Food Traceability and Safety: From Farm to Fork – A Case Study of Pesticide Traceability in Grapes

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***Abstract*—There is a growing need to reduce the use of poisonous chemicals in the food production. We need a system to monitor and manage such chemical usage. Due to globalization, the supplier and the consumer can be across the countries or continents. Hence global crop quality standards must consider; local regulations, grower's knowledge/skills and also agro input ecosystem. We need to carefully study the entire supply-chain, various stakeholders and find the points of exchange of the products or services. Digital technology can help to map and manage this diversity, across different time zones, culture, language and practices. mKRISHI® provides a digital platform to identify the farm, record, the laborer skills, manage pesticide inventory and including consumption date, time, dosage, etc. Each plot was identified by plot code and Global Gap Number (GGN). Hence, it's easy to trace back the produce (grape box) to the plot as well as get the agro inputs used to produce it. Using a QR code and a mobile app, it's easy for the consumer to get the desired information at their fingertips. Such end to end supply chain digitization not only improves the traceability but also creates a digital mapping framework from farm to fork.**

***Index Terms*—agriculture, pesticide, traceability, GAP, mKRISHI, grape**

I. Introduction

Food is a very complex biological product [1] and is a major necessity for life. Food safety is critical for human health. World Health Organization (WHO) has attributed the death of approx. 1.5 million humans to diarrhea resulting from contamination in food and water [2].

Food quality is assessed based on the safe ingredient used during its production, processing (or storage) and handling during transportation [3]. For example, inappropriate use of the poisonous chemicals and preservatives used may lead to adverse health impact leading to ailments such as cancer, organ failure [4]. ISO22000:2005 Food Safety Management Systems defines food safety as 'food will not harm the consumer as long as the intended user guidelines given on the pack are followed when it is prepared or eaten' [5]. In the bygone days, in a small village, the producer of the food as well as the consumer of the food co-existed. It was easy to trace the origin of the food, the quality of the ingredients used in the production and the processes followed. As the number of parameters were less, determining the food quality (and safety), was relatively simpler.

In today's global food supply chain, this is quite challenging and complex. Food grown in one part of the world is processed, packaged and delivered to other parts of the world [6]. This has dramatically changed the entire supply chain. It comes into contact with multiple stakeholders during the entire farm to fork journey.

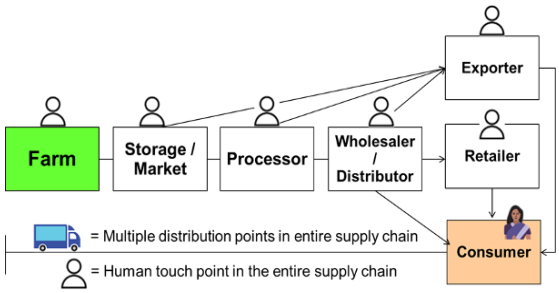

Figure 1. Components (nodes) of food supply chain

Each node of this supply chain – i.e. from farm to exporter or retailer (Fig. 1), must be optimized to add or retain the value for which the consumer will eventually pay for. Because of this multi-point transfer, it also presents the risks of contamination and/or degradation of the quality of the food [7]. Hence, consumer and other agencies (on behalf of the consumers) like regulatory authorities, or processors would like to trace the origin and also the entire journey of the food supply-chain. They would like to know the activities carried out, the resources used and its impact. This requires an integrated traceability system across the entire supply chain which would help in increased awareness, surveillance and quick response time to mitigate the disease outbreak.

II. Materials and Method

Food safety is tightly coupled with the food production and the distribution system [8]. This means the food contamination may occur anytime, anywhere during this entire system. Wrong use of the agro chemicals can contaminate the food at farm. Mixing of the external agents or material can deteriorate the food quality during

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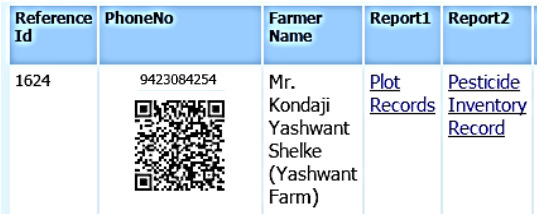
processing or during transit or may be at the supermarkets or retail stores or even at home. Hence, this food system is spread globally are interdependent and involves lots of resource diversity [9]. Hence, there is a need of a traceability system running through all the components and nodes of this system.

A. *Traceability*

The purpose of traceability is to uniquely identify the food source (Fig. 2), document the transition, monitor the compliance of the various qualities, processes, input products and environmental attributes that are associated with food. This helps in detecting the points of contamination or food safety failure points [10].

Wilson and Clarke define traceability as an information system required 'to provide the history of a product or a process from origin to point of final sale' [11].



Reference Id	PhoneNo	Farmer Name	Report1	Report2
1624	9423084254	Mr. Kondaji Yashwant Shelke (Yashwant Farm)	Plot Records	Pesticide Inventory Record

Figure 2. Unique identifier for the farm plot using QR code

From the supply-chain management point of view, traceability system [12]:

Enables efficient identification, collection and documentation of the production information, transit or distribution and consumption;

Enables display of available information and tracking of the original destinations. It also captures the stakeholders involved and their respective roles and responsibilities, thereby establishing the accountability.

Enables a structured, formal process oriented approach, aimed at comprehensive food safety management and risk control.

This paper talks about the design of an Integrated Food Safety Management and Traceability System using the concept of compartmentalization [13]. It details the various components or the nodes of the food supply chain and also of the traceability system to manage these nodes, giving an integrated data view of the entire supply-chain. Majority of the components of this system have been implemented for a grape exporter from India for the season 2014-16.

B. *Food Supply-Chain*

The major nodes in the food supply chains, from its origin to the consumption are [14] (Table I):

- Farms
- Farm Aggregator (Storage / Market)
- Food Processor
- Wholesaler or Distributor
- Exporter
- Retailers
- Consumer

TABLE I. HUMAN RESOURCES, TRANSPORTATION AND POINT OF CONTAMINATIONS

Nodes	Human Resource	Transportation	Point of contamination
Farm	Farmers, Farm Labourers	Tractor	Production: Agro input / Chemicals
Aggregator	Agents, Staffs, Packers,	Pick up vans	Storage: Preservatives
Processor	Employees,	Trucks	Enablers, adding agents/preservatives, enzymes, colours
Distributor	Traders, Loaders, Agents, Retailers	Trucks	Packing Material, point of transfer
Exporter	Lab Assistant, Regulators, Custom Authority	Ship Containers	Packing material, transportation environment
Retailers	Retailer	Local vehicles	Mixing of the unpacked or loose produce / materials from different sources.
Consumer	Family	NA	Storage, cooking

An Integrated Food Traceability System consists of (a) internal traceability system at each component level and (b) an inter component (i.e. supply-chain) traceability.

C. *Traceability at Farm Level*

What is the Risk and why?

It is important to grow the crops recommended as per the prevailing agro-climatic conditions in the region. Failing which the crop may suffer. Difference in temperature, water variations, stress and lack of the required soil nutrients push the farmer to take help of external sources like chemical based fertilizers (Fig. 3).

Use of inappropriate or unapproved crop varieties such as use of non GM (Genetically Modified) varieties, where it is illegal to use.

Figure 3. Farmer and farm registration and farm operation capture using unique plot code (throughout the crop cultivation cycle)

Use of ad hoc or incorrect cultivation practices

Incorrect pest and disease management such as use of banned chemicals, high dosage, spraying the chemical directly on the produce, untrained labor, disposal of the residue bottle/container in the water stream, etc.

Harvesting of the produce immediately after pesticide spray, etc. Use of wax to protect the food wastage or use of the chemical to expedite the ripening.

Majority of the farms being small scale, there is lack of resources to bring them under food safety standard compliance. Also monitoring and documenting the entire farm operation becomes difficult.

How to manage the risk?

First step in the risk mitigation and management is to create awareness. It is important to help the farmers learn about benefits of being compliant to food safety, such as opening up of new market, health benefits and so on. This will also mean keeping the training records of the farmers and farm laborers.

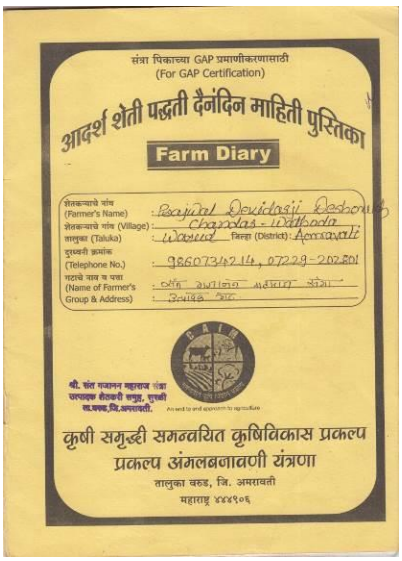
Carry out the soil testing, to understand the nutrient deficiency and perform the nutrient management as per the agricultural expert recommendations [15].

Implementing the Pest and disease management in accordance with the recommendations – which includes avoiding the use of the banned chemicals, appropriate dosage of pesticides, direct spray at the pest area rather than the entire plant and use of the correct protective gears, trained labor, correct disposal of the residue bottle, etc. In certain crops Integrated Pest Management (IPM) [16] must be followed to rear the good pests which naturally feed, on the bad pests damaging the plants.

Maintaining a record (Fig. 4) of the nutrient and pesticide inventory and their consumption in terms of dosage, date and time, etc. [17].

Harvesting the produce only after the recommended duration, post the pest management.

CB 8.8.4 Nikam Eye Wash Facilities



AF 3.4.4 NIKAM FIRSTAID KIT

Figure 4. Farm Diary, Farm Boards and First Aid Kit

How Digitization can help in this?

Digitization helps in enhancing the farmer knowledge about the correct and recommended practices. Best Practices and Frequently Asked Questions (FAQ) help in identification of the correct seeds, nutrients and recommended pest management practices. This helps in multi-media (photo, audio and video based) learning on the mobile phones, in local language [18].

Use of the photo gallery is very crucial in IPM. It helps in identification of the good and bad bugs (pests). Hence, it helps in the appropriate use of the pesticides only when the pests count is above the threshold (known as ETL).

The contents can be shared with other farmers through social media channels, hence increasing the peer, and farmer to farmer learning.

Uploading the soil testing reports for every plot in the web and expert recommendations on the relevant farmer queries, helps personalize the farm advisory.

Pest management best practices include the list of the new and widely used recommended chemicals with the required warning about the maximum dosage. It also helps disseminate the information about the banned chemicals.

Digital Record-keeping of the inventory and its consumption helps in generation of the periodic reports, which can be submitted for the crop certification too.

Based on the pest management data entered, it can help alert on the recommended harvesting date.

At the advanced level and for large farms the technologies like soil and plant sensors, automatic weather stations, Radio Frequency Identification (RFID), Global Positioning System (GPS), etc. can be used to monitor multiple farm and weather materials and helps in analyzing their impact on the food quality and safety.

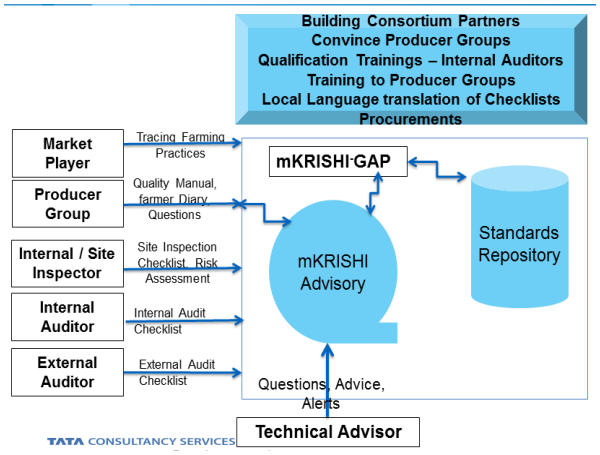
Output (data point or report)?

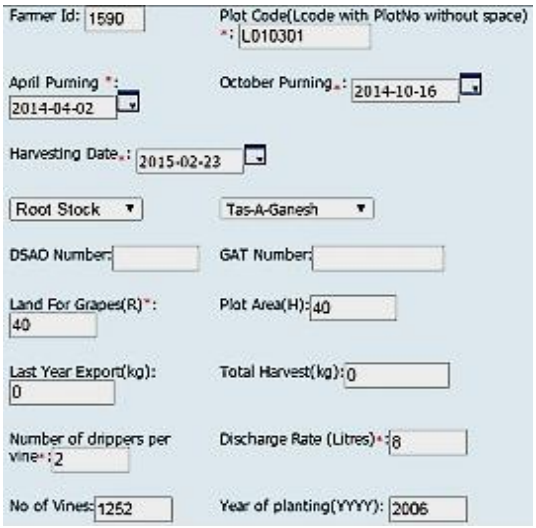
It helps in keeping the total chemical consumption (Fig. 5) per unit of the area and hence, able to generate the training records of the labor,

Date and time of the spray and the time gap between the spray and the harvest, etc.

The digital photo helps in keeping the artifact record of each farm operations, stamped by the system date and time.

The farm can be traced in the map and can also be easily linked with the QR code. Hence, origin of the food is easily traceable.





Target Pest	Product Used	Active Ingredient	Application Date	Rate	Water Volume or Area	Quantity
Pesting	Dormex	Hydrogen Cynamide 49%	2014-10-02	40 ml/L	25 L	1000 ml
Pesting	Indofil M- 45	Mancozeb 75 % WP	2014-10-02	2 gm/L	25 L	50 gm
Pesting	Sulfex	Sulphur 80 W. P.	2014-10-02	2 gm/L	25 L	50 gm
Downy Mildew	Acrobat	Dimethomorph 50 % WP	2014-10-05	1 gm/L	250 L	250 gm
Downy Mildew	Antracol	Propineb 70 WP	2014-10-08	3 gm/L	250 L	750 gm
Downy Mildew	Ridomil gold	Metalaxyl M 4% + Mancozeb 64 % WP	2014-10-12	2.5 gm/L	250 L	625 gm

Application Methodology	Type	Days After Pruning	Pre Harvest Interval	Proposed Pruning End Days	Technical Authorization	Operato
By Hand	Preventive	0	120	135	NRCG + Self	Sachin & Workers
By Hand	Preventive	0	35	135	NRCG + Self	Sachin & Workers
By Hand	Preventive	0	15	135	NRCG + Self	Sachin & Workers
HTP Pump	Preventive	3	66	132	NRCG + Self	Sachin Jadhav
HTP Pump	Preventive	6	40	129	NRCG + Self	S
HTP Pump	Preventive	10	66	125	NRCG + Self	Sachin Jadhav

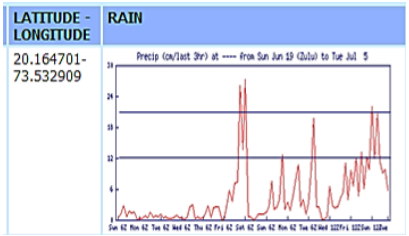


Figure 5. Stakeholders, farm operations digitized, weather based advisory

Outcome – benefit

It brings structure to the entire farm management and documentation process.

Best practices, FAQs and the Photo Gallery help increase the awareness level of the farmers.

It establishes two way, online communications between farmers and the experts.

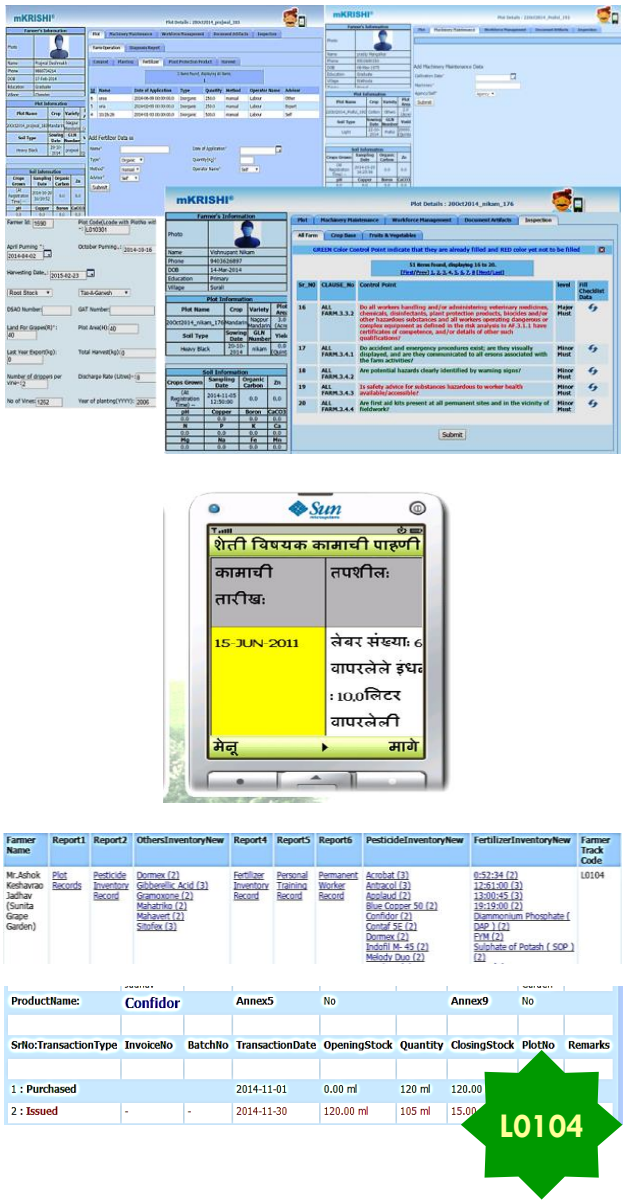


Figure 6. Filled in GAP checklist, farm operations and various reports uniquely identified by Plot code

Digitization helps in a "traceable" artefacts system, which is good for the crop certification processes like Good Agricultural Practices (GAP) (Fig. 6).

Easy reference and archival helps develop a history of the records for the farm. Learning from each season is fed into the system and the improvement can be tracked too.

D. *Traceability at Aggregator Level (Packhouse)*

What is the Risk and why?

An aggregator collects the food from the various farms and stores it at a warehouse or market yard, before it is sent to the processor or the buyer. Since the farm operations and the plot conditions vary from farmer to farmer (or the plot by plot), it is important to maintain the separation of the produce at the warehouse. This is one of the (potentially) biggest nodes, where the mixing of the produce may occur, hampering the entire traceability process.

An integrated harvesting and storage calendar schedule can help improve the inflow of the material (produce) at the storage as well as the outflow. This also helps the effective utilization of space as well as lesser storage duration required for the produce.

How can Digitization help in this?

System generated plot code labels (Fig. 7) can be affixed on the large crate having the produce from the same plot. CCTV cameras also help monitor the process remotely and keep an audit trail for the entire process.

Some of the sensors such as weighing machines, room temperature, moisture level, etc. can help give the automatic data about the inflow/outflow as well as the storage environment conditions.

Output (data point or report)? Outcome – benefit?

Farmer and plot wise produce-quantity reports, uniquely identified by the QR code can help maintain the food segregation and support traceability.

Figure 7. Maintaining the plot code identified from plot to pack house and to smallest packets or pallets

E. *Traceability at Food Processor Level*

What is the Risk and why?

Similar to the food aggregator, food processor gets the food inflow from multiple sources; this increases the risk of mixing of the food. Food processors either repackage the food by sorting, grading and repacking them into smaller packets or pallets, or process or transform them into a different value added products like juice. There is risk of usage of chemicals for ripening of the food or use of preservatives. Hence it is important to keep a record of such usage and need to highlight the same on the packets.

How to manage the risk?

Mechanical automation helps in avoiding contaminations through human touch. It maintains the temperature and the moisture in the area. Basic sanitation of the laborers is important. Since, this is the packet which would reach the consumer, the traceability of the produce at plot level should continue even in this stage and the smaller labels generated should be pasted on the packs.

How can Digitization help in this?

RFID technologies can be used on the produce and the pallets containing the produce. Sensor data helps in managing the cooling temperature whenever it rises above the thresholds. Various reports helps establish the tracking of the foods inflow and outflow between premises.

Pallets are grouped and put into a bigger box, which too has the required labelling. These boxes are loaded in large frames. All these information are entered and maintained in the digital system. Hence, enabling a tracking of the frame to box, box to pallets/packs, and packs to plot (Fig. 8). This enables an end to end tracking of the food.

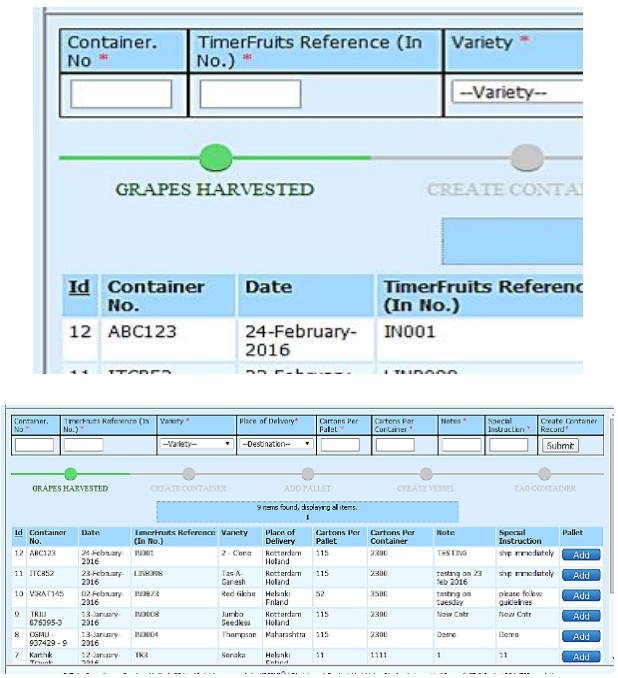


Figure 8. Generation of the pallet, container and vessel tag to maintain the traceability

Output (data point or report)? Outcome – benefit?

System generated plot code labels can be affixed on the produce. The packaging labels must have the details

of the processors, date of processing and also have the QR code, containing all the farm level details or pointers They can be tracked on Google maps too (Fig. 9).

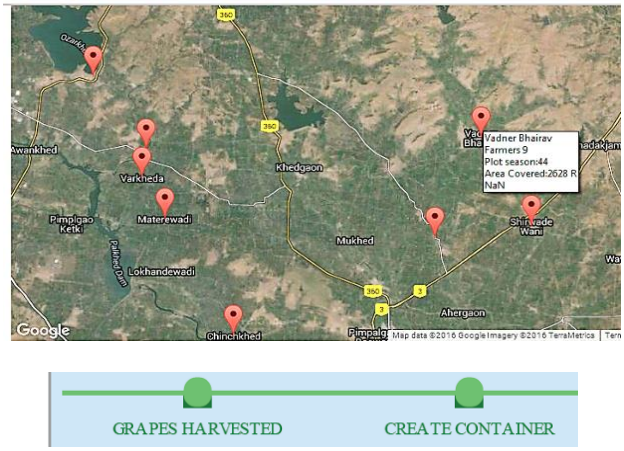


Figure 9. Map and stepper based tracking

Tracking helps in finding the quality of the food and rejection at multiple levels due to inadequate quality standards or compliance.

The inflow and outflow of the produce from the processing bench helps understand the difference between the raw and the processed food, indicating the wastage. This can also help analyze the quantity of the wastage and help minimize it over few iterations.

F. *Traceability at Wholesaler Level*

What is the Risk and why? How to manage the risk?

There is always a risk at wholesaler level regarding packs being opened to mix with other inferior quality food. Good packaging, sealing and use of the hologram labels, can help avoid this.

How can Digitization help in this?

The wholesaler or the distributor may have an Enterprise Resource Planning (ERP) software module for invoicing and ordering, and hence, can easily tag the receivable of the food by its (processing factory) batch no. In the absence of such a system, it would be very difficult to trace the activities at the wholesale level.

Output (data point or report)? Outcome – benefit?

The invoice has the details of the products shipped to the wholesaler with the batch no. and manufacturing / processing details.

G. *Traceability at Exporter Level*

What is the Risk and why? How to manage the risk?

The risks and the management techniques are similar to that at aggregator level.

How can Digitization help in this?

In addition to the recommended steps in the aggregation level, the lot number and, the exporter details also appear on the product labels. All these information, along with the invoice with the details of the shipping (Fig. 10) helps in linking the next food destination.

Output (data point or report)? Outcome – benefit?

Farmer-wise, plot-wise produce quantity reports, uniquely identified by QR code, produce sample lab test report and the invoice help maintain the food segregation and support traceability.

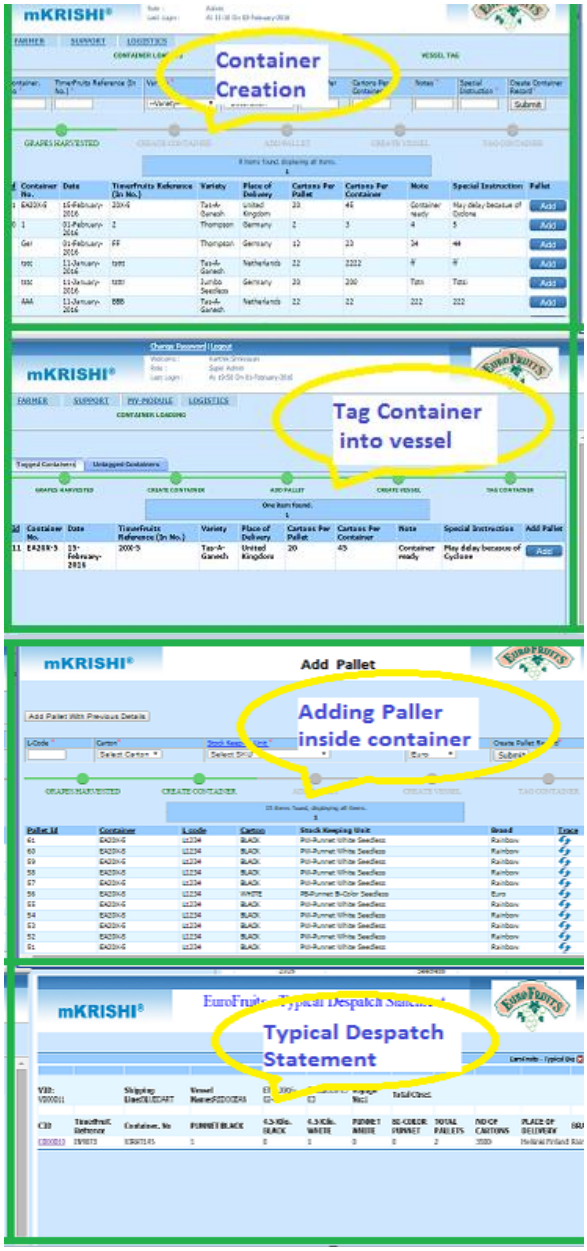


Figure 10. Adding pallet, container and vessels

H. *Traceability at Retailer Level*

The sheer volume of the retailers and their lack of investment in the technology, makes the traceability a very difficult task. The risk level can be minimized by ensuring a sealed product at the retailer level. Maintaining a viable product environment is very crucial through measures taken such as cooling, shades, etc. Otherwise it can make the product susceptible to various external contaminations or degrade the product quality.

I. *Traceability at Consumer Level*

Consumers use the QR code to trace the food origin. This same information can help the regulatory authorities like Food Development Authority (FDA) to recall the

unsafe foods. The package information helps in tracing the food source (Fig. 11), and hence can be traced back.

Figure 11. Grape traceability using QR code mobile app

III. Results

The service has been developed and deployed for a European grape exporter for two seasons since 2014. The traceability system has been implemented

- At Farm level
- At two Pack house level
- At Shipping / Transportation level.

As part of this, farm records of 229 farmers managing 800 plots were digitized. It covered 1.1 million vines in 520 hectare of land. The digital system recorded 45000+ control points filled by internal inspector. It also recorded 48000+ farm operations and 35000+ Inventory records. Authentication helped identify various stakeholders and ensured accountability for entering the data. It provided a holistic view of the entire supply chain and enabled transparent, online information sharing system for tracking of the shipment from farm to the importing country port

Replacing the paper based system with the digital system has helped reduce the latency in decision making and providing online traceability.

IV. Challenges

There are numerous challenges faced by small scale farmers. Low awareness, steep learning curve and lack of a stringent regulatory framework for the local market, restricts the small growers to follow the process proactively. This reduces their participations [19]. The steep cost of the certification and traceability in the beginning stages, is also a prohibitive step for the farmers to join, especially for the small scale growers. There are various political-socio impacts due to the food safety and recalls. Hence, the bigger agencies or the corporates in the food sectors do not want to share their food safety compliance data or to participate in a public food distribution and traceability system. This can negatively impact any such drive to improve the food safety at a global level. A cloud based standardized data sharing online across different components / node can remove the data duplicity and latency [20]. This requires widespread education and cooperation throughout the supply chain.

V. Further Work

In the current work the pack house field agents entered the farm level data on regular field visits. This helped in ensuring that the quality of the data is maintained. Going forward local language mobile applications will be developed to help farmers capture the data for their plots along with various physical proofs. This will help increase the speed of the data entry and audits would be faster too. Integration of wireless sensors [21] will help get the environmental data and would also help farmers with personalized advisory and also ascertain and check the respective farm operations done by the farmers. RFID tags will be used to identify the pallet movements and automatic data entry.

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