Engineering and Technological Outlook on Traceability of Agricultural Production and Products

Linus U. Opara
Department of Bioresource and Agricultural Engineering
College of Agricultural and Marine Sciences, Sultan Qaboos University
P.O. Box 34, Al-Khod 123, Sultanate of Oman. Email: linus@squ.edu.om

Abstract

The demand for verifiable information about product attributes and life history has become a central issue in agriculture and food business. New incidences of food scares and related health hazards such as mad cow disease (BSE), Foot and Mouth Disease (FMD), dioxin in poultry, microbial contamination of fresh produce, and public trepidation over the impacts of genetically modified organisms (GMOs) on food safety and the ecological system, have spurred the demand for traceable chains in agriculture and food industries. In response to growing consumer concern and loss of confidence in the food chain, most developed countries and regional blocs have passed legislations aimed at improving the safety of food as well as raising public confidence in the food chain. The integration of traceability into agriculture and food quality management systems has become a challenge facing farmers, postharvest operators as well as research and development scientists and engineers serving the agricultural industry. The objectives of this article are (a) to highlight the various dimensions of traceability, and review the catalysts for its increasing importance in modern agriculture, and (b) to present an engineering and technology framework for developing traceable agrichains as part of an integrated agricultural mechanization strategy. Like modern agriculture, traceability is knowledge-intensive and information-driven; therefore considerable investments in human resource development and information and communication technology are essential for success. Agriculture-based rural development assistance programmed aimed at linking resource-poor farmers to global markets must address these issues, including providing training on what data to capture and traceable records keeping.

***Key words*:** traceability, mechanization, information technology, precision agriculture, food quality and safety

1. Introduction

Agriculture has undergone considerable changes during the past century. The emergence of concentrated agricultural production has been characterized by intensive application of new inputs such as engine-powered mechanical devices, chemicals, and the use of new and/or modified plant and animal materials (such as high-yielding varieties). New farming practices and processing techniques have been developed to meet growing consumer demand for reliable supply of consistently high quality, safe and diverse food products.

In addition to the demand for consistent supply of top quantity products and services, consumers are increasingly placing new emphasis on quality, safety, functionality, and sustainability of agriculture. These market-pull factors have also placed new demands for traceable supply chains. Authenticity to assure the preservation of product identity and wholesomeness of novel foods (including those containing genetically modified organisms (GMOs) or plants), and diagnostic tests that detect and prevent food safety hazards have become essential elements of a traceable supply chain management system. Recent food-related safety hazards due to the mad cow disease, dioxin in poultry, and fresh produce contamination have increased the publicity and exacerbated consumer concern for the safety of our food system.

The rapid explosion in Foot-and-Mouth Disease (FMD) incidence in the UK and other parts of Europe during the past couple of years called for the implementation of stringent traceability programs to monitor animal movement, and to monitor and control disease spread. As agriculture intensifies and international trade in agricultural products continues to expand in a globalized economy, food materials produced in the remotest part of the world and under different agricultural systems can be found in multiple supermarket chains located several thousand kilometers away. This scenario calls for well articulated traceability management systems to deal with consumer complains regarding breaches of product specifications and safety standards.

Recent engineering and technological advances in product quality measurement science, electronic identification technology, information and communication technology (ICT), and geospatial science and technology (GST), provide opportunities and challenges for scientists, engineers, and technologists to contribute to the development of innovations for implementing cost-effective traceable agri-food chains. Recently, the role of mechanization in traceability of agricultural production and products has been highlighted (Pierce and Cavalieri, 2002; De Castro, 2002). Other researchers have examined traceability from food marketing and food safety perspectives (Golan et al., 2002). The aim of this paper is to highlight the emergence of traceability as new terms of trade in modern agriculture. Specifically, I will define traceability in agribusiness and identify the key catalysts for its growing importance; and finally, a technological systems framework is presented to demonstrate the opportunities and challenges in developing traceability tools for agriculture and other life-science industries.

2. Dimensions of Traceability

The term 'traceability' is now so widely used in a variety of industries and contexts that it is timely to examine the concept, particularly in relation to agriculture and food business. Traceability probably had its origin in engineering metrology, standards, and calibration in the context of requiring the traceability of instruments to nationally accepted standards or measurement systems. A practical example is the traceability of machine parts to master 'master gauges' for gauging and dimensional tolerancing to permit interchangeability of parts or goodness of fit.

2.1 Measurement traceability

The goal of *measurement traceability* is the adequate accuracy of measurement, the compatibility of different measurement systems, the interchangeability of parts (Cameron, 1975; Eisenhart, 1963), and an unbroken hierarchical pathway of measurement comparisons to reference (e.g. national) standards (Garner and Rasberry, 1993). In relation to engineering measurements, traceability can therefore be viewed as a system of transferring the International System of Units (SI) from the point of definition to the user.

According to Belanger (1980), measurement traceability has been achieved when the reference standards base is specified and when the total measurement uncertainty relative to those standards has been shown to be sufficiently small for the intended purpose. Where measurement and calibration standards exist, these requirements may become part of a broader contractual responsibility of the supplier in which the product quality is preeminent. The 'measurement' orientation of traceability has been criticized for undue emphasis on a property (traceability) of an instrument rather the quality of measurement (Cameron, 1975).

2.2 Requirements traceability

Another dimension of traceability that is well developed is *requirements traceability,* which is an essential feature of software development process. In high-risk business activities such as electronic commerce and avionic systems, the need for traceable protocols and security of transactions are of uppermost importance (Balasubramanian, 1998; Pearson and Saeed, 1997). Traceability allows design team members to efficiently navigate through the document structure of a project, and assists in several tasks, e.g., demonstrating test-set completeness, detailed progress assessment, maintenance, answering questions such as "What is this doing here?" This is particularly crucial in an industry where staff retention can be a problem, and as people leave, their knowledge of the connections in the chain between design, implementation, and requirements goes with them, although this knowledge may be recoverable at great cost (Donat, 2000).

As a result, traceability has been advocated as a desirable property of software development (Antoniol et al., 2001; Lindvall and Sandahl, 1996). In the requirements context, it is defined as the ability to trace dependent items within a model and the ability to trace correspondent items in other models. At the end-use/user interface, traceability is a communications protocol, which ensures that the origin and/or destination of messages can be identified while preserving user control over other security service (Boyd, 1997).

Traceability is also vital in software development and use because it facilitates change-effect analysis, software documentation, tests and maintenance, life-cycle analysis, lattice security, access control and monitoring. By integrating traceability and broadcast encryption schemes, for instance, it is possible for broadcast centers to trace users who collude to produce pirate decoders (Gafni et al., 1999). With increasing complexity of computing and information systems, the provision of an effective traceability scheme is recognized as essential for the efficient management of system development (Pearson and Saeed, 1997).

Traceability links between different requirements also facilitate the implementation of the results of theoretical research early in the design phase and tracing them through to design and final product evaluation; in combination with the use of existing object models, they have also been used to achieve a more structured impact analysis process and accurate prediction (Lindvall and Sandahl, 1998). In the public law enforcement arena, traceability requirements embedded in smart cards such as EFTPOS/ATM cards and credit cards have enabled the law enforcement agents to trace the location of criminals or the owner of such electronic cards who had been declared missing.

Electronic access card readers enable property managers to monitor access into buildings for security and property management.

2.3 Agrichain traceability

Traceability has become an essential index for food trade and agribusiness in general. A traceable agricultural supply chain facilitates the following: (i) identification of production practices and product history through verifiable records, and (ii) segregation, isolation and recall of defective products (due to faulty production, manufacturing, contamination) because they failed to meet quality specifications and safety standards. Traceability is also a cost-effective preventative quality and safety management tool, and facilitates crisis management when food product safety standard is breached.

In agriculture and food business, an integrated supply chain traceability system must encompass the following elements (Opara, 2002):

- *product traceability* to determine the physical location of items at any stage in the supply chain to facilitate recall and/or dissemination of information to customers and consumers;
- *process traceability* to determine the type and sequence of events that have occurred during the production and handling of the product: what, where, when. These include (a) physical/mechanical, chemical, environmental & atmospheric factors, treatments and formulations which could result in transformation of the raw material into value-added products, and (b) absence or presence of contaminants;
- *inputs traceability* to determine (a) type and origin (source, supplier) of ingredients used to create the raw product (seeds, stem cuttings and other planting materials, fertilizer, chemical sprays, irrigation water, livestock, feed), and (b) materials (additives, chemicals) used for the postharvest handling, preservation and/or transformation of the basic raw food material into processed (reconstituted or new) food products. Inputs traceability includes the analysis of genetic constituents of products.
- *disease traceability* to determine the outbreak and monitor the epidemiology of biotic hazards such as bacteria, virus and other emerging pathogens which are potential risks to the humans through contamination of foods and other ingested products derived from biological and agricultural raw materials.
- *genetic traceability* to determine the genetic constitution of the product, including variety, type, origin and alterations in the basic DNA structure.
- *measurement traceability* to relate individual measurement results (such as product quality and safety attributes) through an unbroken chain of calibrations to accepted reference standards.

To implement a new traceability system, conduct a traceability analyses as part of routine quality management system, or undertake a traceback in the event of food safety and quality alert, these basic elements must be integrated into a unified computer-based information system that facilitates product identification, data measurement, analysis, and retrieval. This involves the generation of sufficient data to adequately and cost-effectively evaluate the type, origin and location of the source of safety and/or quality concern. Such system integration also enables corrective actions to be taken as part of continuous improvement within the agribusiness chain.

Agricultural traceability involves the collection, documentation, maintenance, and application of information related to all products and processes in the supply chain in a manner that provides guarantee to the consumer and other stakeholders on the origin and life history of a product as well as assisting in crises management in the event of a safety and quality alert (Opara and Mazaud, 2001). With respect to a food product, traceability represents the ability to identify the farm where it was grown, the sources and types of input materials, and the ability to conduct full backward and forward tracking to determine the specific location and life history of the product in the supply chain by means of documented records. Traceability adds value to the other quality and safety management strategies by providing the communication linkage for identifying, verifying and isolating sources of non-compliance to agreed standards and customer expectations (Opara and Mazaud, 2001).

Growing loss of consumer confidence and food and environmental regulatory pressures leave the agriculture and food industries with little option but to implement traceable supply chains as part of the overall food safety and quality management system. As these pressures intensify and agriculture continues to experience declining terms of trade in favour of the high-tech and service industries, there are good reasons to believe that the future of traceability as an important quality attribute and agricultural trade index is assured. Developing cost-effective technological innovations for implementing reliable traceability systems is therefore paramount for new market access as well as meeting existing phytosanitary requirements.

3. Catalysts of Traceability in Agribusiness

Global interest in traceable agrichains has been impelled by the increasing incidence of food-related safety scares and hazards, and most recently, with the appearance of genetically modified organisms (GMOs) and GMO and non-GMO agricultural chains. Furthermore, the promulgation of many new food quality regulations and directives at national and regional levels has placed responsibilities on all participants in the supply chain for the safety and wholesomeness of food products. These operators must now demonstration "due diligence" that every precaution has been taken to prevent food safety hazards, including verifiable evidence that finished products can be traced back to their raw material and farm of origin.

Similarly, forward traceability is also required to determine the location of products in the supply chain to facilitate their recall when quality standards have been contravened. These main catalysts for traceability in agriculture are discussed further in the following subsections.

3.1 Food-related safety hazards and scares

A recent Eurobarometer survey revealed that the most important issue for 68% of consumers was the safety of the food they eat. And this response was, admittedly, after the BSE crises, but before the dioxin crises (Nymand-Christensen, 1999). Numerous microbial, physical, and chemical hazards occur in the human food chain, which contribute to this major safety issue. Concerns over pesticides and other chemical residues have led to the ban of many agrichemicals used in food production and preservation. Physical contaminants (foreign materials) such as broken glass, wood, soil, plastic or metal parts such as nuts, bolts and nails can cause illness or injury to the consumer if they become embedded inside food.

Several major food-related health hazards and scares, particularly in Europe, have raised public concern on the way we practice agriculture as well as the way we handle and process food. Most notable incidents are the potential link between Bovine Spongiform Encephalopathy (BSE) in cattle and the new variant Cruetzfeldt Jacob Disease (CJD) in humans for which there is currently no cure. Food poisoning incidents and death due to *Salmonella* in poultry and eggs, *Escherichia.coli 0157* (*E.coli*) contamination of meat and meat products, fresh, minimally processed and processed fruit and vegetables, and the occurrence of other emerging food pathogens have reduced consumer confidence in the safety of our food systems.

Discovery of high levels of dioxins (known to be carcinogens) in poultry feed, some other animal feeds and in some poultry carcasses, led a major crises in the poultry and livestock industries in Belgium and several other European countries (O'Connor, 1999). Belgian produce including eggs, meats and dairy products were banned by many countries, forcing the Prime Minister Jeaan-Luc Dehaaene in a speech on 8th June 1999 to appeal that "The animal feed producer is asked to declare on their honour whether or not they have bought fat from Verkest between January and June 1st 1999" (Food Trak, 2000). The dioxins were traced to contamination of fat and oil stores used in the production of poultry and animal feed. Though the contaminated fat was supplied to only 5.1% of farms in Belgium, it took three days to trace the poultry system alone and this was complicated further when efforts were made to forward-trace it to products already in the market or consumers.

The recent outbreak and rapid spread of Foot and Mouth Disease (FMD) in the United Kingdom, Argentina and several European countries also caused a major scare within the livestock industry and consumers, resulting in considerable financial losses. Although no threat to public health was involved, consumers began to panic and wonder about the need for massive transport and destruction of animals. According to Bayliss (2000), "the continuing tragedy of BSE and the developments on the continent have highlighted just how important traceability and branding are".

3.2 Genetic modification of food

The ongoing crises of confidence in the food chain, has been exacerbated by the introduction of food products derived from genetically modified organisms (GMOs) or materials. Food safety concern surrounding genetic biotechnology is controversial in both the public and scientific domain; but consumers are generally apprehensive of the uncertainty of introducing new gene sequences, which might impel or provoke other factors that are hazardous to humans and the environment. Intense public concern over the release and utilisation of GMOs, particularly in Europe, has led the EU to pass regulations on traceability and labelling of GMOs and products derived from GMOs (EU, 2000 & 2001; Byrne, 2001). These new rules will require member states to ensure traceability of GMOs at all stages of agribusiness marketing.

3.3 Sustainability & welfare issues

Modern agricultural production methods have undoubtedly contributed to the depletion of natural resources and environmental degradation. Consumers are increasingly aware that modern intensive agriculture and food production practices have considerable impacts on the environment and ecological systems. A significant proportion of the consumers now demand and support the development, promotion and introduction of sustainable agriculture, leading to the growing demand for organic or ‘green’ food. This increasingly important market expect food to be produced and processed in line with good agricultural practices, which embodies greater care of the environment and welfare of animals, which recognizes that animals are sentiment beings.

3.4 Food quality and safety legislations

The increase in food regulations within the European Union member states following recent food scares, and the tightening of controls by other country agencies have challenged agribusiness and other life science industries to examine their production and processing practices. In addition to the European Food Authority, most member states have also established their own national Food Agency responsible for food safety. In 1996, President Clinton signed into law the Food Quality Protection Act in the USA. As a result, regulations and guidelines have been set which cover the production and handling of food in other countries that are destined for the US market.

In the South Pacific, the Australia and New Zealand Food Authority (ANZFA) plays a pivotal role in trans-Tasman food quality and safety regulations. The underpinning premise for these legislations is to improve the safety of ingested products (foods and drugs), enhance consumer confidence, as well as hold producers and handlers in the supply chain accountable and liable. These enterprises therefore need full backwards and forwards traceability to be able to identify exactly where, when and how things go wrong if a problem occurs.

3.5 Globalisation of world economy and international trade

Globalisation of the world food system is a major driver for agricultural traceability chains. Governments and farmers in most countries have also been seeking assurances that imported foods and raw materials would not damage domestic agricultural and ecological systems. With increasing consumption of food products grown in locations far removed from the point of production, traceability of the supply has become an important new instrument in trade. This trade is undoubtedly set to grow further with increasing membership of the World Trade Organisation (WTO).

Also related to globalisation is the emergence of multinational and transnational food companies, who increasingly source their raw materials from distant locations and a variety of sources. Juxtaposed on this is the use of the Internet (e-commerce) for trading in agricultural commodities and inputs. The procurement of agricultural products from different sources obviously introduces further variability in quality; and thus traceability becomes a valuable tool to assist in identifying and managing sources of safety hazards and quality defects.

In addition to these factors, other considerations such as product liability and indemnity can provide impetus for implementing a traceability chain. Traceability in agriculture is by and large driven by market/consumer demand for top quality and safe food within a transparent, traceable supply chain. However, the pace at which traceability systems will evolve will depend largely on current and future technological innovations for their implementation. In this regard, technologies developed elsewhere in other industries such as avionics and software will find ready application in agricultural traceability.

4. An Engineering and Technological Framework for Traceability in Agriculture

Traceability is not an entirely new concept in agriculture and food business, but the availability of modern engineering and technological innovations developed elsewhere in other industries such as information and communications technology and metrology have revolutionized the intensity, speed and versatility of its application. Historically, traditional bar codes provided the first major innovation for identifying products during marketing and logistics but the drivers were different to the modern era. In the past, bar codes merely provided information on the product origin/source/batch and price at retail outlets. However as consumer demand for top quality products and concerns for safety increased and supply chains got longer and increasingly vertically integrated, the need for more information and further product segregation and differentiation became imperative.

A technological framework for integrating traceability into agricultural mechanization can be developed based on the following total systems synthesis:

1. agriculture is comprised of three key interrelated domains – external (inputs & environmental), production (on-farm mechanization activities), and postharvest (handling, preservation, processing and marketing);
2. products delivered to the consumer results from the interaction of a raw material(s), processes (manufacturing) and information;
3. technological innovations exist to characterize and quantify the domains, products and processes;
4. information and data generated from the measurements and analyses can be stored, transmitted and retrieved in a form that enables transparent business decisions to be made;
5. quality and safety hazards can result from biological, chemical and physical factors related to process conditions, diseases agents, chemical inputs, and external objects;
6. an integrated agricultural traceability chain should be capable of providing time-bound, site-specific data along the supply chain on product location, inventory, composition, quality specifications, and safety status.

The above synthesis demonstrates that a traceability chain exists when full trace-back and trace-forward can be undertaken to determine the location, life history, genetic status, composition, quality and safety status of the product. To successfully implement an agri-food supply chain traceability system, technological innovations are required to accomplish the following:

(a) identify the product and measure its attributes;
(b) characterise the activities involved throughout the supply chain, from farm to fork; and finally
(c) integrate the overall supply chain with full backward and forward traceability using appropriate information and communication technology.

4.1 Production identification

Bar codes are the most common technologies for identifying raw food materials or finished products. In the livestock industry, ear tags are attached to the animal and the label on the tag may contain numbers or their combination with alphabets, which together contain information such as breed, date of birth, farm/paddock, movements, vaccinations, etc. When the animal is slaughtered, additional information may be added to the label such as date slaughtered, time put in storage and environmental conditions in the store. In addition to the information contained in the label, the farm record should also document the type and source of feed and other treatments and inputs used the raise the animals. Electronic identification tags are now available which can store high volume of data and also enable data on tags to be read automatically without contact using electronic card readers. These cards may be connected to a computer or downloaded later out of the measurement site.

Advances in geospatial science and technology (Bossler, 2001) such as remote sensing (RS), geographic information systems (GIS) and global positioning systems (GPS) have made precision agriculture a reality. These technological innovations can be used to collect site-specific data on individual animals, plants, soil properties, maturity, yield, quality, environmental and climatic data, and to monitor animal movement and disease epidemiology. Grains and fresh produce are generally handled in batches that may contain materials from different farms, particularly when the volume supplied by each individual farm is not sufficient to warrant a separate supply chain. Even so, it is possible to label each produce or bag of grain so that it can be traced back to the origin.

4.2 Quantification of product and processes attributes

Several laboratory-based measuring instruments, field devices and on-line equipment are available for assessing the maturity, quality attributes and safety status of plant and animal-based foods (Kader et al., 1992). These include force sensors for assessing firmness and other textural attributes; refractometer and other chemical analyses for measuring sweetness, acidity, flavour, nutritional composition, and residue levels; and non-destructive tests such as near infrared sensors and nuclear magnetic resonance imaging for assessing the internal quality of products.

New DNA tests based on quantitative analysis of polymerase chain reaction (PCR) products have been developed to evaluate the genetic constitution of plant and animal products, including inputs such as seeds and embryos, thereby making genetic traceability a reality (Giese, 2001). Biosensors, automatic gas analyzers, and environmental sensors enable real-time data on microbial and air contaminants, temperature, humidity and volatiles in the product storage and handling environment to be monitored and measured to detect when safety standards are breached. Regular calibration of the measuring devices and reference to measurement standards is vital to maintaining confidence in the data.

Proper characterization of the activities involved in the handling and transformation/processing of the raw material into finished products is vital to full traceability. Activities such as drying, frying, boiling, freezing, cooling, communition, dehydration, fermentation, dipping into solutions or spraying with treatments such as calcium (to enhance firmness in fresh fruit) must be accurately described and documented with respect to time, duration and magnitude or concentration. The magnitude and duration of these bioprocesses have impacts on the final product organoleptic and safety attributes, and well as storage stability.

4.3 Computer-based system integration

Finally, a traceability chain exists when all the activities and measurements are fully integrated in the supply chain by appropriate information system, which enables recorded data to be entered, stored, accessed and retrieved at any link in the chain. To achieve this requires computers (hardware), database for data entry, storage and processing, and software to drive the information system and to provide interface with the user. Designated stakeholders in the traceability chain must have access to infrastructure and know-how to collect relevant data and load them into the database; equally, they must be able to access information already in the system on the location and history of the products, as well as its quality and safety status.

By incorporating quality standards at each link in the traceability chain, with feedback control systems to detect when these standards are breached, stakeholders who have access to the traceability information system can receive warning signals when defects occur and/or when food safety are violated. Such an integrated traceability system will facilitate product withdrawal from the supply chain and minimize transaction costs associated with uncertainty in product quality and safety.

5. Future Prospects for Agrichain Traceability Technology (ATT)

The ability to trace products at every step in the supply chain has become an essential requirement in agriculture and other life science industries. Just like quality of products and services emerged as a competitive business weapon in the late part of the 20^{th} Century, traceability is now a strategic tool for agribusiness advantage – the new king from field to plate! Low consumer confidence in the safety of foods, backed by increased regulation and tightening of controls at national and regional levels, assure a continued interest in the development and application of cost-effective technologies for agricultural traceability.

Existing concepts of traceability in other industries such as engineering metrology and software development have relevance and adaptability to traceability in agriculture. For instance, advances in measurement traceability can be adapted towards developing national and/or international standards, calibration and reference systems for food quality specifications and safety standards. The principle of requirements traceability in software development as the flow and transformation of information from requirements to design, code, and tests (Donat, 2000), can be applied by considering agriculture as a supply chain involving the transformation of raw biological materials and information from requirements to delivery of new products.

Many technological innovations that are already being applied in agriculture will contribute to speedy implementation of traceability chains. Geospatial tools currently used in precision farming such as remote sensing, global positioning systems and geographical information systems can assist in linking site-specific and process-specific data to products at any stage in the supply chain. Biosensors for rapid genetic and microbial evaluation, environmental data recorders (EDRs) for measuring temperature, relative humidity and air composition, instrumented spheres (IS) for recording force history in the handling chain, non-destructive tests for quality assessment, and non-invasive imaging, are some of the innovations that can integrated into a total traceability supply chain. Ongoing advancements in computers and electronics have made it possible to implement automatic and rapid acquisition systems from these instruments, both on-site and from remote locations using radio frequency transmitters.

Traditional fingerprinting is one of the oldest forms of identification of humans and is still used today in legal matters and commerce. DNA fingerprinting is however is a modern science that has potentials for genetic traceability of GM food products. Recent breakthroughs in retinal imaging in the avionics and security industries offer potentials and challenges for livestock traceability from field-to-plate-to-field! Obviously, high development costs may make these technologies expensive initially for the small and medium scale farmer.

Commercial technologies (such as digital/electronic tags) already exist for real-time identification and registration of livestock and food products. Hand-held electronic readers equipped with customized data loggers for information storage are also available to read the electronic identity from tags. Advancement in this area is progressing rapidly with many countries and businesses have committing considerable resources to a national/business-wide animal tracing system. Durability of the identification system is critical because the ineffectiveness of traditional bar-codes in resisting wear and tear over longer and extended supply chains.

Three main challenges will need to be addressed at the international level for the full technological potentials of traceability in agriculture to be realized. There is a need for a code of practice in agricultural traceability that is linked to Codex Alimentaris. Such a code should address issues such as standardization of measurement systems and setting of reference data for safety of fresh and processed agricultural products. Secondly, the impact of traceability as a new index of trade needs to be evaluated on the least developed countries. Traceability is both knowledge- and technology-intensive; therefore development projects aimed at linking small-scale farmers to markets must include aspects of technology transfer in traceability and postharvest technology to facilitate market access. The efforts would assist the farmers to derive the maximum benefits from investments already made at the production (on-farm) level.

Finally, current perceptions of traceability are dominated by either the forward link from production site to the consumer (e.g. 'farm to fork', 'between conception and the plate', 'field to plate', 'paddock to plate', 'stable to table') or the backward link from site of hazard to the source of the product (traceback). Ultimately a traceability chain management system and the supporting technologies must facilitate both forward and backward traceability of products, their life history, and processes/activities. With growing public acceptance of web-based electronic commerce and the successful penetration of computer technology into businesses and family homes, the prospects are bright for a traceability chain that enables the individual consumer to obtain real-time updated information about a food product bought from a local supermarket, by scanning the product on the home computer or television that is connected to the information highway! Under such integrated, ICT-based traceability system, a product which has been recalled due to potential contamination or manufacturing defect prompts an 'alert' signal that informs both the end-user, consumer, and supplier on the next line of remedial action. This will not only facilitate product recall - it will also the assure consumers' peace of mind and thereby enhance public confidence in the safety of the food system.

6. Conclusions

Traceability has become an important index in global agribusiness trade. Various factors related to rising incidence of food-related health scares and hazards, changing consumer demand patterns, introduction of GMO-based food supply chains, new regulatory food standards, and concern for environmental sustainability are some of drivers. Traceability enables full backward and forward identification of the product with respect to time and location in the supply chain and thereby facilitates cost-effective withdrawal of products when defects occur and when safety standards are violated.

Traceable chains are technology-intensive and information-driven. Based on a systems approach to supply chain management, a framework has been presented to demonstrate the role of technological advancements in measurement science, product identification tools, and information technology in agribusiness and food chain traceability. Based on their knowledge of the interactions between machines, the environment and biomaterials, agricultural and biosystem engineers can lead the evolution of this new science and technology of agrichain traceability as part of an enlarged vision of mechanization and automation of agricultural production and processing. Current advances in computers and electronics (mechatronics) in agriculture and progress in geospatial science and technology tools for precision agriculture will facilitate successful integration of traceability into existing agricultural mechanization systems.

Traceability is knowledge-intensive and information-driven. Its implementation, therefore, requires considerable investments in human resource development and information and communication technology. This poses additional obstacles to the transformation of subsistence rural farmers in developing countries into market-driven enterprises. Efforts to link resource-poor farmers to global markets must address these issues, including the provision of appropriate training on what data to capture and "how to" implement traceable records keeping.

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