Expert Systems with Applications 41 (2014) 7328–7337

Contents lists available at ScienceDirect

Expert Systems with Applications

journal homepage: www.elsevier.com/locate/eswa

A hybrid fuzzy evaluation method for safety assessment of food-waste feed based on entropy and the analytic hierarchy process methods

Ting Chen [a], Yiying Jin [a,*], Xiaopeng Qiu [b], Xin Chen [a]

[a] School of Environment, Tsinghua University, Beijing 100084, China
[b] China Urban Construction Design & Research Institute, Beijing 100120, China

ARTICLE INFO

Article history:
Available online 12 June 2014

Keywords:
Food-waste feed
Product safety
Fuzzy mathematics
Entropy method (EM)
Analytic hierarchy process (AHP)

ABSTRACT

The product safety of food-waste feed is the key factor limiting the development of its industrial chain. In this paper, we construct a method based on data from the testing of food-waste feed with comprehensive evaluation of its product safety by integrating fuzzy mathematics effectively, i.e., the entropy method (EM), and the model of the analytic hierarchy (AHP) process. Furthermore, a hierarchical three-level evaluation-index system including biological-safety and chemical-safety considerations is first established via data analysis, data surveys and expert experiential investigation as well, with an actual case in China being fully applied. In addition, we apply the EM and AHP process to calculate the weights of the individual evaluation indices. Finally, through the dimensionless treatment of test data from samples, we determine the degree of membership of each test value relative to the different levels of safety using a trapezoidal membership function. By adopting the developed three-level model of fuzzy mathematics for comprehensive evaluation, we derive the safety grades of tested samples. The comprehensive evaluation method developed in this paper can effectively overcome the shortcomings of traditional single-factor evaluation and offer the qualitative and quantitative advantages of expert survey and basic data research as well. As a result, it is considerably applicable for the product-safety analysis and production control of animal feed generated from food waste.

1. Introduction

The safety of feed produced from food waste is closely related to both human and animal health and a key factor influencing the market acceptance and industrial-chain development of treatment processes for food-waste feed (Lin, Wu, Lee, & Kuo, 2011). Therefore, the safety of food-waste feed has been a matter of concern to government regulators and entrepreneurs for a long time, and it is also a subject of intense research (Elferink, Nonhebel, & Moll, 2008; Viana, Schulz, & Noronha, 2003; Westendorf, 2000).

Similar to other issues of food safety, most current studies on the safety of food-waste feed are focused on the evaluation of single-factor indices, such as pathogens, heavy metals, organic pollutants or/and nutrients. Sancho, Pinacho, Ramos, and Tejedor (2004) offered a one-year microbiological analysis on food waste collected from the supermarkets, shops and restaurants for animal feeding; Jin, Chen, and Li (2012) investigated the inactivation of hygienic microbial indicators during hydrothermal process from food waste- amended animal feed. Li, McCrory, Powell, Saam, and Jackson-Smith (2005) determined the heavy metal content of 203 typical dairy ration components sampled from 54 dairy farms in Wisconsin. Sayeki, Iga, Suzuki, Sunakawa, and Abe (2002) evaluated protein digestibility of dehydrated food waste manufactured with different heating temperatures (60 °C, 80 °C, 100 °C, 130 °C) and durations (3 h, 8 h) for swine feed.

However, there have been few systematic comprehensive studies in feed safety. Yang, Ji, Baik, Kwak, and McCaskey (2006) studied the effects of lactic acid fermentation on the microbial physical and chemical properties of food waste for swine feed. García, Esteban, Márquez, and Ramos (2005) examined the safety issues involved in using food waste as a primary ingredient in animal feed, from the perspectives of nutritional properties, microbiological contamination, metal content and PCDD/F pollution. These papers always presented the feed safety status through the one–one index enumeration, with the shortage of comprehensive description on overall safety status.

Conventional research approaches to the evaluation of feed safety, such as toxicological or animal-feeding experiments (Kwak & Kang, 2006; Westendorf, Dong, & Schoknecht, 1998), are the most direct methods characterizing product safety (Nam et al., 2000), but the cost of these approaches is relatively high,

* Corresponding author. Tel.: +86 10 62794352; fax: +86 10 62797618.
E-mail address: supcql@gmail.com (Y. Jin).

http://dx.doi.org/10.1016/j.eswa.2014.06.006
0957-4174/

and they are time-consuming as well. It is difficult to determine the present status of various safety factors in a product and the overall safety status of a product in a timely manner. Moreover, the practical guidance being offered from an engineering perspective is rather limited.

On the other hand, in the existing legal provisions (EU: Regulation (EC) No. 1069/2009, 2009; FDA, 1997; NACFPFR, 2008; NPCC, 2006; US, 1980), although it is clearly specified that food-waste feed "should not have an impact on the health of animals or human beings", there are still no specific requirements for the methods and criteria used to quantify such impacts. In China, for example, currently, there exist various food-waste feed treatment methods based on different techniques, including direct cooking, moist–heat treatment and biological fermentation. However, because the assessment of the safety of food-waste feed involves many indices and the level of hazard can vary widely, no dedicated regulations on the safety of food-waste feed have been established yet in China. In any case, a safety benchmark based on only one specific index can serve basically to ensure that the relevant feed- or food-related requirements may be satisfied with the results of compliance tests, but it cannot distinguish the overall safety status of products or characterized differences among indices. Therefore, it is significantly important to apply a mathematical model to identify the safety of food-waste feed effectively in a timely manner.

Food/feed safety problems are very complicated and require numerous factors considering, ranging from microbial aspects to chemical ones. Qualitative and quantitative data always exist simultaneously in real multiple criteria assessment situations. Over the past decades, there has been a rapid growth in the number of multiple criteria decision-making methods to assist the product/service quality or safety evaluation, such as TOPSIS (Technique for order preference by similarity to ideal solution), COPRAS (Complex proportional assessment), AHP (Analytic hierarchy process), SAW (Simple additive weight), etc. (Déjus & Antuchevičieé, 2013; Hashemkhani Zolfani, Sedaghat, & Zavadskas, 2012; Hsueh, Lee, & Chen, 2013; Kildiené, Kaklauskas, & Zavadskas, 2011). Particularly, Zou, Li, and Dai (2010) established an appraisement model of meat products safety monitoring system by AHP, with a comprehensive consideration on influence of the single factor and the interaction among them. Kadir et al. (2013) designed a fuzzy logic-based food supply security risk level assessment system to determine the whole level of prevailing food security risk by monitoring various but independent risk elements with food supply systems. Most of these studies apply only a multi-criteria theory, and the weights of factors are made by AHP based on humans' judgments. The human has significant impact on the assess results, which lead these researches becoming less scientific and rational. In addition, none of work was specifically related with particular feed product.

The safety of food-waste feed is a relatively fuzzy concept, and there is no absolute definition on describing safety or unsafety. To overcome the shortcomings of traditional single-factor evaluation, we adopted the theory of fuzzy mathematics to quantify various risks associated with food-waste feed for comprehensive multi-factor evaluation and developed a comprehensive evaluation method for the safety of food-waste feed. Fuzzy multi criteria decision making techniques are appropriate tools to prioritize under sophisticated environment (Fouladgar, Yazdani-Chamzini, Lashgari, Zavadskas, & Turskis, 2012; Hung, Yang, Ma, & Yang, 2006; Kahraman, Suder, & Cebi, 2013; Soto-Zarazúa, Rico-García, Ocampo, Guevara-González, & Herrera-Ruiz, 2010). The theory of fuzzy mathematics is primarily based on the concept that changes in the objective character of matter exhibit indistinguishable features during intermediary transitions and that a membership function should be applied to describe the intermediary transitions through which changes occur. It applies precise mathematical language to describe and judge the fuzziness of a given problem. Since this theory was first developed by Zadeh in 1965, it has been widely applied in the fields of traffic management (Celik, Er, & Ozok, 2009; Ozkoka & Cebi, 2014; Wang et al., 2014), pattern recognition (Cho & Lee, 2013; Hsu, Chen, & Tzeng, 2007; Im & Cho, 2013), market decisions (Boran, Genc, Kurt, & Akay, 2009; Cakir & Canbolat, 2008; Chen & Wang, 2013; Fouladgar, Yazdani-Chamzini, & Zavadskas, 2011; Kar, 2014; Zhang, Zhou, Zhou, & Chen, 2014; Zolfani, Rezaeiniya, Pourhossein, & Zavadskas, 2012), technological comparison (Cheng, 2013; Tsai & Chang, 2013) and risk assessment (Kadir et al.,2013; Qi, Liu, Liu, & Yao, 2013; Radivojević & Gajović, 2014; Xu, 2010) etc. However, it is rarely applied in the field of food/feed safety evaluation (Debjani, Das, & Das, 2013; Shi & Wang, 2010; Zou et al., 2010).

Simultaneously, developments of fuzzy theory motivated us to explore the possible application in feed safety evaluation. Considering the sophisticated factors, including qualitative indices as well as quantitative indices, the single entity always presents some drawbacks in assessing the safety of food-waste feed. For instance, AHP has inherent excellent ability to handle qualitative indices and less cumbersome mathematical calculations, based on the support of expert system (Aghdaie, Hashemkhani Zolfani, & Zavadskas, 2013; Ertay, Kahraman, & Kaya, 2013; Fouladgar et al., 2012) but it cannot solve involved uncertainties and subjectivities (Chen & Wang, 2009). The entropy method (EM) could reflect the index's utility value with relatively high correlation based on the information entropy, while it is relatively strict in the text numbers and values. Thus, solving multivariate evaluation problems with relative independent, fuzzy measures can be used for weighting the criterion and their combination by the merger of AHP and EM methods. Our proposed work can be seen as a fuzzy evaluation framework where fuzzy numbers are used in linguistic scales, and the weights of each index are given by the AHP and EM methods. The insertion of AHP and EM methods in fuzzy mathematics evaluation makes weigh value more scientific and rational and it can reflect the degree of various factors on the importance of holistic safety and evaluation level better, by taking advantages of qualitative and quantitative data as much as possible. Thus, the hybrid method gives a new look to the fuzzy evaluation framework, which could be used in the multivariate assessment.

Specifically, to improve the accuracy of the method to a proper extent, we must introduce a large number of indices or sources of expert information. Because of the differences among the indices used to characterize the safety of food-waste feed, including the degree of quantification and the accessibility of basic data, in this paper, we introduce the AHP and EM process to determine each index and its weight. In particular, we adopt the EM to determine the weights of some indices with relatively high degrees of quantification, such as heavy metals, by combining the results of surveys of the basic data concerning these indices, whereas we adopt the AHP to determine the weights of less quantitative indices. Finally, this paper establishes an assessment method using fuzzy mathematics based on the AHP and EM process to evaluate the safety of food-waste feed, and an actual engineering case is assessed to illustrate the application of method as well.

2. Safety of food-waste feed and its evaluation indices

Food-waste feed is considered to be "safe" if the feed product produced from food waste does not contain toxic or harmful substances and does not involve materials that will cause actual harm to the health and production performance of animals reared on the feed; the safety of food-waste feed involves many aspects, including environmental health, food safety and environmental