 4.52 by both tools. This calculation result demonstrates that Hazelnut Ontology is a typical deep, in other words, vertical ontology. A vertical ontology contains detailed information concerning a particular domain. Average population metric was calculated by only OntoMetric tool; and the result is 1.196667. This calculation shows us comparison between the count of individuals and the count of classes. The relevant calculation result could inform us regarding how well the instances represent the whole knowledge. The computed average population of Hazelnut Ontology by both tools is low. This means that Hazelnut Ontology does not have enough number of individuals per classes. On the one hand, it is important to emphasize some classes might have many instances. On the other hand, some of them might not have many instances within the ontology. As a consequence of that, this metric is not enough to express regarding the rank of quality of Hazelnut Ontology. Class richness of Hazelnut Ontology is measured by OntoMetric as 56.97, respectively. If class richness is high, in other words, closes 100%, it means that knowledge base is represented well. According to the value of class, richness of Hazelnut Ontology has enough results in terms of class richness. Relationship richness is computed by OntoMetric as 12, respectively. These results show that classes in Hazelnut Ontology are used by fewer numbers of instances. Attribute class ratio is measured as 0 by OntoMetric. This means that Hazelnut Ontology has no class with attributes. Similarly, equivalence ratio has been measured as 0; and this expresses that Hazelnut Ontology has no equivalent classes. The size of ontology has been measured by TOMM as 721. This value is the summation of the number of classes (300), object properties (44), data properties (18), and individuals (359) in Hazelnut Ontology. Atomic size of Hazelnut Ontology has been computed as 4.80 approximately using TOMM. This calculation result specifies that 4.80 axioms of the ontology are grouped together in an atom. Optimal appropriateness metric's value is 1. The value of appropriateness metric computed by TOMM is 1 for Hazelnut Ontology. When this calculation result is taken into consideration, it would be acceptable to indicate Hazelnut Ontology as appropriate. The calculation result of the intra-module distance metric helps us specify the distance between entities within the ontology. This value is computed by TOMM as 289450 for Hazelnut Ontology; and it indicates that the entities of Hazelnut Ontology are close to each other. The cohesion metric is related to the relationship between entities and measured by TOMM as 0.06 approximately for Hazelnut Ontology. As this value is relatively low, it can be expressed that the entities of Hazelnut Ontology have less relationship with each other.

3.4. FOCA Methodology-Based Quality Evaluation Results

FOCA methodology based on Goal, Question, and Metric (GQM) consists of thirteen different questions which aim to compute significant metrics and belong to five essential goals [41]. It enables evaluators to grade six metrics as follows: adaptability, clarity, completeness, computational efficiency, conciseness, and consistency. Afterwards, total ontology quality is computed using the beta regression models (Eq. 1) considering the mean values of each goal. Some of these questions have sub questions, so to calculate the grade of the relevant question, the average of grades of sub questions should be calculated first. Table 9 demonstrates the grades that were given by the ontology evaluator for each question. It is not convenient to answer some of these questions due to the type of ontology. According to FOCA methodology, if evaluating ontology is a kind of domain or task ontology, Question 4 (Q4) should not be answered by the evaluators. So, Q4 was not verified for Hazelnut Ontology because it is a domain ontology. FOCA methodology recommends grading these questions using appropriate points like 25, 50, 75, and 100. At the end of the grading process, the evaluator should calculate the final grades for each question considering the sub questions. It should be noted that if a question has sub questions, the final score of it is the mean of sub questions' grades.

Table 9

FOCA Methodology's Quality Evaluation Results

Goal	**Question**	**Metric**	**Sub Questions**	**Grade**
1. Check if the ontology complies with Substitute.	Were the competency questions defined?	Completeness	Does the document define the ontology objective?	100
			Does the document define the ontology stakeholders?	100
			Does the document define the use of scenarios?	100
	Were the competency questions answered?	Completeness	-	100
	Did the ontology reuse other ontologies?	Adaptability	-	0
2. Check if the ontology complies with Ontological Commitments.	Did the ontology impose a minimal ontological commitment?	Conciseness	-	-
	Did the ontology impose a maximum ontological commitment?	Conciseness	-	100
	Are the ontology properties coherent with the domain?	Consistency	-	100
3. Check if the ontology complies with Intelligent Reasoning	Are there contradictory axioms?	Consistency	-	100
	Are there redundant axioms?	Conciseness	-	50

4. Check if the ontology complies with Efficient Computation	Does the reasoner bring modelling errors?	Computational efficiency	-	100
	Does the reasoner perform quickly?	Computational efficiency	-	50
5. Check if the ontology complies with Human Expression.	Is the documentation consistent with the modelling?	Clarity	Are the written terms in the documentation the same as the modelling?	100
			Does the documentation explain what each term is and does it justify each detail of modelling?	100
	Were the concepts well written?	Clarity	-	100
	Are there annotations in the ontology bringing the concepts definitions?	Clarity	-	25

Table 10 represents final grades of the questions. According to these results, one can make the following inferences:

- Hazelnut Ontology is adequate in terms of completeness because the scores of entire completeness' metric questions are 100,
- Hazelnut Ontology is poor in terms of adaptability because it does not reuse any ontology,
- The conciseness and computational efficiency scores of Hazelnut Ontology is over average
- It could be expressed that Hazelnut Ontology is consistent, considering the grades of consistency questions
- The score of clarity metric for Hazelnut Ontology is 81.25. This score is sufficient. However, it could be enhanced by adding annotations in the ontology bringing the concepts definitions.

Table 10

Summary Table of Question's Grades

Question	Grade	Question	Grade
Q1	100	**Q8**	50
Q2	100	**Q9**	100
Q3	0	**Q10**	50
Q4	-	**Q11**	100
Q5	100	**Q12**	100
Q6	100	**Q13**	25
Q7	100	-	-

From Table 11, it is apparent that averaged point of second goal is the highest as each question belonged to this goal has 100 points. On the other hand, third and fourth goals have the same and the lowest averaged points of question because one of the questions regarding each of these goals have only 50 points. First and the last goals have almost the same average value, too. The results represented on this table demonstrate that Hazelnut Ontology has attained each goal proposed by FOCA methodology.

Table 11

The Mean Value for Goals

Goal	Mean
1	80
2	100
3	75
4	75
5	81.25

At the end of the quality evaluation process for Hazelnut Ontology, Equation 1 might thus be used to calculate the overall quality of it using average values of the relevant goals represented on Table 11.

Equation 1

The Formula for Calculating Overall Quality

$$\mu_i = \frac{exp\left\{-0.44+0.03(Cov_s\ x\ Sb)_i+0.02(Cov_C\ x\ Co)_i+0.01(Cov_R\ xRe)_i+0.02\left(\ Cov_{Cp}xCp\right)_i-0.66LExp_i-25(0.1xNl)_i\right\}}{1+exp\left\{-0.44+0.03(Cov_s\ x\ Sb)_i+0.02(Cov_C\ x\ Co)_i+0.01(Cov_R\ xRe)_i+0.02\left(\ Cov_{Cp}xCp\right)_i-0.66LExp-25(0.1xNl)_i\right\}}$$

(Cov_S average grades of goal 1, Cov_C average grades of goal 2, Cov_R average grades of goal 3, Cov_{Cp} average grades of goal 4,LExp experience variable of evaluator ,Nl is 0 if the evaluator is good at ontology assessment)

(*If the evaluator would like to calculate the overall quality of the relevant ontology Sb, Co, Re, and Cp should be 1.*)

Equation 2 shows the formula with real values of variables regarding Hazelnut Ontology. After this calculation is carried out, the overall quality of Hazelnut Ontology is obtained as 0.997994791.

Equation 2

Overall Quality Score of Hazelnut Ontology

$$\mu = \frac{exp\{-0.44+0.03(80x1)+0.02(100x1)+0.01(75x1)+0.02(75x1)-0.66(0)-25(0.1x0)\}}{1+exp\{-0.44+0.03(80x1)+0.02(100x1)+0.01(75x1)+0.02(75x1)-0.66(0)-25(0.1x0)\}}$$

$$\mu = 0.997994791$$

4. Conclusion and Future Work

This research contributes to better understanding and fulfilment of requirements for Hazelnut Ontology. The arguments given within the "Research Background" part of this paper claim that existing ontologies are not suitable for hazelnut. However, the stakeholders of the agricultural domain need more sophisticated, publicly available, freely accessible, and in a machine-readable format data. This could be provided by using the power of semantic web technologies. Considering this power, we created Hazelnut Ontology as initial work to build semantic annotation layer for open data processing model. A number of restrictions of our study and areas for future research should be mentioned. For instance, ensuring ontology consistency, viability, reliability, difficulties in user and developers' scenarios while evolving the process of the ontology might be a restriction and reluctance towards using this ontology. However, we submit that the contribution of our paper rests on knowledge engineering, semantic web, and building domain ontologies, we are not experts of the hazelnut domain. Thus, the contributions of hazelnut domain experts are crucial for the future of this study. A considerable amount of literature has been published on the evaluation of quality of ontologies. One of the main aims of this research is to assess the Hazelnut Ontology by using the existing quality evaluation tools and methodologies. One question-based methodology and four different tools that measure similar metrics are used to evaluate Hazelnut Ontology. Similar or distinct calculation results are obtained from these tools and methodology for Hazelnut Ontology. These results are analyzed within the Model and Findings part of this paper. Analyzing the calculation results gives us a general opinion rather than making a certain decision regarding the quality of Hazelnut Ontology. It is worth bearing in mind that including domain experts to evaluation processes of ontologies might provide a better understanding in compliance with their quality. In this paper, domain experts are not included in the evaluation stage of Hazelnut Ontology. However, our focus just is on introducing Hazelnut Ontology, expressing the requirements of creating it, and evaluating the quality of it by using existing tools and methodologies. Therefore, handling the evaluation of the quality of Hazelnut Ontology under the supervision of domain experts would provide important insights to spread its usage into a wide range. Further research should be done to investigate a new approach for evaluating the quality of ontologies including the domain experts.

In addition, further studies, which take into account storing hazelnut ontology and publishing sophisticated data using it, will need to be undertaken. We shall focus on data interchange and publishing mechanisms, evaluating various options for storage infrastructure of Hazelnut Ontology, and semantic web services as future work. Furthermore, taking into consideration gathering domain-specific data using ontologies is a complexity; and it is an essential research topic to focus on in the future.

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