Review

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Review

Definition of Food Consumption, Loss, and Waste

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Abstract: The global food system has three recognized challenges: (a)increasing the availability of food consumption, (b) reducing food loss, and (c) reducing food waste. The increasing demand for food consumption, increasing quantity of food loss, and corresponding increase in food waste are resulting in serious health, aesthetic, social, economic, and environmental problems due to a lack of appropriate planning and management. Despite its importance, there is no clear, concise, and comprehensive definition of food consumption, loss, and waste. Generally, food consumption, food loss, and food waste are dealt with separately. This article presents a logically constructed ontological framework of food consumption, loss, and waste. It gives equal importance to all three aspects of global food management. The systematic ontological framework is general, and the analysis can be applied to any country. The framework deconstructs the combinatorial complexity of the problem and explicates the pathways to manage the consumption, loss, and waste. The ontological framework encapsulates 19*8*7*4*5*6 = 25,536 possible components of the challenge. A critical analysis based on available data using the framework will help to develop strategies to deal with the problem. It can help to discover the gaps and to find ways to bridge the gaps. It is novel to conceptualize food consumption, loss, and waste together.

Keywords: ontological analysis; systematic; food consumption; food loss; food waste

1. Introduction

Food Loss and Waste (FLW) is a complex construct without a "comprehensive and globally applicable" [1] (p. 1) definition. Expressing its complexity clearly, concisely, and comprehensively in natural-English (or another language) is a major challenge in defining the construct. The construct's complexity arises from the scale, scope, and semantics of what it denotes. First, food in FLW denotes an array of plant- and animal-based products consumed as food, each with its subcategories. Second, loss and waste denote three sequential steps (consumption is implicit) by which the food is consumed and discharged. Third, food is used by an array of users. Fourth, food serves many purposes for the users. Fifth, and last, FLW is affected by the many stages of food production, storage, processing, and distribution. Thus, FLW is a combinatorial product of the many categories of food, multiple processing steps, different users, their different purposes, and sequential handling stages. There is a very large number of these combinations, each of which is a facet of the construct. Boiteau and Pingali's [1] (p. 7) harmonize the definition as : "Food loss and waste is a reduction in the quantity or quality of the edible portion of food intended for human consumption when food is redirected to non-food uses or when there is a decrease in the nutritional value, food safety, or other quality aspect from the time food is ready for harvest or slaughter to consumption." Their definition does not express the complexity comprehensively. An ontology using structured natural-English (or another language) can express this complexity succinctly. Thus, building on the paper by Boiteau and Pingali [1], we present an ontological definition of food consumption, loss, and waste that addresses the challenge highlighted by the authors.

An ontology is an organization of the terminologies, taxonomies, and narratives of a problem that can be conceptualized as a scientific theory of the problem [2–6]. As a scientific theory it can be used to describe, explain, predict, and control [7] FLW through feedback and learning [8,9] systemically as part of a broader ecosystem, and systematically by exploring the innumerable pathways within it. The authors have used ontologies to study solid waste management [10], bio-medical waste management [11], air pollution management [12], and similar topics. In the study we: (a) present an ontology of food consumption, loss, and waste (the addition of consumption is necessary to make the construct logically complete, although we shall continue to use the common FLW acronym), (b) demonstrate how it encapsulates the present definitions of FLW, (c) discuss how it extends the present definitions to be "comprehensive and globally applicable" [1] (p. 1), and (d) delineate its implications for research on, policies for, and the practice of FLW.

2. Materials and Methods – Ontology of Food Consumption, Loss, and Waste

We approach the problem of unifying the definition of FLW top-down instead of bottom-up as Boiteau and Pingali's [1] have sought to do. We logically deconstruct FLW as:

FLW = Stage of food chain + Food type + CLW (Consumption, Loss, Waste) of food + User of food + Objective of food

We take a systemic view of each subconstruct of FLW in the text-equation. Thus, the proposed ontology of food consumption, loss, and waste (Figure 1) is an organization of 60 key words/ phrases that define the FLW construct. These are terms selected based on field knowledge and research publications[13,14]. It is a word-picture of FLW. The words/phrases are grouped into five columns – each represents a dimension of the problem. They are: (a) Stage – the stages from production to utilization of food, (b) Food – the types of food, (c) CLW (Consumption, Loss, and Waste) – the steps from consumption to waste of food by a user, (d) User – the primary users of food, and (e) Objective – the purpose of food consumption by the user. The words/phrases in each dimension constitute a taxonomy of the subconstruct denoted by that dimension. The elements in each taxonomy are reasonably mutually exclusive and sufficiently exhaustive. The dimensions are ordered left to right with adjacent words/phrases to connect them. Concatenating a word/phrase each from across the five dimensions with the adjacent connectors forms a natural-English sentence, as illustrated by three sentences below the ontology. Each sentence is semantically meaningful (although a little awkward grammatically), and the ontology can generate a very large number of them. The complete set of sentences so generated constitutes the definition of FLW.

Next, we explain the dimensions denoting each subconstruct in the following order: Objective, User, Food, CLW, and Stage. We conclude the section with a discussion of pathways to manage FLW that can be generated from the ontology.

2.1. Objective

Food is valued for the energy, the macro-nutrients, micro-nutrients, and medication purposes[15–19]. It is also valued for the additives and excipients that contain, preserve, deliver, and enhance the first four values. Last, the residue from one user is valued for the value it may provide for another user (Figure 1 – Objective).

FLW is dominantly focused on the first three (energy, macro-nutrition, and micro-nutrition) and residue; it is marginally focused on medication, and tangentially on additives/excipients in as much as they affect the first three. The priority is contextual. In an energy-starved population, minimizing the energy loss and waste will be important. In an energy-adequate population, optimizing macro- and micro-nutrition will be important. For all populations, especially those dependent on traditional and indigenous medicine, after assuring energy and nutritional adequacy, preserving the medicinal value will be important. The value of additives/excipients may be based on explicit knowledge of their capacity to deliver the first four, or on tacit knowledge of historical, cultural, and local practices. The value of residue from a user will depend on the knowledge of its potential for use by another user.

Figure 1. Ontology of Food Consumption, Loss, and Waste.

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The properties of food ingredients that determine the different types of value vary. Some properties are visible (for example, energy, sometimes synonymous with quantity), and many are invisible (for example, macro-nutrients, micro-nutrients, and medication). Some are based on formal, explicit knowledge; many are based on informal, tacit knowledge. Some can be measured easily; many cannot be measured easily. These properties determine the efficacy of feedback and learning to manage FLW.

2.2. User

Food is consumed in the traditional sense by people, animals, and plants [15,20–23](Figure 1 – User). Food that is not consumed by anyone reaches the environment, which absorbs it. Conceptualizing environment as a user would help explicitly address the problems associated with environmental protection and sustainability. The four types of users constitute the ecosystem of FLW. Food that is lost or wasted by people may be consumed by animals and plants; food that is lost or wasted by animals may be consumed by plants; and food that is lost or wasted by all three is necessarily consumed by the environment. Completing the cycle, what is consumed by the environment may affect subsequent production of food, its quality and quantity, and thus FLW. The iterative cycle may continue increasing or decreasing FLW.

Each user's objectives are different in consuming food, and the consequent loss and waste. The objectives vary widely among and between users. The overall objective of managing FLW would be to optimize the value for all the users and their objectives.

2.3. Food

Food is broadly classified as plant-based and animal-based (Figure 1 – Food)[24,25]. Plant-based food includes grains, vegetables, fruits, and the residue from the three. Animal-based food includes meat/poultry, fish/seafood, dairy, and the residue from them. Plant-based food may be fed to animals to produce animal-based food; animal-based food is unlikely to be fed to produce plant-based food. There is a third category of physical/chemical food substances that can significantly affect the consumption, loss, and waste of plant- and animal-based foods. These are additives, preservatives, nutraceuticals, etc. While their loss and waste are unlikely to be a major concern, they can have a significant effect on the loss and waste of the plant- and animal-based foods. They can also have long-term effects on the subsequent links in the FLW chain.

The subcategories of the three types of food vary in their value to fulfil the objectives for the different users. Balancing them is central to optimizing the value and managing FLW. They are an integrated part of food production, storage, processing, and distribution cycle, but they are interdependent on each other. The composition of food consumed by the users varies based on their requirements, preferences, practices, and objectives. The composition of FLW varies correspondingly.

2.4. CLW (Consumption, Loss, and Waste)

CLW denotes the three, generally sequential, stages of the transformation of food to waste (Figure 1 – CLW). Consumption denotes the direct consumption, its reduction to other forms, and its reuse by/for the user [15,19,21,26–29]. Loss follows consumption and denotes processes of recovery and repurposing some of the value of food after consumption by/for the user [14,19,26,30,31]. Waste denotes what is left after consumption and loss – it may be active or inert. The CLW stages may be repeated with different users and objectives for the same food. For example, grains rejected by people may be consumed by animals.

The challenge of managing FLW is to optimize the value to the people, animal, and plant users and minimize the waste, both active and inert, reaching the environment. Realizing this may require multiple iterations with different types of food, users, and objectives.

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2.5. Stage

Exogenous to the CLW of different types of food by the users for their value are many stages in handling food where too FLW can occur [32]. These stages are production, handling, storage, processing, distribution, marketing, and utilization (Figure 1 – Stage). The stages and their subcategories are listed in the corresponding column of the ontology. How the food is handled at each stage can affect its consumption, loss, and waste. Further, since the stages are sequential, the effects of early stages on FLW can be amplified or attenuated in the subsequent stages through appropriate intervention.

The contribution of each stage to FLW will depend on the type of food, users, and the objectives of consumption. These stages may also be spatially and temporally remote from the ultimate user. Thus, loss and waste may occur without an opportunity for the food to be consumed.

2.6. Pathways

The 60 key words/phrases (excluding the column titles and connectors) in the ontology could be combined into ${}_{60}C_5$ = 5,461,512 (60! / (5! * 55!)) five-word/phrase unique combinations. From among these combinations, the ontology encapsulates 19*8*7*4*5*6 = 25,536 combinations that denote the potential pathways to managing FLW in natural-English. It is 0.47% of the total possible combinations. These pathways constitute the definition of FLW.

Three illustrative pathways generated from the ontology are (Figure 1 – Illustrative pathways):

- Production (crop farmer) of plant-based (grains) for food consumption (use) by people for optimal energy value.
    a. Managing grains loss and waste at the stage of production of crops by farmers for optimizing the delivery of calorific value to people.
- Handling (logistics) of animal-based (fish/seafood) for food waste (active) by environment for optimal macro-nutrition value.
    a. Managing the logistics of environmental recycling of biologically active fish/seafood waste.
- Utilization (restaurant) of physical/chemical (preservatives) for food loss (repurposing) by plants for optimal micro-nutrition value.
    a. Managing the disposal of preservatives in food by restaurants as food to plants.

The large number of pathways encapsulated in the ontology as a small subset of the very large number of possible combinations of the 60 words/phrases demonstrate both the generative and selective power of the ontology. It is like a 'Google Map' of the challenge of FLW. It can be used to navigate, with feedback and learning, solutions to the challenge like with the ubiquitous digital map. It shows the large number of pathways some may be known to be effective, some known to be ineffective, and many whose effectiveness is unknown. It is necessary to reinforce the effective pathways, redirect the ineffective ones, and research the unknown ones. In the next section a comprehensive analysis of the current definitions of FLW is discussed through the lens of the framework.

3. Discussion – Correcting the Lacunae

The ontology defines FLW as a multi-dimensional, multi-step, iterative, dynamic process. Each column in the ontology is a dimension of the process. The steps may be within a dimension or may cut across many dimensions. Similarly, the iterations may be within and across dimensions. In other words, the pathways of FLW may crisscross the dimensions of the ontology and the elements within them. FLW is a process not a state. The present definitions fail to capture the dynamics of such iteration and associated complexity.

A major impediment to unifying the definition of FLW is the implicit gap in what the acronym denotes – food loss and waste. Loss and waste have a symbiotic relationship with consumption as they are deeply interconnected. As specified in the ontology, the focus should be on consumption,

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loss, and waste (CLW). Any definition that considers only loss and waste is necessarily incomplete. The ontology avoids this implicit bias.

Boiteau and Pingali's [1] in their review correctly point to the following lacunae in the definitions of FLW:

- "An abundance of terms with overlapping meanings." (p. 3)
- "Definitions driven by perspectives associated with FLW." (p. 5)
- "Timing and terminology" (p. 5) of measurement of FLW.
- Scope of food in FLW.
- Criterion for utilization of food – by who – to determine FLW.
- Criterion of edibility of food – by who – to determine FLW.
- Type – quantitative and qualitative – of FLW.

It is an excellent list. However, the harmonized definition the authors propose does not resolve the lacunae and help unify the definitions. In the following we explain how the ontology can be a unifying definition of FLW that addresses the above issues, and be a "comprehensive and globally applicable" [1] (p. 1) definition.

3.1. Parsimonious Terminology

The 60 key words/phrases in the ontology, derived from the common body of knowledge on the subject, are adequate to define FLW. The columns represent distinct dimensions of FLW and are comprehensive. The taxonomies of the dimensions are reasonably mutually exclusive and sufficiently exhaustive. The organization of the ontology is such that: (a) a dimension can be added to extend the scope of FLW, (b) each dimension's taxonomy can be extended, if necessary, by adding elements, and (c) the elements of a dimension can be refined by adding sub-elements and coarsened by aggregating elements to change the granularity of the definition. The modularity of the ontology lends itself to such changes without the necessity of reworking the whole definition. Such additions and refinements may add only a few terms, but extend the scope (dimensions), scale (magnification), and size (number of pathways) in the ontology exponentially. The ontology, with a parsimonious terminology, can capture the complexity of FLW clearly, concisely, and comprehensively.

Even if the terminology of the ontology is not identical to that in the definitions, one can establish equivalence through synonyms, hypernyms, and hyponyms. Keeping the ontology constant as the framework for integration of the definitions, in line with the top-down approach, would be easier than attempting to integrate and unify them ground-up.

3.2. Stakeholder Perspectives

The present ontology includes the perspectives of the stakeholders in all the stages from production to utilization, steps from consumption to waste, and users from people to the environment. A stakeholder's perspective can be denoted by a subset of the ontology. Multiple stakeholders' perspectives can be integrated by mapping them onto the ontology. The modularity of the ontology makes such denotation and integration possible. Further, the ontology's scale, scope, and size can be changed (as described earlier) to accommodate and fit any stakeholder's perspective.

Last, the ontology can frame a stakeholder's perspective in the unified context of the universal definition. Such part-whole framing will highlight the systemic biases in a stakeholder's perspective – what is emphasized, what is not emphasized, and what could be emphasized. Such an analysis will help define the intended consequences of the definition, its unintended consequences, and its potential innovative consequences.

3.3. Timing and Terminology

The timing and terminology issue is that of choosing the segment of the Stage dimension for the definition. Considering the cascading interdependence of the stages, it would be appropriate to include all of them. However, should one want to study Handling in greater depth and detail, the

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other stages can be hidden. Further, additional subcategories of handling can be added for greater detail, and sub-subcategories can be added for greater depth.

Continuing, the focus can be further narrowed to plant-based foods by hiding other types of foods, and to people's CLW by hiding other users. Thus, the ontology: (a) provides an integrated timing framework, and (b) permits segmentation of the timing based on a stakeholder's requirements.

3.4. Scope of Food

The denotation of food in the ontology is inclusive and exhaustive. In addition to the plant- and animal-based foods, it also includes physical/chemical ingredients in food. The last category likely to be present in minute quantities compared to the bulk of what is considered food can have an oversize influence on FLW and the value the food delivers. Food in the ontology also includes residue from plant- and animal-based foods that could likely be used by a different user in a subsequent iteration [33,34].

By refining the food categories, the ontology highlights the importance of considering the differences in their CLW. These subcategories fulfill different objectives and have different user profiles.

3.5. Utilization of Food

The food may be utilized by people, animals, plants, and the environment. It may be utilized in a household, restaurant, hotel, or an institution. There is an interdependence between the utilization by the four users that is a necessary part of the food ecosystem. Loss or waste for people may be a gain or choice for the animals and plants. Thus, the estimation of utilization FLW will depend upon the boundary chosen. It may include only people, people + animals, people + animals + plants, or people + animals + plants + environment. It is a problem of definition that will also likely affect the temporal boundaries for the determination of FLW. Focusing on a single type of user will have the shortest time horizon, adding more types will expand the time horizon. Thus, if one is focused only on the short-term FLW, one may focus on a single type of user; on the other hand, if the focus is on long-term FLW and ecological sustainability, one must focus on the full spectrum of users.

3.6. Edibility of Food

Edibility of food depends on its user. Food that is inedible to people may be edible to animals; food that is inedible to animals may be edible to plants; and food that is inedible to plants may be 'edible' to the environment by default. The propagation along the edibility chain will depend upon the type of food and its subtype. Plant-based food may propagate better than animal-based foods. Ultimately, all waste must necessarily be 'edible' to the environment, with potentially desirable and undesirable long-term consequences to the food cycle.

Further, physical/chemical ingredients in the food, both plant-based and animal-based, can affect its edibility to the users and consequently its FLW. These substances may be introduced at one or more of the stages from production to utilization, consumption-reuse, or loss-recovery and loss-repurposing. Thus, edibility may be transformed in significant ways for each type of food as it undergoes iterations among the stages, CLW steps, and the users.

3.7. Type of FLW

The ontology can describe all possible types of FLW qualitatively and exhaustively. It would be difficult to quantify all the qualitative descriptions due to difficulties of measurement, availability of data, quality of data, and similar factors. However, the challenge of quantification must not deter one from addressing a type of FLW.

Quantification can be at many levels [20,35,36]. At the nominal level, one may simply measure the presence/absence of a type of FLW. At the ordinal level, one may rank order different types of FLW. At the interval level, one may assign subjective regular interval scale values (for example, using a Likert-like scale) to the FLWs with an arbitrary anchor. Last, at the ratio level, one may measure FLW on a scale with an absolute zero and objective regular interval scale values. Nominal and ordinal level specification can be very relevant despite not appearing to be rigorous. Interval and ratio level specification can be rigorous but due to challenges of measurement, quality of data, and related issues may not be very relevant. The ontology specifies all possible types of FLW qualitatively; from them on can choose the level of measurement suitable in a context.

3.8. Managing the Dynamics of FLW

FLW is a dynamic process and not a static state of a household, organization, locality, city, state, or country. Like on a 'Google Map', food traverses many pathways in the ontology in the process of being consumed, lost, and wasted within the boundaries of the entity. Many of these pathways have been discussed above. The pathways are iterative, cutting across many dimensions, and including many elements of a dimension. They are complex and able to traverse systematic feedback, learning, and redirection to optimize the value of objectives of user food consumption and manage the associated loss and waste. The ontology provides a framework for such feedback, learning, and redirection in research, policies, and practices.

Mapping the state-of-the-research on, -policies for, and -practice of FLW will highlight the gaps in each and the gaps in translation between the three. It will highlight the elements and themes that have been: (a) frequently emphasized, (b) infrequently emphasized, and (c) never emphasized. From such a systematic analysis one can conclude about: (a) pathways that have been effective and must be reinforced, (b) pathways that have been ineffective and must be redirected, and (c) pathways that have not been explored and must be researched.

3. Conclusions

The paper presents a unified definition of food consumption, loss, and waste as an ontology. It relates the ontology to the other extant definitions of the construct and assesses them systematically to integrate the definition of FLW and address their lacunae. With the increasing demand of sustainable practices for food consumption and reducing the food loss and food waste in the system, it becomes important to understand the system. The framework helps to define the construct to include all three - food consumption, food loss, and food waste. It can help understand the dynamics of the full spectrum of stages, their impact on consumption, loss, and waste, and the complete knowledge cycle associated with it.

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