

CASE STUDY

OPEN ACCESS

ISSN Print: 2516-3949

doi: 10.31585/jbba-1-1-(10)2018

Food Traceability on Blockchain: Walmart's Pork and Mango Pilots with IBM

Reshma Kamath¹*Northwestern University, Chicago, IL, USA***Correspondence:** reshmakamath2017@gmail.com**Received:** 1 June 2018 **Accepted:** 9 June 2018 **Published:** 12 June 2018**Competing Interests:***None declared.***Ethical approval:***Not applicable.***Author's contribution:***RK¹ is the primary author responsible for data collection and writing the manuscript. The Blockchain Research Institute (BRI) provided layout and proof-reading services.***Funding:***The project is funded by the BRI. IBM is a paid member of the BRI.***Acknowledgements:***RK¹ would like to acknowledge Irving Wladawsky-Berger, Visiting Lecturer at MIT (Massachusetts Institute of Technology) Sloan School of Management, for reviewing and providing feedback on the manuscript; Don Tapscott and Alex Tapscott of the BRI for facilitating conversations between the author and the parties involved in the pilot projects, namely Brigid McDermott, IBM's Vice President of blockchain business development, and Frank Yiannas, Walmart's Vice President of food safety and health.***Abstract**

In response to food contamination scandals worldwide, retail giant Walmart is tackling food safety in the supply chain using blockchain technology. In 2016, it established the Walmart Food Safety Collaboration Center in Beijing and plans to invest \$25 million over five years to research global food safety (Yiannas and Liu, 2017). Using IBM's blockchain solution based on Hyperledger Fabric, Walmart has successfully completed two blockchain pilots: pork in China and mangoes in the Americas (IBM, 2017). With a farm-to-table approach, Walmart's blockchain solution reduced time for tracking mango origins from seven days to 2.2 seconds and promoted greater transparency across Walmart's food supply chain (Yiannas, 2017). IBM called it "complete end-to-end traceability" (McDermott, 2017). This case study highlights the challenges of implementing blockchain technology in the food supply chain and the opportunities for deploying blockchain solutions throughout the global food ecosystem to increase safety and reduce waste.

Keywords: *Food safety, provenance, supply chain, Walmart, IBM, traceability***Broken food chains: food contamination scandals**

Health hazards from food mismanagement and contamination are well documented. The Centers for Disease Control and Prevention estimate 48 million people in the United States contract foodborne illnesses every year (2011). The World Health Organization estimates that one in ten people suffers from food poisoning worldwide, with 420,000 fatalities, each year (2017).

In North America, isolating the cause of the E. coli outbreak in 2006 wasted time, energy, and the resources of the entire ecosystem (wholesalers, retailers, farmers, and regulators), shattering public trust in the supply chain. American consumers stopped eating spinach altogether, while restaurateurs and grocery stores pulled spinach off their shelves and menus. Health officials took almost two weeks to identify the source of the contamination: one supplier, one day's production, and one lot number (Produce Processing, 2007). The inability to rapidly track and trace the source of the contaminated spinach resulted in significant and lasting economic harm to spinach farmers and erosion of consumer trust (Yiannas, 2017).

In 2011, China witnessed a massive pork mislabeling

debacle, along with a contamination hoax in which donkey meat products were recalled because they were found to include fox meat (Bradsher, 2011; Clemons, 2014). Additional contaminants such as melamine, Sudan red, clenbuterol, Sanlu toxic milk powder, and trench oil—all of which had breached the food supply chain—further eroded Chinese trust in food markets (Hatton, 2015). With arcane agricultural food logistics systems, China faces an agri-food loss ratio of 25 to 30 percent annually. The Office of Economic Cooperation and Development identified several challenges: deficient information at each stage of the food value chain, decentralized storage of food, waste in the restaurant and catering sector, and a lack of coordination among regulatory agencies and ministries (Liu, 2013).

In 2013, bad actors in the EU supply chain replaced lamb and beef with horsemeat (Castle, 2013). The illegal substitution affected more than 4.5 million processed products representing at least 1,000 tons of food (Ruitenbergh, 2013). This fraud caused lasting damage to profits and corporate reputations. According to PricewaterhouseCoopers and Safe and Secure Approaches in Field Environments (2016), food fraud is estimated to cost the global food industry \$40 billion a year.

In July 2017, papayas in the US market were linked to a multi-state outbreak of Salmonella. By mid-August 2017, the CDC reported 173 cases of salmonellosis, 58 hospitalizations, and one death across 21 states (2017). Health officials advised consumers to avoid eating papayas and retailers not to sell them. Even by replicating measures in the spinach outbreak, health officials took almost three weeks to trace the source to a single farm in Mexico. Papaya farmers from unaffected areas suffered economic losses because of the inability to rapidly track and trace food products (Yiannas, 2017).

The inability to trace products in the supply chain comes from the disparate record-keeping methods in use (Culp, 2013). The widely-accepted “one up, one down” (OUOD) approach—whereby food supply chain participants know only the immediate supplier (one link up the chain) and the immediate customer (one link down the chain) for a product—is simply insufficient. In suspected contaminations, investigators review paper documentation step by step. Erroneous or incomplete data can further delay their investigations. Multi-ingredient foods and bulk containers may include elements from a variety of sources and multiple countries and traceability gets even more complicated. As a precautionary step, entire shipments are thrown out under OUOD parameters (Blanchfield and Welt, 2012). With blockchain technology, such food shipments “will be identified as being safe at a much earlier juncture,” while saving millions in sales as well as valuable human lives (Hodge, 2017).

Walmart’s blockchain pilots for food provenance

Walmart worked with IBM to develop and implement its food provenance pilots using blockchain technology (Tiwari, 2016). According to McDermott (2017), “Blockchain solves business problems where trust is part of the solution” by providing what traditional databases cannot: data immutability as well as speed and security of dissemination.

Leaders at IBM recognized that they could accelerate the adoption of blockchain and avoid a proliferation of internal systems and data formats by using existing open standards such as the Electronic Product Code Information Services and Core Business Vocabulary of Global Specifications 1 (Blanchfield and Welt, 2012). IBM’s blockchain is based on Hyperledger Fabric, which supports modular architecture and plug-and-play components such as consensus and membership services (IBM, 2017). It allows both efficient data capture and data control. Most importantly, users have a shared view of the truth at any point in time as well as ownership and control over their own information. Records include audits, agricultural treatments, identification numbers, manufacturers, available device updates, known security issues, granted permissions,

and safety-protocols, all logged in real time and permanently stored as e-certificates.

This foundational trust has a flywheel effect. According to McDermott (2017), “The trust it delivers enables more efficient and complete sharing of the critical data that drives enterprise transactions.”

Pork chains across China

China is both a leading importer of pork and a producer of nearly half of the world’s pork; large, industrialized pork production systems similar to those in the United States have been displacing small-scale “backyard” pork producers (Gale, 2017). In line with this trend, government officials in China called for the country’s pork industry to modernize its production system from farm to fork.

As consumer focus in China has shifted to food safety and quality, trust is critical to purchasing decisions. The Chinese government is investing heavily in its food system, upping food inspection and safety methods, putting pressure on production systems, and partnering with corporate retail giants. Given the country’s sizeable population and its immense appetite for pork (with an annual consumption of 12.7 million tons), Walmart had an incentive to explore new technologies for creating trust in food provenance in China (Bunge, 2015).

Collaboration, collaboration, collaboration

In October 2016, Walmart launched the Food Safety Collaboration Center (Burkitt, 2014). At the center’s opening, Doug McMillon, president and CEO of Walmart Stores, said, “By bringing together the best food safety thinkers from across the food ecosystem, from farmers to suppliers, retailers to policy regulators, we’ll accelerate food safety awareness and help make Chinese families safer and healthier” (Walmart, 2016). The center studies food-borne contaminants and develops risk assessment models that other corporations and organizations will be able to use (Bloomberg, 2016). Walmart also invested in food-related technologies to detect food-borne pathogens and to monitor packaged food for contamination in the supply chain.

Cooperation with governmental entities was crucial to the success of Walmart’s blockchain pilot. Regulators were enthusiastic about blockchain technology and its potential, as it aligned with their work (McDermott, 2017). With collaborators in place and a green light from regulators, Walmart was ready to apply features of blockchain technology to pork safety and supply chain management.

Farm and slaughterhouse tracking

For pork, the process begins at pens—where every pig is smart-tagged with bar codes—and follows the product all the way to packaged pork. While using radio frequency identification and cameras, participants record the pig’s movement as well, and cameras installed in slaughterhouses capture the entire production process. These efforts protect both piglets and sows and modulate temperature so that babies stay warm while mothers stay cool (Clark, 2017).

In pork production, shipping trucks have deployed temperature and humidity sensors, along with global positioning and geographic information systems, to ensure the meat arrives at retailers under safe conditions; Walmart can trace whereabouts of trucks and monitor conditions in each refrigerated container and, if conditions exceed established thresholds, receive alerts to prompt corrective action (Gale, 2017).

Walmart distribution center and store tracking

With blockchain, procurement managers can remotely trace all information, from expiration dates to warehouse temperatures (Kaye, 2016). Information about farm origination, batch numbers, processing data, soil quality and fertilizers, and even storage temperatures and shipping details can be uploaded on an e-certificate and linked to the product package via a QR code (Murphy, 2016).

Walmart’s blockchain pilot involved different systems of data capture and improved speed and accuracy in providing relevant information from the farm to the store (Blanchfield and Welt, 2012). Such systems typically include Global Trade Identification Number with a handler’s production lot or batch number (National Mango Board, 2017).

Traceability improves food safety and public confidence. Should any tainted food reach a consumer, the system can better pinpoint which products should be discarded without jeopardizing an entire product line (Bottemelier, 2011). This holistic traceability model has the potential to cut costs of product recalls, reduce process inefficiencies, and enable retailers to track individual pork products in seconds, not days (Del Castillo, 2016).

Mango chains in the Americas

Walmart concurrently conducted a pilot using IBM’s Hyperledger-based blockchain* to trace sliced mangoes from South and Central America to North America (Burkitt, 2014). Mangoes as well as mango origins and derivatives are shipped worldwide and susceptible to *Listeria* and *Salmonella* contaminations (Yiannas, 2017; Andrews, 2012). Therefore, Walmart’s mango pilot had

to demonstrate transferability and accountability across borders (Andrews, 2012) so that, were there another recall of such produce, blockchain traceability would enhance public trust in the information about the supply (McDermott, (2017).

** (Hyperledger is a non-paying affiliate of the Blockchain Research Institute.)*

Food production: pre-seedling stage

In production, mangoes can suffer from “fruit decay, surface defects, internal breakdown symptoms, chilling and heat injury, disorders during ripening, and more” (National Mango Board, 2017). The production phase tends to require an all-hands-on-deck approach. Producers may cut corners by using contaminated fertilizers, hiring children, paying poverty wages, or requiring laborers to work extremely long days. Workers may have no contracts and no trade union to defend their interests (Humbert, 2013). Marginalized farmers have limited information on market prices and production inputs, limited quality control, variable access to quality fertilizer and pesticide, and non-existent bargaining power with traders (Matta, 2013). Blockchain technology can raise red flags as to these practices (Van der Wal, 2013).

Food processing: warehouse storage stage

Greater perishability of agri-foods mandates an exacting check of temperature and moisture in the logistics process (Ontario, 2016). For mangoes, Walmart analyzes fruit quality throughout the supply chain—on the tree, at harvest, at the packing shed, at wholesale markets and at retail outlets—to determine quality and marketability at each stage. Such analysis could help to anticipate potential losses from sap burn, bruising, physical damage, diseases, poor methods of harvesting, and poor transportation from packing shed to wholesale markets (Mazha, 2010). At all stages, participants can collect and store data to benchmark industry performance beyond traditional practices (Matta, 2013).

Food distribution and aggregation: shed stage

Mango importer facilities and retail distribution centers inspect for quality, measure and record shipments, document proper certificates, ascertain cargo and temperature excursions, measure temperature, sample at arrival, and evaluate external and internal quality (National Mango Board, 2017). All these data can be stored and traced on a blockchain. In distribution, blockchain-connected devices and smart sensors will eventually be able to record produce damage caused by excessive sunlight (or any rotting of meat) due to temperature and humidity (Gantait, 2017). Walmart is working with shipping and logistics providers

to improve data capture of bills of lading (or warehouse warrants) and propel invoice consents, dispute resolution, and cargo provenance and tracking. For example, distributed ledger technology has the ability to record updates to legal agreements and platforms, thereby ensuring both legal and security integrity (essDOCS, 2017). Walmart has a patent application for a “delivery management system” involving distributed ledgers, robotics, and sensors (Hackett, 2017). IBM is also developing blockchain solutions for cross-border supply chains in collaboration with the global transport and container logistics giant, Maersk (IBM, 2017).

Marketing and retailing: supermarket stage

Traceability is a major competitive advantage for supply chain participants (Webb, 2004). Supermarkets will be able to connect their enterprise resource planning and point-of-sale systems to the blockchain-enabled platform and trace every item sold. According to Yiannas, “With blockchain, you can do strategic removals, and let consumers and companies have confidence” (Kharif, 2016). Retailers should be able to generate customer loyalty with transparent record keeping and could slash recall costs and increase profits, while reducing their risk exposure (Simon, 2016).

Household and food purchasing: consumer stage

Should a consumer fall ill, “Walmart will be able to obtain crucial data from a single receipt, including supplies, detail on how and where food was grown and who inspected...from the pallet to the individual package” (Kharif, 2016). Customers can also provide retailers with specific feedback regarding quality that can be linked to growers and sources (Yiannas, 2017). In addition, customers can enjoy reduced prices and fresher produce and know when their groceries will arrive. Restaurant owners and managers of school and government cafeterias will also benefit: by “digitally tracking the provenance and movement of food throughout the entire supply chain, purveyors have instant quality assurance that the products they receive and serve customers are safe” (Van Kralingen, 2016). Food inspectors could include restaurant or cafeteria health and safety ratings on the blockchain as well.

Post-cumulative data capture: post-harvesting or finish

Whether pork or mangoes, Walmart’s blockchain pilots have the capacity to document post-cumulative losses from potential supply chain inefficiencies (Gantait, 2017). Such digital tracking could enhance food safety mechanisms, provide quality assurances, and smooth supply chain disruptions from food wastage and spoilage. Each transaction will generate a proof of record, from the pre-seedling stage to the consumer’s table at home. Combined with data analytics and

existing industry standards, the entire supply ecosystem should benefit from such a comprehensive data snapshot.

Discussion

Blockchain has demonstrated its potential for providing greater transparency, veracity, and trust in food information so that supply chain members can act immediately, should problems arise. To evolve their blockchain solution and apply it to the global food system, IBM and Walmart expanded their collaboration to include Dole, Driscoll’s, Golden State Foods, Kroger, McCormick and Company, McLane Company, Nestlé, Tyson Foods, and Unilever (IBM, 2017).

Traceability is essential in preventing or responding quickly to food contamination, disease, drug or pesticide residues, or attempted bioterrorism (IAEA, 2011). According to McDermott (2017), “Blockchain is not solving a technical problem, it is solving a social problem.” With prevention, preparedness, and proof, Walmart’s blockchain pilot serves a larger purpose and has a positive effect on the Walmart brand.

Walmart’s blockchain solution needed to be “business-driven and technology-enabled,” the capacity to solve such business problems as time efficiencies, cost reduction, long-term good will, and revenue generation (Burkitt, 2014). Ensuring value for all participants in the ecosystem will be critical to wider adoption; breeders/farms, processing plants, cold storage facilities, distribution centers, and retail stores need to have a strong value proposition to join.

To maintain whole-chain traceability, this kind of initiative requires leadership to coordinate stakeholders and promote awareness of different technology solutions. “This is not about competition, this is about collaboration,” according to Yiannas (2017). “[It’s about] creating a solution that offers shared value for stakeholders.” Throughout the product life cycle, supply chain participants were able to record, crosscheck, and ensure a product’s authenticity and trace its movement and quality (Doyle, 2014). This information gave all participants greater control over their brands and businesses and supported deeper learning capacities from enhanced gathering of data and analytics. Such a supply chain network could eventually include research and development centers, primary production facilities, aggregation and mobilization providers, trading and grading participants, wholesalers, retailers, and customers (Matta, 2013).

Blockchain technology enables food traceability to the item level, not just batch level, so that participants can trace each item in the supply chain (Wuest, 2015). Walmart’s blockchain pilot identified which data were relevant to capture and compiled a list of mandatory

attributes (lot number, pack date, quantity shipped, unit of measure, purchase order number, shipment identifiers) and a list of optional attributes (carton serial numbers, pallet number, harvest date, buyer identifier, vendor/supplier identifier). Consistency is key. Pilot leaders should adopt data structures that align with standards and develop requirements for master data and guidelines for data retention (Can-Trace Secretariat, 2004). This supply chain portrait accounts for interoperability among ledger participants with an in-depth grasp of data.

Walmart chose IBM's blockchain solution because it was "not recreating supply chain, but leveraging existing technologies to enhance supply chain traceability using Hyperledger" (Burkitt, 2014). Like Walmart's blockchain pilot, "traceability systems that are integrated with existing company business practices are more likely to be maintained and more likely to be accurate than stand-alone traceability systems" (Can-Trace Secretariat, 2004). "Visibility, optimization, and demand" are key challenges in creating interoperable devices and platforms (Gantait, 2017).

Walmart took a three-pronged approach to cultivating knowledge in food safety and delivery in China. First, it collaborated with a non-profit in China that provides food safety education developed for children. Second, it brought together American and Chinese academics and Chinese poultry producers to study safety in poultry supply chains. Third, it pooled talent from top academic institutions to leverage supply chain analytics and superior technology (Lindell, 2016). This approach will instantaneously predict and detect areas of greatest vulnerability and threats for food adulteration in China's food supply chains.

Walmart will continue to experiment, scale, and learn from its blockchain pilots as it builds coalitions within the supply chain ecosystem where members are seeking to implement blockchain applications more broadly. Blockchain is bigger and broader than these pork and mango pilots. However, for Walmart, blockchain technology was deployed specifically to solve societal issues of broken food chains. Leveraging existing devices and sensors, Walmart's blockchain pilots identify systemic vulnerabilities in the food supply chain and go beyond technology and business to regain people's trust and confidence in food.

References

- Allison, I., "IBM enlists Walmart, Nestlé, Unilever, Dole for food safety blockchain," *International Business Times*, August 24, 2017. www.ibtimes.com/ibm-enlists-walmart-nestle-unilever-dole-food-safety-blockchain-2582490.
- Andrews, J., "Mango outbreaks connected through interviews," *Food Safety News*, October 26, 2012. <http://www.foodsafetynews.com/2012/10/mango-outbreaks-connected-through-interviews/#.WYtXcMneGPBI>.
- Blanchfield, J.R., and B. Welt, "Food traceability," *The International Union of Food Science and Technology*, March 2012. www.iufost.org/iufostftp/IUF.SIB.Food%20Traceability.pdf.
- Bloomberg, "Walmart to invest 25 million in china food safety research," *Bloomberg Markets*, October 19, 2016. www.bloomberg.com/news/articles/2016-10-19/Walmart-to-invest-25-million-in-china-food-safety-research.
- Bottemelier, H., "IBM and China Team Up to Build Pork Traceability System," *Food Safety News*, Dec. 19, 2011. www.foodsafetynews.com/2011/12/ibm-and-china-team-up-to-build-pork-traceability-system/#.WZjWBCiGPIU.
- Bradsher, K., "Chinese city shuts down 13 WalMart's," *New York Times*, October 11, 2011. www.nytimes.com/2011/10/11/business/global/wal-marts-in-china-city-closed-for-pork-mislabeled.html.
- Bunge, J., "How to satisfy the world's surging appetite for meat," *Wall Street Journal*, December 4, 2015. www.wsj.com/articles/how-to-satisfy-the-worlds-surging-appetite-for-meat-1449238059.
- Burkitt, L., "Walmart to triple spending on food safety in China," *Wall Street Journal*, June 17, 2014. www.wsj.com/articles/Walmart-to-triple-spending-on-food-safety-in-china-1402991720.
- Can-Trace Secretariat, "Can-Trace pork pilot project report," *Can-Trace, Electronic Commission of Canada, Agriculture and Agri-Foods Canada*, 2004. www.can-trace.org/portals/0/docs/Can-TracePorkPilotProjectReport.pdf.
- Castle, S., "Europe says tests show horse meat scandal is 'food fraud,'" *New York Times*, April 16, 2013. www.nytimes.com/2013/04/17/business/global/european-study-affirms-role-of-fraud-in-horsemeat-scandal.html.
- Center for Food Safety and Applied Nutrition, "FDA investigates multiple Salmonella outbreak strain linked to papayas," August 18, 2017. www.fda.gov/food/RecallsOutbreaksEmergencies/Outbreaks/ucm568097.htm.
- Centers for Disease Control and Prevention, "Foodborne illnesses and germs," June 2011. www.cdc.gov/foodsafety/foodborne-germs.html.
- Clark, J., "Pig premise ID registrations top 13 thousand and growing," *The Pig Site*, August 2, 2017. www.thepigsite.com/swinenews/43919/pig-premise-id-registrations-top-13-thousand-growing.
- Clemons, S., "China's latest food scandal: fox-tainted donkey meat," *The Atlantic*, January 2, 2014. www.theatlantic.com/

international/archive/2014/01/chinas-latest-food-scandal-fox-tainted-donkey-meat/282776.

Culp, S., "Supply chain disruption a major threat to business," *Forbes*, February 15, 2013. www.forbes.com/sites/steveculp/2013/02/15/supply-chain-disruption-a-major-threat-to-business/#2ed93c7673b6.

Del Castillo, M., "Walmart blockchain pilot China pork market," *CoinDesk*, October 19, 2016. www.coindesk.com/walmart-blockchain-pilot-china-pork-market

DeCovny, S., "Blockchain in supply chain: edging toward higher visibility," *ChainBusinessInsights.com*, Chain Business Insights LLC, May 2017. www.chainbusinessinsights.com/uploads/1/0/0/0/100045726/blockchain_in_supply_chain_survey_brief_final.pdf.

Doyle, T., "Enabling trusted trade through secure track and trace technology," *World Customs Journal. International Network of Customs Universities, Vol. 8, Issue 1, Section 2, Practitioner's perspective*, March 2014. [worldcustomsjournal.org/Archives/Volume%208%2C%20Number%201%20\(Mar%202014\)/14%20Doyle.pdf](http://worldcustomsjournal.org/Archives/Volume%208%2C%20Number%201%20(Mar%202014)/14%20Doyle.pdf)

essDOCS, "2017 blockchain for freight panel," March 3, 2017.

Food Safety News, "Organic mangoes recalled for possible listeria contamination," May 26, 2014. www.foodsafetynews.com/2014/05/organic-mangos-recalled-for-possible-listeria-contamination/#.WYtXqneGPBI.

Gale, F., "China's pork imports rise along with production costs," *Economic Research Services, US Department of Agriculture*, January 2017. www.ers.usda.gov/webdocs/publications/81948/ldpm-271-01.pdf?v=42745.

Gantait, A., J. Patra, and A. Mukherjee, "Integrate device data with smart contracts in IBM blockchain," *IBM Developer Works*, January 9, 2017. www.ibm.com/developerworks/cloud/library/cl-blockchain-for-cognitive-iot-apps-trs/index.html.

GS1 AISB, "GS1 recommends use of existing data standards in enterprise blockchain implementations," *The Global Language of Business*, 2017. www.gs1.org/sites/default/files/docs/internet-of-things/g1-blockchain-pov-paper-a4.pdf.

Hackett, R., "Walmart blockchain drones patent," *Fortune*, May 30, 2017. fortune.com/2017/05/30/walmart-blockchain-drones-patent.

Hatton, C., "Will China's new food safety rules work?" *BBC News, Beijing*, September 30, 2015. www.bbc.com/news/blogs-china-blog-34398412.

Hodge, S., "Can blockchain technology transform safety standards in the global food supply chain?" *Supply Chain Digital*,

August 25, 2017. www.supplychaindigital.com/technology/can-blockchain-technology-transform-safety-standards-global-food-supply-chain.

Humbert, F., "Mangoes with blemishes: the market power of German supermarket chains and unfair working conditions in Peru," *www.oxfam.de*, Oxfam Deutschland e.V., June 2013. www.oxfam.de/system/files/130705_oxfam_mangostudie_englisch_web.pdf.

IBM, "Hyperledger—open source blockchain for business – IBM Blockchain," *IBM Cognitive Advantage Reports*, IBM Corporation, 2017. www.ibm.com/blockchain/hyperledger.html.

IBM, "IBM announces major blockchain collaboration with Dole, Driscoll's, Golden State Foods, Kroger, McCormick and Company, McLane Company, Nestlé, Tyson Foods, and Unilever, and Walmart to address food safety worldwide," *press release, IBM.com*, August 22, 2017. www-03.ibm.com/press/us/en/pressrelease/53013.nws.

IBM, "Maersk and IBM unveil first industry-wide cross-border supply chain solution on blockchain," *press release, IBM.com*, March 5, 2017. www-03.ibm.com/press/us/en/pressrelease/51712.nws.

Kaye, L., "Responding to food safety concerns, Walmart invests \$25 million in China," *Triple Pundit*, Oct. 25, 2016. www.triplepundit.com/2016/10/responding-food-safety-concerns-walmart-invests-25-million-china.

Kharif, O., "Walmart tackles food safety with trial of blockchain," *Bloomberg Technology*, Bloomberg LP, November 18, 2016. www.bloomberg.com/news/articles/2016-11-18/walmart-tackles-food-safety-with-test-of-blockchain-technology

Lindell, C., "Walmart to invest in \$25M in food safety in China," *Food Engineering*, BNP Media, October 20, 2016. www.foodengineeringmag.com/articles/96277-walmart-to-invest-25m-in-food-safety-in-china.

Lui, G., "Food losses and food waste in china: a first estimate," *Office of Economic Cooperation and Development*, 15 June 2013. www.oecd.org/site/agrfcn/Food%20losses%20and%20waste%20in%20China_Gang%20Liu.pdf.

Matta, M., et al., "Mango supply chain: who is more sustainable—MNC or co-operative society?" *The George Washington University School of Business*, March 20, 2013. talk.aboutfoodjb.files.wordpress.com/2013/08/f_brittell_gautam_keefe_mata_shab_wang.pdf.

Mazhar, M.S., et al., "Managing mango fruit quality through the supply chain: a Pakistan case study," *Institute of Horticultural Sciences, University of Agriculture*, November 2010. www.researchgate.net/publication/235258157_Managing_Mango_Fruit_Quality_through_the_Supply_Chain_A_Pakistan_Case_study.

- McDermott, B., IBM's vice president of blockchain business development, interviewed by R. Kamath, June 23, 2017; edited by B. McDermott, September 12, 2017.
- Murphy, D., "Meat of the matter: when solutions are seen as problems," *Farm Journal's Pork*, November 29, 2016. www.porknetwork.co/community/contributors/meat-matter-when-solutions-are-seen-problems.
- Nash, K.S., "Walmart readies blockchain pilot for tracking US produce china pork," *Wall Street Journal CIO Journal*, Dec. 16, 2016. blogs.wsj.com/cio/2016/12/16/wal-mart-readies-blockchain-pilot-for-tracking-u-s-produce-china-pork.
- National Mango Board, "Production and post-harvest best practices," www.mango.org, 2017. www.mango.org/en/postharvest.
- Ontario AgriFood Technologies, "User needs assessment final report: precision agri-food scoping study," *Precision Strategic Solutions*, September 1, 2016. static1.squarespace.com/static/583f56.1af7e0ab824c0b77c8/t/586ad4a23e00bec12e6c1ff7/1483396389489/User+Needs+Assessment.pdf.
- PricewaterhouseCoopers and Safe and Secure Approaches in Field Environments, "Fighting \$40bn food fraud to protect food supply," January 14, 2016. press.pwc.com/News-releases/fighting-40bn-food-fraud-to-protect-food-supply/s/44fd6210f7-46c7-8431-e55983286e22.
- Produce Processing, "FDA finalizes report on 2006 spinach outbreak," *Great American Media Services and Produce Processing*, March 23, 2007. produceprocessing.net/news/fda-finalizes-report-on-2006-spinach-outbreak.
- Ruitenbergh, R., "Horse-meat suspect Spanghero denies beef scam responsibility," *Bloomberg LP*, February 15, 2013. www.bloomberg.com/news/2013-02-15/horse-meat-suspect-spanghero-denies-scam-admits-some-negligence.html.
- Simon, G., "Supply chain loyalty – the evolution of coupons," *Loyal*, February 15, 2016.
- "Supply Chain Resilience Report," *Business Continuity Institute*, 2016, p. 11. <https://www.risk.methods.net/resources/research/bci-supply-chain-resilience-2016.pdf>.
- The Pig Site, "TEA accuses pig processors of undermining pig meat market," *5m Publishing*, August 7, 2017. thepigsite.com/swinenews/43938/ifa-accuses-pig-processors-of-undermining-pigmeat-market.
- Tiwari, T., "Profit alert: Walmart is adopting the blockchain right now," *Palm Beach Research Group*, December 6, 2016. palmbeachgroup.com/content/palm-beach-daily/profit-alert-walmart-is-adopting-the-blockchain-right-now/32499.
- Tiwari, T., "Walmart, IBM developing a food safety solution," *The Association for Convenience and Fuel Retailing*, February 28, 2017. www.nacsonline.com/Media/Daily/Pages/ND0228171.aspx#.WZNNQJGGPIV.
- Van der Wal, S., "Peruvian mango production: not enough improvements," *The Centre for Research on Multinational Corporations*, July 30, 2013. www.somo.nl/peruvian-mango-production-not-enough-improvements.
- Van Kralingen, B., "Blockchain's role in improving global food safety," *IBM.com*, October 19, 2016. www.ibm.com/blogs/think/2016/10/blockchain-food-safety.
- Walmart, "Walmart invites global collaboration on food safety in China," *press release*, www.wal-martchina.com, October 19, 2016. www.wal-martchina.com/english/news/2016/20161130-4.htm.
- Webb, J., "Tracking pork from pen to plate," *Advances in Pork Production*, 2004. www.prairiesvine.com/pdf/2426.pdf.
- WHO, "Food safety: key facts," *World Health Organization*, October 31, 2017. www.who.int/mediacentre/factsheets/fs399/en.
- Wuest, T., "Identifying product and process state drivers in manufacturing systems using supervised machine learning," *WTI-Frankfurt eG*, 2015. www.wti-frankfurt.de/images/top-themen/Identifying-Product-and-Process-State-Drivers-in-Manufacturing-Systems-Using-Supervised-Machine-Learning.pdf.
- Yiannas, F. and R. Liu, e-mail to R. Kamath, September 6, 2017.
- Yiannas, F., *Walmart's vice president of food safety, interviewed by R. Kamath, June 28, 2017.*