TRACEABILITY AND MANAGEMENT INFORMATION SYSTEM OF AGRICULTURAL PRODUCT QUALITY SAFETY IN CHINA

Yang Xinting[1,2]*, Li Ming[1,3], Sun Chuanheng[1,2], Qian Jianping[1,2], and Ji Zengtao[1,2]

1. National Engineering Research Center for Information Technology in Agriculture, Beijing, China; 2. Key Laboratory for Information Technologies in Agriculture, Ministry of Agriculture, Beijing, China; 3. College of Information and Electrical Engineering, China Agricultural University, Beijing, China

ABSTRACT

Agricultural product quality safety is the hot topic in the world. From the technical view, the agricultural production management and traceability are the key measurement for insuring the quality safety. From 2005 until now, we have been investigating the information technology support for improving the management and traceability level of product quality, such as barcode, RFID, PDA/Cell Phone, MIS, electronic scale, GIS, GPS, GPRS and decision support models, etc. We have developed six techniques, four equipments and six kinds of information systems. The six techniques include ①individual identification and coding, ②barcode generating and printing middleware, ③barcode encryption and decryption, ④RFID middleware, ⑤GAP-based (good agricultural practices) early warning, ⑥XML-based data transferring. The four equipments ①portable real-time record-keeping equipments for agricultural production, ②portable intelligent dispatching equipments for agricultural products, ③portable supervision equipments for agricultural products, ④control equipments for agricultural product sale. The six kinds of information systems are ①environmental evaluation systems for agricultural fields, ②management information systems for agricultural safe production, ③wholesale market management system, ④logistics management system, ⑤agricultural product quality safety supervision and traceability systems and ⑥emergency management systems for agricultural product quality. Until Nov. 2009, we have developed the management and traceability systems for aquatic products, vegetables and fruits, as well as livestock, and applied them in Beijing, Tianjin, and Guangdong, China. The application has gained significant economical, social and ecological benefits.

Keywords: Traceability, management information system, agricultural products, quality safety, RFID, barcode

INTRODUCTION

ISO 22005-2007 defined traceability systems as “a technical tool to assist an organization to conform with its defined objectives and is applicable when necessary to determine the history, or location of a product or its relevant components”(The International Organization for Standardization, 2007). Recently, the information and communication technology (ICT) is used to support and improve the practical implementation of traceability systems (Pinto et al. 2006). The traceability systems are popular in the developed countries, such as USA, Canada, Japan and New Zealand (Matsuda 2005; Schwagele 2005; Smith et al. 2005; Shanahan et al. 2009), and extended to the developing countries like China, etc (Wang et al. 2005; Qu et al. 2007; Sun et al. 2007).

However, the traceability systems encountered many difficulties. Firstly, for the small-scale and scattered agricultural production in China, the results that production recordkeeping and its transfer are inefficient have prevented the wide application of traceability systems in China (Dong and Jensen 2004). With the mobility and computability, Personal Digital Assistant (PDA) and cell phones provide a new way for agricultural information portable collection to solve the above problems. Secondly, in China, the logistics management systems have to deal with many different distributors or wholesalers (Jiang and Prater 2002) to achieve the goal of traceability from the farms to tables. So many information management systems are needed for different and complex logistics link. Thirdly, because the package level of agricultural products is lower than other goods, especially the labels, the barcodes and RFID technologies are needed for ultimate product traceability in the Point of Sales. Finally, China is a vast and varied country, so the authorities need supervision, emergency management, and data exchange platforms. Therefore, it is essential to investigate the solution including some key techniques, equipments and information systems by China’s situation and custom. So we conducted systematic research on traceability and management information system of agricultural product quality safety, and applied the achievements in China.

SYSTEM ARCHITECTURE

Based on long-term requirement investigation and analysis, we summarized the data flow in agricultural product quality safety information service (Fig.1). The whole system was under directed by functional departments, such as the Bureau of Agriculture and Administration of Industry and Commerce, et al. We discriminated between subjects of supervision and responsibility, and divided the procedure between information transfer and commodity circulation. The goal is developing an agricultural product traceability and management system from production, circulation, retail to consumption.

KEY TECHNIQUES

In this part, the key techniques in the systems were described. The barcodes and RFID are common technologies in the traceability and management information systems, which include individual identification and coding, barcode generating and printing middleware, barcode encryption & decryption and RFID middleware. GAP (good agricultural practices) are defined as general practices to reduce food safety hazards in the agricultural productions, early warning and risk analysis is the hot and difficult topic for GAP application. The XML-based data exchange between various nodes on agricultural product supply chains and the center of traceability systems were essential for government supervision and traceability mode.

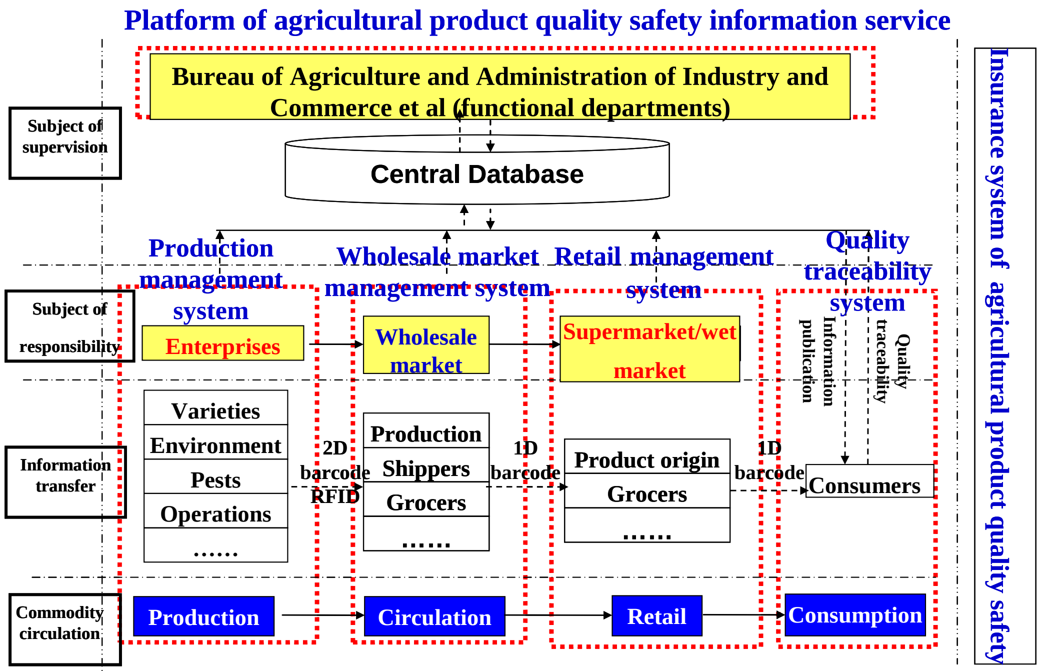


Fig.1 The architecture of traceability and management information system of agricultural product quality safety in China (Ji et al. 2007)

Individual identification and coding

According to the individual characteristics, package styles and production ways of different agricultural products, the batch identification method was used for fruit, vegetable and fishery products. The agricultural products harvested in the same day, production unit (plot, greenhouse or pool), variety and grade, were defined as the same batch and quality (Yang et al. 2006; Yang et al. 2007). In practice, the identification method used linear, 2D or mixed barcodes according to the requirement of enterprises (Fig.2). For livestock products, the individual identification method was used. Considering the product status and operation during the flow from the farm to the slaughterhouse, processing plant, storage and distribution, the quality safety information transferring from the individual animal to ultimate product was realized using information exchange between RFID and barcode(Sun et al. 2007). For traceability purposes, an EAN 128 barcode is used to encode the identification and supplementary information relating to an item, such as production date and famers' information.

Fig.2 Agricultural product traceability code (Sun et al. 2010)

Barcode generating and printing middleware

Based on the component programming technology, the EAN 128 barcode was generated. Combining with barcode debug theory and algorithms, the barcode identification was realized with great precision, the barcode printing was made device-independent, and the barcode generating was seamlessly integrated with production flow.

To decrease the cost of traceability system and increase the capacity of information, a universal alignment pattern method was proposed based on a thorough study of national standard of Chinese-sensible code, an algorithm of sampling grid above the 4th version was improved, the key technologies were broken through, such as mixed encoding, RS error correcting and midpoint extracting of detection pattern, and a Chinese-sensible code encoding and decoding engine was set up by NET 2.0 platform. Fig.3 showed the Chinese-sensible code in version 23 generated by 240 Chinese characters (data storage was 453 bytes). The results show that the proposed algorithm can perform feasibly and reliably, and the generated engine has high speed and accuracy (Ding et al. 2008).

Barcode encryption and decryption

Encryption can be used to totally secure the contents of the 2D barcode, which provides effective techniques for agricultural product quality safety supervision and anti-counterfeiting. We combined DES and RSA encryption technology to encrypt the original information, then used dispersed fractional Fourier double random phase encode technology to encrypt the 2D barcode image, and got the final two-dimension barcode. When decoding the 2D barcode, firstly, we decoding the 2D barcode image, then decoding the information in 2D barcode to get the original information(Fang and Fu 2009).

Fig.3 Structure of the Chinese-sensible code in version 23 (Ding et al. 2008)

RFID middleware

For masking the incompatibility of standards between tags and readers and making the information flow smoothly in the different chains of agricultural product traceability systems based on RFID, the RFID middleware was investigated. Based on ALE (application level event) conventions, we investigated the non-blocking I/O mechanism of data stream transfer, multi-thread concurrent access and bulk data transmission technologies. Then the Web-service interfaces facing supply chain were constructed, which were compatible with industrial mainstream RFID readers/writers and supported concurrent access of multi RFID readers/writers (Fig.4). The middleware can manage distributed readers, and filter redundancy data and extract semantic message, and share message by publish/subscribe model. The agricultural product safety traceability system, based on this layered architecture, can reduce the cost of application and maintenance of RFID for agricultural product companies, and ensure the effective and real-time information share among different chains in the traceability system.

GAP-based early warning

Integrating plant disease epidemiology, early warning theory, risk analysis theory and the CHINAGAP standard, the flow chart of an early warning system for cucumber downy mildew is shown in Fig.5. The logic courses included warning indicators analysis (infection model), warning indicators analysis (incubation period and symptom appearance model), warning source searching, provide warning, warning obviation, risk assessment, risk management and risk communication (Yang et al. 2007).

XML-based data transferring

The issues of data exchange between various nodes on supply chain and the center of traceability system were needed to address for traceability based on government supervisor mode. The eXtensible Markup Language (XML), an advanced language standards for Internet, is capable of modeling any data structure and used as a main tool for information sharing on WWW. Based on analysis of data flow of supply chain, the data model of traceability on vegetable products was summarized. Aiming at fulfilling seamless exchange of data, an XML-based vegetable traceability markup language (VTML) was established and an XML-based schema for vegetable traceability (VTML schema) was designed (Fig.6). The application result showed that the differences of heterogeneous databases were shielded by setting up data mapping between VTML document and data source. It is proved that the mode of data exchange based on VTML is an effective approach to achieving the traced data synchronization (Yang et al. 2007).

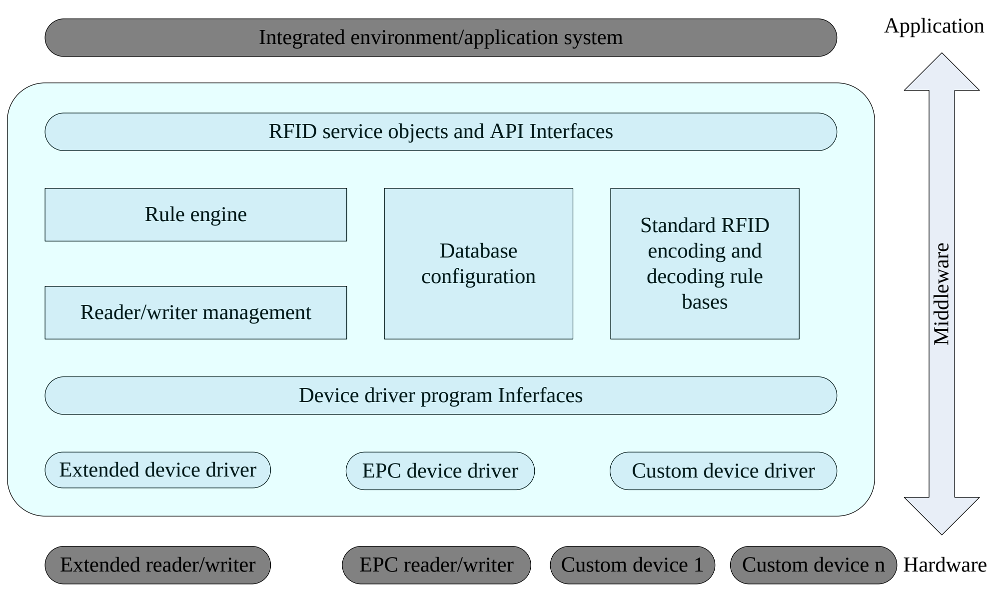


Fig.4 RFID middleware architecture

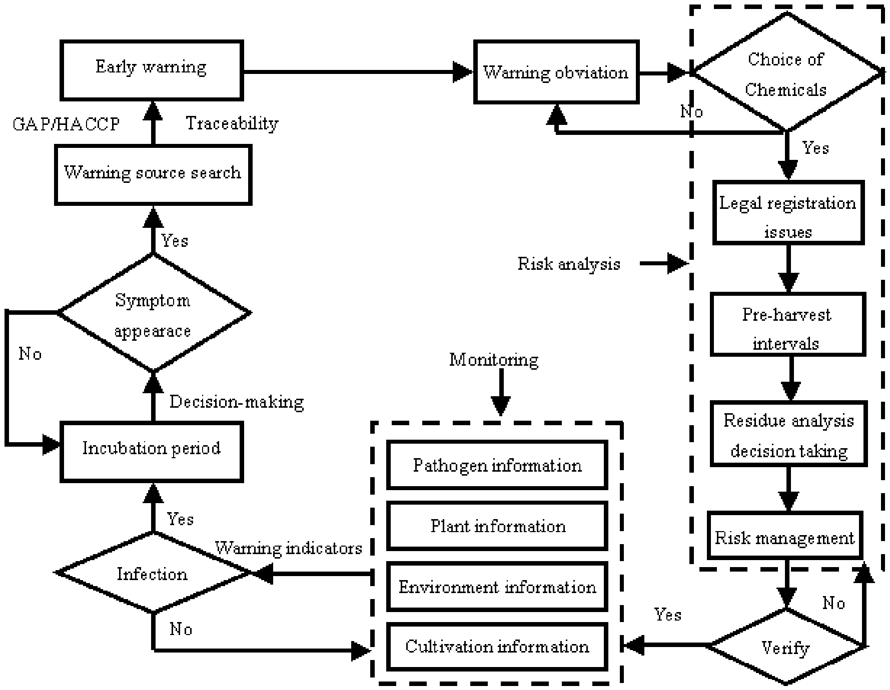


Fig. 5 The model structure of early warning and risk analysis for cucumber downy mildew(Yang et al. 2007)

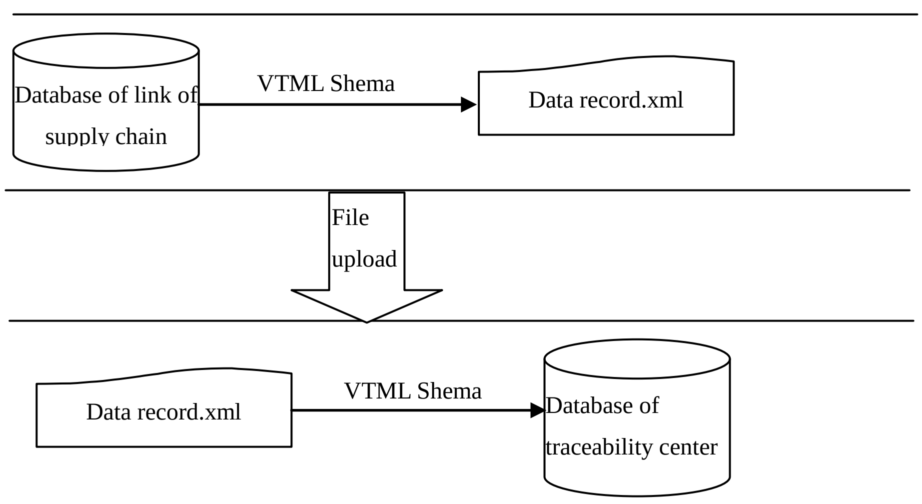


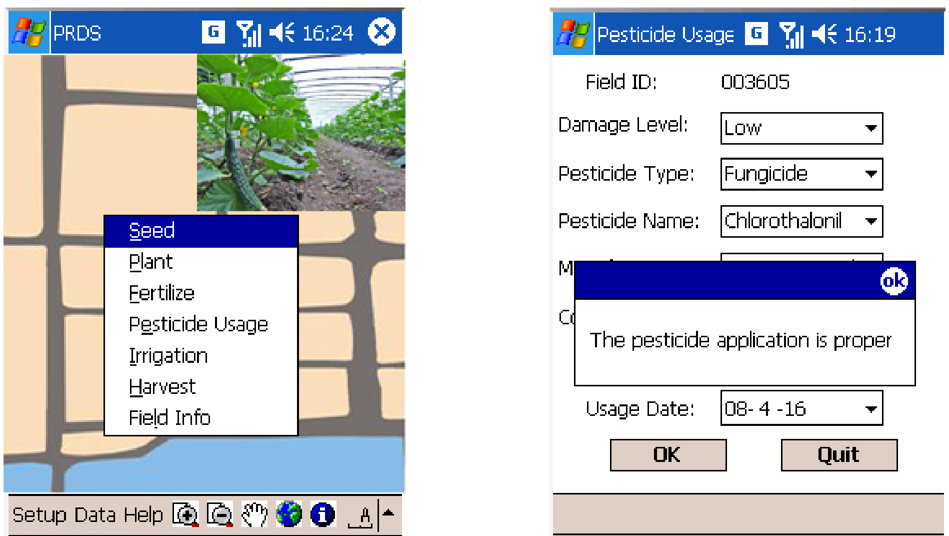
Fig.6 Model for data exchange based on VTML(Yang et al. 2007)

INTELLIGENT EQUIPMENTS

The portable real-time record-keeping, intelligent dispatching and supervision equipments for agricultural production were investigated to solve the first problem described in introduction, and control equipments for agricultural product sale were developed for the third problem.

Portable real-time record-keeping equipments for agricultural production

A PDA-based Record-keeping and Decision-support System (PRDS) for traceability in cucumber production was developed on Windows Mobile platform invoking a Geographic Information System (GIS) control (Li et al. 2010). For improving the decision making feasibility of PRDS, the fertilization recommendation model and pesticide usage early warning model were developed by using the Technical Specification of Balanced Fertilization by Soil Testing and the Guideline for Safety Application of Pesticides in China. The architecture of PRDS was provided. With Unified Modeling Language (UML), a requirement model including two types of users and 17 use cases was described, and a static class model was also designed, which consisted of table class, table operation class, algorithm class and interface class. Based on these models, the functions of system setup, map management, data management, production record-keeping and decision-support and query, etc., were implemented by adopting Hosting MapInfo MapX Mobile Controls on the .NET Compact Framework 2.0, and the data synchronization was realized by Remote Data Access (RDA) (Fig.7).



(a) Select items of production operation (b) Record keeping and decision making results

Fig.7 Interfaces of the PDA-based Record-keeping and Decision-support System (Li et al. 2010)

Also the cellular phone are becoming increasingly prevalent, which can offer great convenient for farming data recording. Therefore, in order to improve the farm product yield and make efficient management on agricultural production, a J2ME based production data recording system for farming (JRSF) was developed (Zhao et al. 2009)

Portable intelligent distribution equipments for agricultural products

Agricultural product distribution is an important part of the whole supply chain. For ensuring quality safety of agricultural product in the process of distribution, it is most important to obtaining quickly and managing precisely the loading and unloading information, and supervising effectively the distribution process. The framework, function and database of portable intelligent distribution system (PIDS) were designed and the data update mechanism was planed. The data synchronization development with RDA and implement steps of loading with barcode scanning was realized, and the PIDS was implemented with vs.net. The operation of the PIDS requires supports of GPS/GPRS/GSM modules (Fig.8) (Qian et al. 2009).

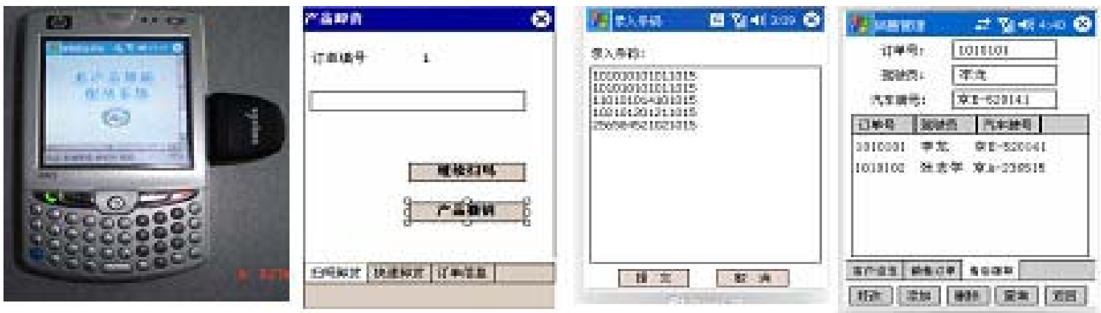


Fig.8 Interfaces of portable intelligent distribution system (Qian et al. 2009)

Portable supervision equipments for agricultural products

To enhance the standard production, ensure the authority of agricultural product certification systems, and protect the legal benefits of consumers and production bases, the 2D barcode-based supervision system for agricultural product certification was designed and developed, which included agricultural product quality standards, quality certification, technique extension, security enforcement, etc (Fig.9). The 2D traceability barcodes can store the origin identification and product certification information and encrypt them for anti-counterfeit in traceability. Through generating and distributing encrypted 2D barcodes, the system combined product labels and certification marks, which was a new investigation of agricultural product certification and supervision method.

Control equipments for agricultural product sale

The sale control machine for agricultural products was developed and used for quality traceability in the circulation of agricultural products, including weighting products, status identification, mixed barcode printing, and wireless upload of agricultural transaction information (Fig.10). The existed responsibility management method of “request inspection certificates” was transformed into the “credible circulation” process control system, which provided strong support for the establishment of agricultural products traceability system(Sun et al. 2010). The equipments supported one-dimensional code system, such as EAN-13, EAN-128, etc., and two-dimensional code system, such as QR codes, Chinese letter code, DataMatrix, etc. Their printing speed was 100mm/s high, and the information of agricultural production date, shelf-life date, producer, weight information was printed on the label through text, numbers, one-dimensional code, two-dimensional code, etc., so as to provide convenience for tracing agricultural product information.

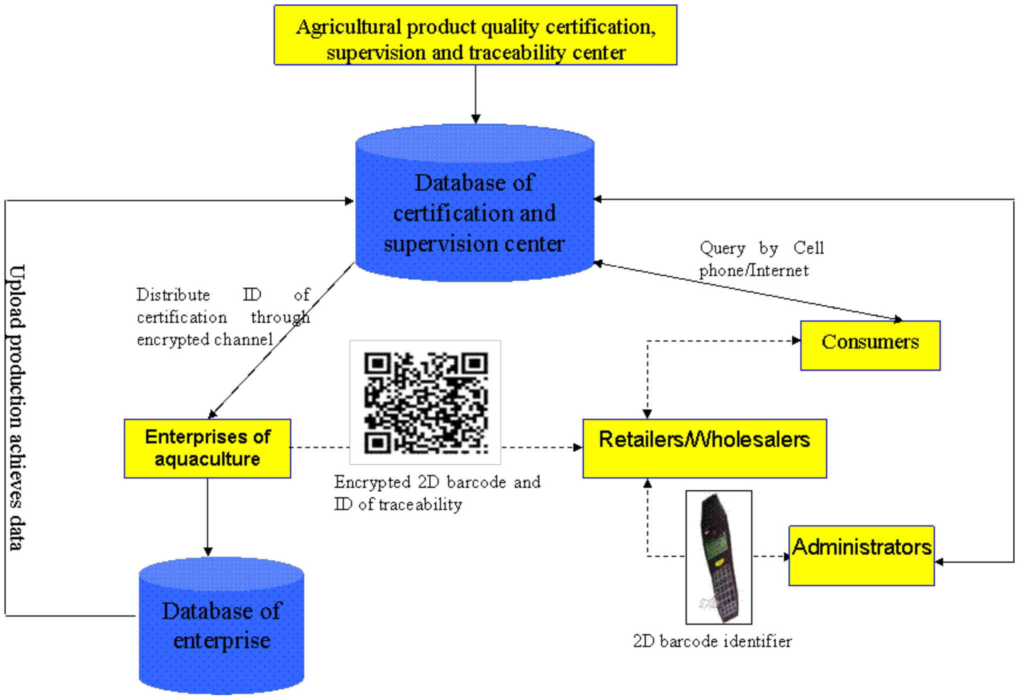


Fig. 9 Platform of agricultural products quality and safety supervision and traceability

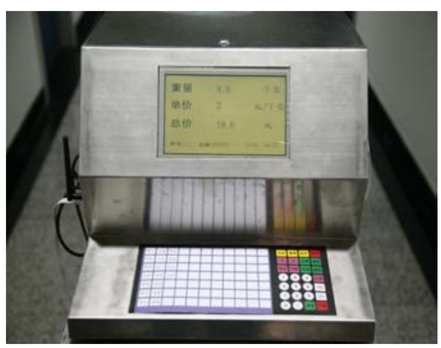


Fig.10 Control equipments for agricultural product sale

INFORMATION SYSTEMS

Corresponding with the complex and long supply chain in China, the environmental evaluation systems for agricultural fields, management information systems for agricultural safe production, wholesale market management system and logistics management system were researched and developed for solving the second problem in introduction. The agricultural product quality safety supervision and traceability systems and emergency management systems were investigated to provide decision support services for authorities, which were a solution for the final problem described in introduction.

Environmental evaluation systems for agricultural fields

In order to support decision-making for relevant departments and simplify the process of management, the environmental evaluation system was designed and implemented (Fig.11), which integrated the environmental evaluation of pollution-free food, green food and organic food producing area, and the visualization management between spatial date and attribute date was achieved using GIS and Mapobjects (Zhou et al. 2007).

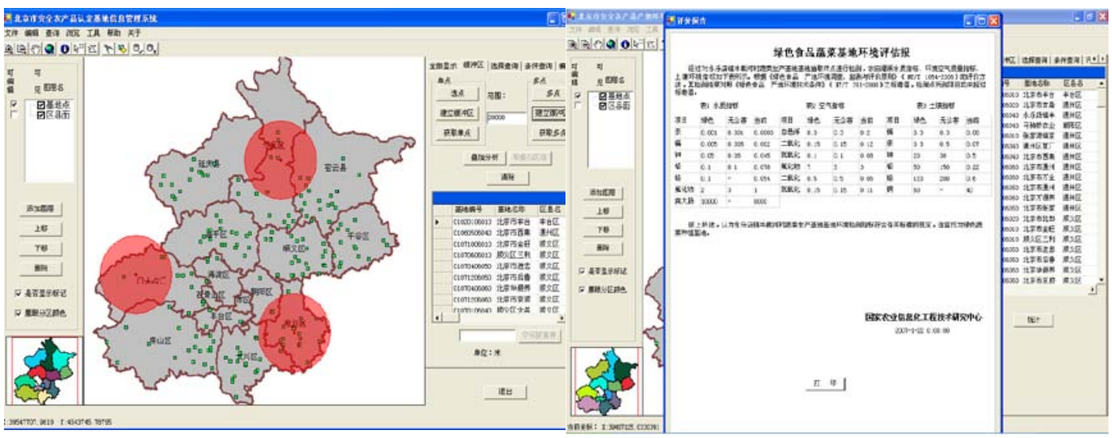


Fig. 11 Interfaces of environmental evaluation systems for agricultural fields(Zhou et al. 2008)

Management information systems for agricultural safe production

A safe production and quality traceability system was established to implement quality tracing for agricultural products. Based on .net framework, the system was implemented with the technologies of database, network, encoding and early warning. The system realized the functions of production management, production early warning, statistical comparison, bar code printing, short message communication, quality feedback, health guidance for consumers and so on. This study laid a basis for realization of quality traceability of the whole process from farm production to consumer tables (Fig. 12).

Fig. 12 Main interface of management information systems for agricultural safe production(Yang 2008)

Wholesale market management system

Facing the requirements of wholesale market management and aiming for management of market access permit and market transactions, the information management systems were developed for wholesale markets with different levels of informatization. The system was divided into three models: electronic scales, signing, and direct sales. It could provide bills of sale with barcode and signature (Fig. 13).

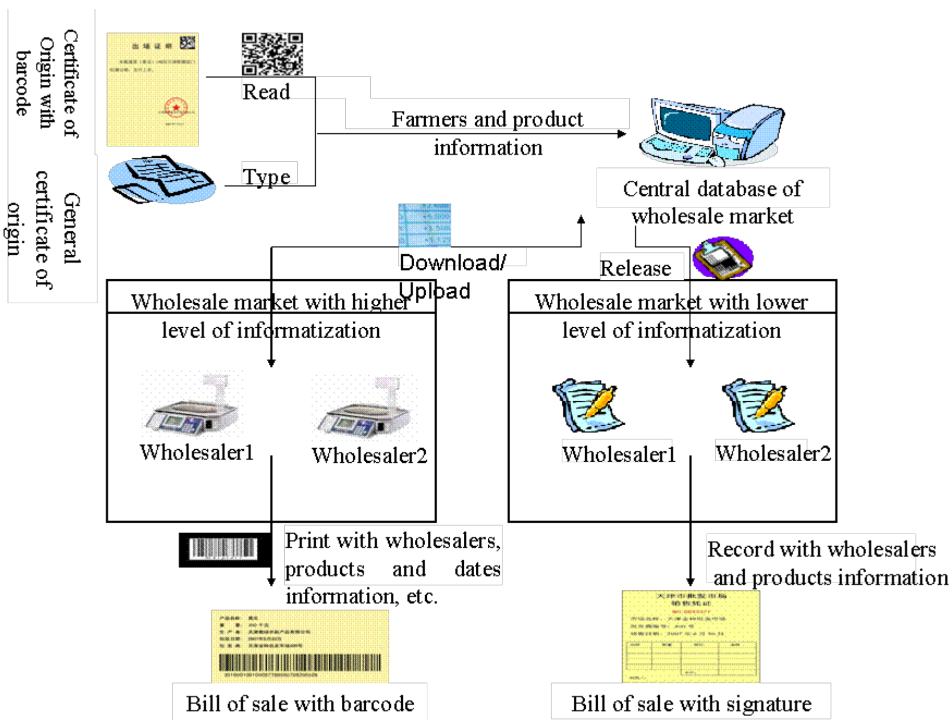


Fig.13 Architecture of management system of wholesale market(Liu et al. 2008)

Logistics management system

According to the link of agricultural product logistics, combing the RFID middleware and information management of agricultural product logistics, the network environment of application in logistics enterprises was constructed, and the rewritable RFID-based logistics management system was developed to realize the automatic collection of in-out storage information and data transfer between retail units and freight transportation.

Agricultural product quality safety supervision and traceability systems

Facing the link of agricultural product supervision, combing the production base identification, digital management of product certification and constructed techniques of agricultural production field environment evaluation model, the database including production base, production record, logistics and sale information was constructed, and the agricultural product quality supervision system was developed for government departments to realize the certification and anti-counterfeit management. Integrated with data communication techniques of different traceability platforms, the traceability system combing computer networks, wireless communication networks and telephone networks was constructed. The agricultural product quality traceability system with different trace methods, such as websites, POS machines, short messages and telephone numbers was developed to meet the requirements of consumers and improve the agricultural product quality safety level (Fig. 14).

Fig.14 Agricultural product quality safety supervision and traceability systems

Emergency management systems for agricultural product quality

Aiming for emergency management of agricultural product quality safety, based on the traceability information, the emergency management flows for agricultural product quality were designed, and the quality safety event diffusion model and evaluation model were constructed. The system was developed using ArcGIS Server and could provide decision support of agricultural product quality emergency management for authorities (Fig. 15).

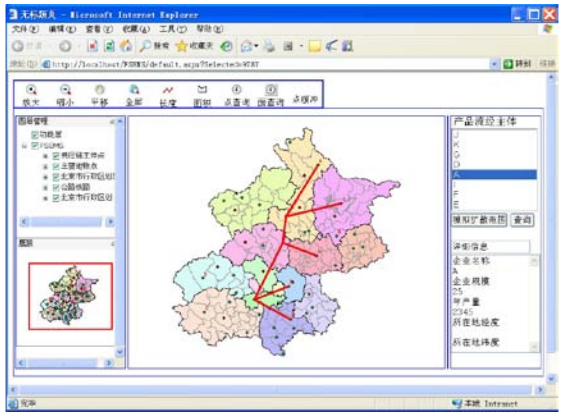


Fig.15 Emergency management systems for agricultural product quality(Wu et al. 2010)

CONCLUSION

Until Nov. 2009, we have developed the management and traceability system for aquatic products, vegetables and fruits, as well as livestock, and applied them in many areas of China, i.e. Beijing, Tianjin, Guangdong, etc. The system tests in enterprises were promising and satisfying. The level of production management was improved and the sensitivity of consumers to food safety was enhanced after adoption of the traceability and management system.

ACKNOWLEDGMENTS

This work was funded by the Hi-Tech Research and Development Program of China (No: 2006AA10Z265), National Key Technology R&D Program (No: 2006BAD10A08 and 2008BADA8B03) and Beijing Science & Technology Commission project (Z09090501040901).
***Corresponding author:** Dr. Yang Xinting. China National Engineering Research Center for Information Technology in Agriculture (NERCITA)
Address: Room 307, Building A, Beijing Nongke Masion, 11# Shuguang Huayuan Middle Road, Haidian District, Beijing, China, 100097
Tel: ++8610-51503476, Fax: ++8610-51503750, Email: yangxt@nercita.org.cn

REFERENCES

Ding, Y.J., X.T. Yang, J.C. Zhang, C.H. Sun, J.P. Qian, and Z.T. Ji. 2008. Chinese-sensible code encoding and decoding engine for agricultural product quality traceability system. (In Chinese, with English abstract.) Trans. CSAE. 24 (Supp.2):161－165.

Dong, F., and H.H. Jensen. 2004. The challenge of conforming to sanitary and phytosanitary measures for China's agricultural exports. MATRIC Working

Paper 04-MWP 8.
Fang, Y., and H. Fu. 2009. The research of two-dimension bar code encrypt. (In Chinese, with English abstract) Electronic Technology (Shanghai):42-43.
Ji, Z.T., X.X. Liu, J.P. Qian, C.H. Sun, and X.T. Yang. 2007. Towards developing a quality safety attestation and supervision information system for farm products in china. p. 533-536. *In* C.J. Zhao (ed.) 4th International Symposium on Intelligent Information Technology in Agriculture. China Agricultural Science&Technology Press, Beijing.
Jiang, B., and E. Prater. 2002. Distribution & logistics development in china: The revolution has begun. International Journal of Physical Distribution & Logistics Management 32:783-798.
Li, M., J.P. Qian, X.T. Yang, C.H. Sun, and Z.T. Ji. 2010. A PDA-based record-keeping and decision support system for traceability in cucumber production. Comput. Electron. Agr. 70:69–77.
Liu, X.X., L. Ma, C.H. Sun, X.T. Yang, Y.J. Ding, and Z.T. Ji. 2008. Design and realization of fishery products circulation quality traceability system. (In Chinese, with English abstract) Agriculture Network Information.12: 22-24.
Matsuda, T. 2005. Gap as a baseline, traceability as a pipeline to build consumer confidence. Proc. International seminar on Technology Development for Good Agricultural Practice (GAP) in Asia and Oceania, Tsukuba, Japan.
Pinto, D.B., I. Castro, and A.A. Vicente. 2006. The use of tic's as a managing tool for traceability in the food industry. Food Res Int. 39:772-781.
Qian, J.P., X.T. Yang, M. Li, Z.T. Ji, and C.H. Sun. 2009. Portable intelligent distribution system for agricultural product based on PDA. (In Chinese, with English abstract.) Trans. CSAE. 25 (Supp.2): 298－302.
Qu, X.H., D.F. Zhuang, and D.S. Qiu. 2007. Studies on GIS based tracing and traceability of safe crop product in China. Agricultural Sciences in China 6:724-731.
Schwagele, F. 2005. Traceability from European perspective. Meat Sci. 71:164-173.
Shanahan, C., B. Kernan, G. Ayalew, K. McDonnell, F. Butler, and S. Ward. 2009. A framework for beef traceability from farm to slaughter using global standards: An Irish perspective. Comput. Electron. Agr. 66:62-69.
Smith, G.C., J.D. Tatum, and K.E. Belk. 2005. Traceability from a US perspective. Meat Sci. 71:174-193.
Sun, C.H., Z.T. Ji, X.T. Yang., X. Han, and Z.L. Wang. 2007. A traceability system for beef products based on radio frequency identification technology in china. New Zeal. J. Agr. Res. 50:1269-1275.
Sun, C.H., X.X. Liu, Y.J. Ding, W.Y. Li, D.L. Li, and X.T. Yang. 2010. Design and realization of agricultural products circulation traceability system based on linux embedded technology. (In Chinese, with English abstract.) Trans. CSAE. 26 (4): (In press).

Sun, C.H., X.T. Yang, X. Han, W.Y. Li, and L.N. Li. 2010. Application of the chinese-sensible code in aquatic product quality traceability system. (In Chinese) China Auto-ID.(3): (In press).

The International Organization for Standardization. 2007. Traceability in the feed and food chain-general principles and requirements for system design and implementation. ISO 22005: 2007, Switzerland.

Wang, L.F., C.H. Lu, and J.F. Xie. 2005. Review of traceability system for domestic animals and livestock products. (In Chinese, with English abstract.) Trans. CSAE. 21(7):168-174.

Wu, X.M., X.T. Yang, J.P. Qian, and X.M. Zhou. 2010. Realization of agricultural products quality safety traceability model supported by ArcGIS server. Journal of Agricultural Mechanization Research. (5): (In press).

Yang, X.T., M. Li, C.J. Zhao, Z. Zhang, and Y.L. Hou. 2007. Early warning model for cucumber downy mildew in unheated greenhouses. New Zeal. J. Agr. Res 50: 1261-1268.

Yang, X.T., C.H. Sun, J.P. Qian, L.P. Chen, and X.X. Liu. 2006. Design and application of barcode traceability label under food safety control. (In Chinese, with English abstract) Chinese Agricultural Science Bulletin 22 (5): 98-101.

Yang, X.T., C.H. Sun, J.P. Qian, L.P. Chen, and X.X. Liu. 2007. Application of UCC/EAN-128 bar code technology in agricultural product safety traceability system. (In Chinese, with English abstract) Computer Engineering and Application 43 (1): 242-244.

Yang, X.T. 2008. Whole-process management and traceability system for farm product quality safety. (In Chinese, with English abstract.) Trans. CSAE. 24 (Supp.2): Back cover.

Yang, X.T., J.P. Qian, C.J. Zhao, X.X. Liu, C.H. Sun, and Z.T. Ji. 2007. Construction of information description language for vegetable traceability based on XML and its application to data exchange. (In Chinese, with English abstract.) Trans. CSAE. 23 (11): 201-205.

Zhao, G.G., L. Zhao, G.F. Chen, and X.T. Yang. 2009. J2ME-based collection system for agricultural production record. (In Chinese, with English abstract.) Trans. CSAE. 25 (Supp.2):190-193.

Zhou, X., X.T. Yang, S.Q. Wang, J.P. Qian, and C.H. Sun. 2007. Design and implementation of environmental evaluation system of safe agricultural product producing area supported with GIS. (In Chinese, with English abstract.) System Sciences and Comprehensive Studies in Agriculture 23 (4): 389-393,398.

Zhou, X., X.T. Yang, S.Q. Wang, J.P. Qian, and C.H. Sun. 2008. Design and practice of information management system for agriculture products standardized production base of Beijing city based on Map objects. (In Chinese, with English abstract.) Chinese Journal of Agricultural Resources and Regional Planning 29 (1):36-40.