Chapter 14
Designing New Supply Chain Networks: Tomato and Mango Case Studies

Jack G. A. J. van der Vorst, Rob E. Schouten, Pieternel A. Luning and Olaf van Kooten

Abstract Consumers expect product availability as well as product quality and safety in retail outlets. When designing or re-designing fruit and vegetables supply chain networks one has to take these demands into consideration next to traditional efficiency and responsiveness requirements. In food science literature, much attention has been paid to the development of Time-Temperature Indicators to monitor individually the temperature conditions of food products throughout distribution as well as quality decay models that are able to predict product quality based upon this information. This chapter discusses opportunities to improve the design and management of fruit and vegetables supply chain networks. If product quality in each step of the supply chain can be predicted in advance, good flows can be controlled in a pro-active manner and better chain designs can be established resulting in higher product availability, higher product quality, and less product losses in retail. This chapter works towards a preliminary diagnostic instrument, which can be used to assess supply chain networks on QCL (Quality Controlled Logistics). Findings of two exploratory case studies, one on the tomato chain and one on the mango chain, are presented to illustrate the value of this concept. Results show the opportunities and bottlenecks for quality controlled logistics depend on product—(e.g. variability in quality), process—(e.g. ability to use containers and sort on quality), network- (e.g. current level of cooperation), and market characteristics (e.g. higher prices for better products).

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Introduction

Consumers expect food in retail stores to be of good quality, to have a decent shelf life and to be fit for purpose (Smith and Sparks 2004). Furthermore, consumers demand product diversity, safety, convenience (e.g. ready to eat products), and sustainable food production and supply production systems. Well-informed customers are stimulating retailers and other actors in the food supply chain network to adapt new business concepts. They require year-round availability of high-quality fresh products (such as pine-apples, citrus fruits, kiwi fruit), which has stimulated partners in food supply chains to pursue a coordinated approach to establish more effective and efficient supply chains.

Design of supply chain management (SCM) has received a lot of attention in the academic (IJOPM 2007) as well as business world (Simchi-Levi et al. 2007; Chopra and Meindl 2007; Christopher 2010). SCM is about matching supply and demand; it is about the integrated planning, coordination, and control of all business processes and activities in the supply chain to deliver superior consumer value at less cost to the supply chain (Van der Vorst and Beulens 2002). Aim of SCM is to produce a consistent view on how a supply chains should look like in terms of supply, production and distribution processes and their coordination.

The design and management of AgriFood Supply Chain Networks (AFSCNs) is characterised by a focus on product availability and its quality. The way in which food quality is controlled and guaranteed in the supply chain is an important performance indicator and very much linked to another performance indicator, food safety (Luning et al. 2009, 2011). Investments in chain design should not therefore only be aimed at improving logistics performance but also at the preservation of food quality so that products are delivered with the right quality at the right time (Van der Vorst et al. 2011).

Typically, food degradation is related to intrinsic properties (initial microbial contamination, respiration rate and specific cultivar characteristics), environmental conditions (temperature and humidity) and the time the product is exposed to these conditions. Environmental conditions may be influenced by, for example, the type of packaging, and the availability of temperature conditioned warehouses. In food science literature, much attention is paid to food quality decay modeling and the development of Time Temperature Indicators (TTI) to monitor the temperature conditions and assess the impact on the quality deterioration throughout distribution (Sloof et al. 1996; Taoukis and Labuza 1999; Schouten et al. 2002; Bobelyn et al. 2006). When we combine these food quality change models with logistics decision support models, new opportunities arise to improve the performance of AFSCNs (e.g. Rossi et al. 2012).

This paper discusses opportunities to use time-dependent product quality information to improve the design and management of AFSCNs. Product quality in consumer markets is influenced by the product quality at origin (when harvested) and the conditions that the products have been exposed to during in the supply chain network. The logistics concept therefore influences market opportunities and vice versa. If quality is known in advance, goods flows could be steered in all phases of the AFSCN. This chapter describes a preliminary diagnostic instrument, which can be used to identify improvement opportunities in the supply chain as to increase product availability of the right quality at the right place and time. Two exploratory case studies are presented to illustrate the value of this diagnostic instrument.

Temperature-Controlled AgriFood Supply Chain Networks

A temperature-controlled AFSCN requires products to be maintained in a temperature controlled environment, rather than exposing them to whatever ambient temperatures prevail at various stages of the supply chain (Smith and Sparks 2004). In this paper, we focus on fresh fruits that need controlled temperatures to maintain or even improve product quality (due to ripening of fruits: ripe-on-arrival). Considering the increasing consumer demand for ready-to-eat products (like ready meals and prepared salads) the ability to optimize temperature-controlled AFSCN becomes increasingly important.

There are a number of difficulties in managing temperature-controlled AFSCNs such as the short shelf life, which puts additional requirements on speed and reliability of logistics systems and require specialized transportation and storage equipment. Furthermore, modern chains distribute multiple types of products—often with multiple temperature regimes. This means that a 'best fits all' solution is taken, which means that the temperature is not optimal for any of the products. Moreover, one must be careful for product interferences, for example, bananas produce ethylene, which accelerates the ripening process of other fruits. Finally, in these chains temperature control and prevention of product interferences are very important from the perspective of food safety; typical safety problems concern *Listeria* in cheese products, *Salmonella* in chickens and eggs, *BSE* (bovine spongiform encephalopathy) in cattle, *EHEC* (enterohaemorrhagic *Escherichia coli*) in vegetables. These typical food related issues should be considered when designing a AFSCN, using risk assessment as an important tool (Luning and Marcelis 2009).

It is clear that the design and management of temperature-controlled FSCNs is a complicated process; how can a retailer ensure that products are always under the appropriate temperature regime? Fruit and vegetables might look fresh from the outside, but what is the remaining period of consumer acceptance? Retailers and chain partners realize that they can distinguish themselves in the market place by setting up a reliable temperature-controlled FSCN that guarantees product quality and reduces shrinkage (price cuts) in retail outlets.

State of the Art

In a recent special issue in *OR Spectrum* (Grunow and Van der Vorst 2010), Akkerman et al. (2010) presented a review of the design and management of agri-food distribution networks. They concluded that the limited shelf lives of food products, requirements with regard to temperature and humidity, possible interaction effects between products, time windows for delivering the products, high customer expectations, variability in supply and demand (e.g. weather dependability), and low profit margins make distribution management of fresh products a challenging area. This has only recently begun to receive more attention in the operations management literature.

The introduction of unbroken cold chains, an uninterrupted series of storage and distribution activities which maintain a given temperature range, has improved the quality of food products at the market place. Quality assurance guidelines and standards such as Good Manufacturing Practice (GMP) and HACCP (Hazard Analysis and Critical Control Points) have been developed and implemented in food supply chains (Luning et al. 2008, 2009). Moreover, breeding and cultivation practices have improved in order to increase the initial product quality at harvest. From a logistics point of view, emphasis has been on developing management concepts that improve delivery reliability and lead times. This is accomplished via increased information exchange and changes of roles in the chain, e.g. Cross Docking, Vendor Managed Inventory (VMI), Efficient Replenishment, Collaborative Planning Forecasting and Replenishment (CPFR) and Factory Gate Pricing (FGP). Also innovations in logistic means, such as reefers and RFID's (radio frequency identification) have been important. It is clear that logistics improvements go hand in hand with technological developments and quality assurance systems. However, up to now a complete integrated perspective has not been taken.

Temperature monitoring and recording is a prerequisite for chain control and any logistics management system that aims on product quality optimization. New technological developments, such as time-temperature integrators or indicators to individually monitor the temperature conditions of food products throughout distribution, offer possibilities to improve temperature monitoring throughout the distribution system (Giannakourou and Taoukis 2003). This allows for shelf life estimation using quality prediction models, as is for example shown by Tijskens (2004) for fruit and vegetable chains, Raab et al. (2008) for pork and poultry chains and Dalgaard et al. (2002) for fish chains. The additional information gained from these technologies would allow for advanced logistics decision making during the complete distribution process knowing the required product quality at its final destination, a concept called "Quality Controlled Logistics" (Van der Vorst et al. 2007, 2009, 2011).

Quality Controlled Logistics

Fresh AFSCN are characterized by heterogeneous batches of products (i.e. product quality differs within the batch and between batches) delivered by a diversity of producers to multiple market outlets that have different demands. Long supply chains of perishable products suffer from risk of quality degradation. Storage, handling, transport, and distribution conditions have a strong impact on freshness and shelf-life of the produce. The common strategy for dealing with the variability in quality is tailoring the supply chain towards 'average' quality. This might not be the most effective approach, since variability can also be strategically exploited through flexible management of quality differences for specific market outlets. Instead of homogenizing product quality in the chain, we advocate differentiation of product flows based upon the batch quality at different stages in the AFSCN. This might improve chain revenues via improved product quality on retailer shelves and/or improved matching of supplied products at a certain price to specific market segments. Batches of high quality could be sent to different market segments with higher added value.

Quality Controlled Logistics (QCL) makes use of variation in product quality, developments in technology, and heterogeneous needs of customers, and the possibilities to manage product quality development in the distribution chain. QCL can be defined as that part of supply chain management that dynamically plans, implements, and controls the efficient, effective flow and storage of food products, services, and related information between point of origin and point of consumption. The goal is to meet customers' requirements with specific attention to the availability of specific product qualities in time by using real-time product quality information in the logistics decision process. QCL starts with obtaining detailed knowledge on customer requirements in the different market segments (Table 14.1). At the harvest stage, products are collected and characterised based on variation in quality attributes. For example, due to sun light exposure apples or mangos on the outside of the tree have different quality attributes compared to products inside the tree, or between the sun-side and the shade-side of the tree. QCL makes use of the quality distribution profile of each batch by matching them with customer demands for specific products and the price that is paid for each batch. Instruments for this approach are to either redirect the goods flows to other markets/consumer groups or to influence the quality level of the products by changing, for instance, storage time, temperature or gas atmosphere (for instance during long term apple storage or modified air packaging of fresh cut fruits or vegetables).

In order to put the QCL concept in practise we identified the following six elements based (Van der Vorst et al. 2011):

a. Consumer Preferences and Acceptance Period of Product Quality Attributes

This element refers to (1) the quality attributes that consumers prefer as well as the target values of each attribute, and (2) the acceptance period (AP; Schouten et al. 2007b). The AP refers to the time period consumers find all attributes of a product acceptable. By consumer research it becomes possible for a specific consumer group to determine the limits of acceptability for the specific quality attributes like color and firmness or taste. If this is known it becomes possible to aim for these specific characteristics for the products in retail shelves.

Table 14.1 Generic logistics decisions versus specific QCL decisions. (Van der Vorst et al. 2011)

Generic logistics decisions	Specific QCL decisions
Determine generic customer service standards Customer needs (e.g. quantity, quality) Customer service levels (e.g. lead time, reliability) Determine requirements on supply of products in each stage of the chain	Determine customer acceptance levels and periods for specific market segments using accepted and measurable quality standards. Translate this into specific product quality requirements for each stage in the supply chain (next to of course volume and timing requirements)
Determine facility network design Number, location of stocking points Equipment selection, capacity planning	Use customer requirements data, information on supply qualities and volumes and transport scenarios with quality predictions to determine the required network design and equipment
Determine inventory management Position Customer Order Decoupling Point (CODP); push-pull strategies Warehousing policies	Use supply chain data to determine the optimal position of inventory points in the network taking predicted quality changes (and thus environmental conditions) into account
Determine information flows and order processing Ordering rules Order inventory interface procedure Order picking procedures	Determine Critical Quality Points (CQPs) to monitor quality changes. Use quality prediction models and product quality information to apply optimal picking policies (e.g. first-expired-first-out policy). Re-sort batches if needed. Aim for homogenous batches for specific market segments
Plan order fulfilment Allocate harvested produce to customer orders and deliver the products without dealing with quality changes and differences that occur in the supply process. A batch is not re-sorted or re-allocated unless serious issues arise. Determine transport management (mode, scheduling)	Dynamic logistics planning in the complete chain based upon real time product-quality information (using critical quality points and predictive models). If needed, batches are re-sorted into homogeneous batches, re-allocated to different market segments, transported with different modes or environmental conditions are adapted to meet customer requirements. Technologies such as data loggers, RFID and GPS are used to capture all relevant information, translated into meaningful information through models

b. Critical Quality Points

A critical quality point (CQP) refers to a point in the process where variation in product properties and or processes results in unacceptable and or irreversible deviations in required quality attributes of the final product (Luning and Marcelis 2009). By studying chain conditions and relating the findings to the dynamic behavior of quality attributes, it becomes possible to determine the effects of different chain configurations (and thus logistics decisions in different stages in the chain) on the product quality and product availability. This supports the determination of locations in the chain where certain measurements should be done and logistics and quality control actions should be taken. As a result, one can change conditions such as temperature, storage time, and order picking procedures as well as moment of positioning the product in the shelves (Schepers and Van Kooten 2006).

c. Product Quality Measurement and Prediction

Several techniques are available and in development that enable us to measure and predict the dynamic quality development of fresh food products in the AFSCN. They enable us to predict the ripening or quality decay development under different environmental conditions, which allows the development of Quality Controlled Logistics in fresh AFSCN and positioning of food in retail shelves precisely when consumers expect and accept them. Provided consumer preferences (step a), chain conditions are known, measurements are carried out at the CQPs (step b) and predictive quality models are available (step c) it becomes feasible to direct batches varying in quality attributes though the chain in a way that all batches end up with the same quality at the consumer. This is the essence of the next steps of QCL.

d. Logging and Exchange of Information

The fourth element relates to data logging and exchange of relevant information with supply chain partners. The quality of fresh food products depends on its temperature history, from production through distribution and storage to consumption. Monitoring the temperature in the chain—as well as all other relevant environmental conditions—allows prediction of shelf-life if product quality models are available to replace the sometimes meaningless expiry dates on fresh produce (Bobelyn et al. 2006). New technologies like RFID and GPS (global positioning system) provide innovative means to capture data. Next to product quality- and environmental data also demand, inventory and supply data could be exchanged in the supply chain. This facilitates advanced logistics decision making central in the following two elements.

e. Local Dynamic/Adaptive Logistics and Quality Control

In the end, QCL comes down to adaptive control by supply chain stages based upon customer wishes and current product quality, i.e. to change the flow of products and environmental conditions to which these products are exposed to. Furthermore, new stock rotation and order picking systems can be implemented by individual supply chain partners, which are not based on First-In-First-Out (FIFO) or Last-In-First-Out (LIFO), but on First-Expired-First-Out or Right-Quality-First-Out (RQFO). In the case of FEFO, the products with the closest expiration date are advanced first,

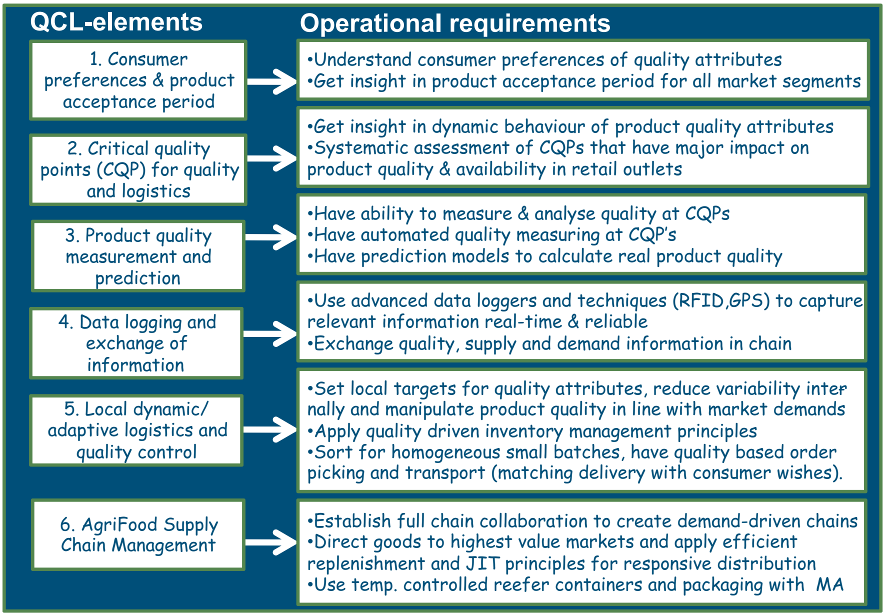

Fig. 14.1 Operational requirements of QCL elements

and with RQFO exactly that batch is delivered, which has the right quality for that particular customer.

f. Supply Chain Management (SCM)

Finally, all SCM practices as discussed earlier (like CPFR, VMI) can be applied in the complete supply chain to match supply and demand using the advanced product information exchanged in the supply chain and collaborative logistics decision policies; production and distribution lead times can be shortened, full chain transparency created and waste and costs reduced.

These six elements can be combined in a preliminary diagnostic instrument that indicates the operational requirements of each QCL element (see Fig. 14.1). The next step is to develop different performance levels to assess specific supply chains and to analyse the relationship between QCL elements and supply chain performance. To get some first insight in this the next sections describe case studies in the tomato and mango supply chain network.

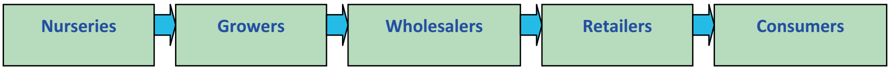

Fig. 14.2 Supply chain for tomatoes in the Netherlands

Case Study in the Tomato Supply Chain

The Tomato Supply Chain

The supply chain for fresh tomato starts with nurseries that produce young plants from hybrid cultivars. Growers will deliver tomato fruit (sometimes as part of a grower association), to wholesalers or, direct to retailers. Tomatoes are harvested after reaching the breaker stage of ripening (Schouten et al. 2007a). They are then stored and transported. The period of storage and transport is kept to a minimum given the constraints of the logistics of large quantities and market demand. Supermarkets are the main distribution channels of vegetables, with a market share of 85 %. The period between moment of harvest and positioning in the retail shelf for sale generally varies between 2 and 10 days. Retail managers try to procure amounts that can be preferably sold within one day. The last chain actor is the consumer. Figure 14.2 shows a typical tomato supply chain in The Netherlands.

Tomato Quality

In practice, color and firmness of tomatoes in the shelves varies considerably over time. Also the taste can vary from acceptable to far below acceptability (Bruhn et al. 1991) even within the same cultivar and origin of production. This leads to complaints from consumers and retail managers about insufficient quality (van Kooten 2006). Growers associations produce tomatoes with differences in quality due to differences between individual growers and between batches of one grower. Current practice in the horticultural chain is to harvest tomatoes after they reach the breaker stage and transport them at the prescribed temperature of 12 °C to slow down ripening while also avoiding chilling injury. This may result in an insufficient color (pink color stage) and firmness (too firm) at the moment of consumption. On the other hand, when tomatoes are harvested and transported over long distances or stored too long in retail shops, firmness can become a limiting quality attribute, now due to tomatoes being too soft. In other words: the quality attributes of both color and firmness are of importance for consumers (Tijskens and Evelo 1994) and thus determine the willingness to buy and consequently the price settings.

QCL Analysis in the Tomato Supply Chain

Schouten et al. (2006, 2010) determined the acceptance limits for both color and firmness of round tomatoes when consumers want to buy them for direct consumption and also for consumption after several days. As indicated before, the acceptance period (AP) consists of the period that all quality attributes are considered acceptable and takes into account that tomatoes can first be unacceptable due to being immature, then be acceptable, and then be unacceptable again, due to being over-ripe. Based on a hybrid (kinetic-stochastic) quality model, calibrated on (non-destructively measured) color and firmness data gathered at different storage temperatures, predictions on the development of both color and firmness through time at variable temperatures could be established. By combining this calibrated model with the acceptance limits it becomes possible to predict the time it takes, depending on the chain temperature conditions, when a batch becomes acceptable and how long the batch will stay acceptable.

The acceptance period model was calibrated for 10 tomato cultivars from one Dutch breeder. All tomatoes from all cultivars were grown in the same greenhouse and harvested on the same day for each maturation level, i.e. breaker, pink and red. A tomato supply chain from a well-known Dutch producer group, known as Prominent, was studied. From this study 12 different actual and possible supply chains were designed. The chains were typical for different seasons, e.g. in the summer the supply is large and so the chain duration lengthens, while in winter the supply is small and the chain duration is short. When the tomatoes were harvested on Friday there was a weekend effect prolonging the chain duration. Some of the results are depicted in Fig. 14.3.

Figure 14.3 shows the duration of the AP between 12 and 13 days for the best Dutch tomato cultivar compared to the worst Dutch cultivar with an AP duration varying between 1 and 3 days. Four scenarios depicted as horizontal bars are shown starting at day 0 (harvest). The colors indicate the different chain temperatures the tomato batch experiences throughout the chain. It is clear that a short AP (lower plot) results in a batch that is still unacceptable at the moment the batch hits the shelf. In most cases the tomatoes are far from optimal when displayed to the consumer. Except in Scenario 3 (whole chain at 25 °C), where the tomatoes are mainly overripe when the consumer can buy them. The only case that we have a good match is in scenario 4 when the tomatoes are harvested in the pink stage of maturity. It is clear that if tomatoes have a short AP duration this demands high precision chain management. This situation could be dealt with, but that would mean an exact knowledge of all chain conditions ahead of time and adapt accordingly. These are, for now, unrealistic in fast flowing high volume chains like tomato chains. Even for the best Dutch cultivar (upper plot) suboptimal chain performance may occur. As we see in scenario 1 the chain is too short for the AP. A proper logistic decision in this case would be to store the tomatoes or keep them at a higher temperature to make sure they reach the shelf in an optimal state. Scenario 3, at 25 °C, shows that part of the AP is lost due to early ripening within the chain. A proper logistic decision would be here to lower the chain temperature.

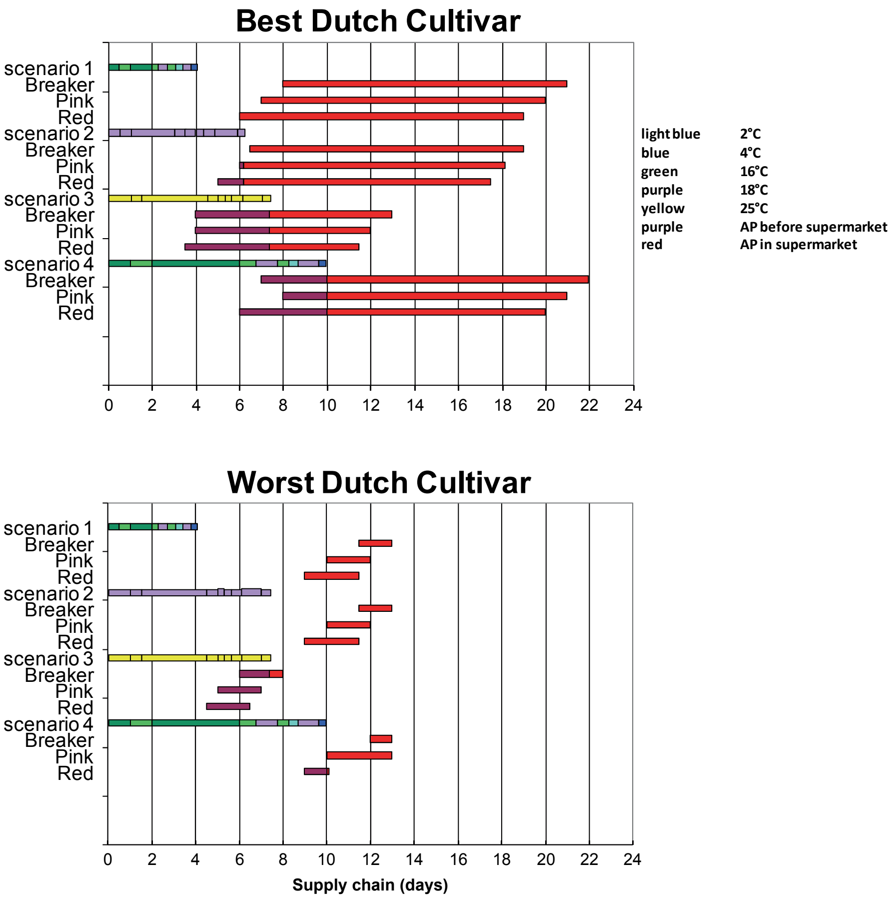

Fig. 14.3 Scenario analysis of the best and worst Dutch tomato cultivar with regard to the start and the duration of the acceptance period. (Schouten et al. 2010)

Table 14.2 presents an overview of improvement opportunities when implementing the QCL concept in the tomato and mango supply chains.

Case Study in the Mango Supply Chain

The Mango Supply Chain

Typically, mango fruits are picked in an unripe stage in tropical or sub-tropical countries and cooled during weeks of sea transport in reefers to slow down the ripening process. Most mangoes are harvested when they reach a sufficient size

Table 14.2 Overview of identified improvement opportunities in real life tomato and mango supply chains

	QCL element	Improvement opportunity in the chain
1.	Consumer preferences & AP	Different market segments and its customer requirements should be identified. Next, the APs for these specific markets should be determined
2.	Critical quality points (CQP)	More insight should be gathered on the CQPs Transport conditions such as temperature need to be set. This setting depends again on the travel/ storage time and how far the products need to be developed at the retailer
3.	Product quality measurement and prediction	Different quality classes are defined with help of procedures and standards, such as colour scale card for manual grading. Batches should get their own ID code showing quality score As the product arrives at wholesaler site, there should be advanced measurements of products quality Regular monitoring should take place to adjust product offerings related to APs Predictive models of product quality at the grower should be used to support the decision to harvest products at a certain stage and time
4.	Data logging and exchange of information	Detailed information on quality status of cargo and environmental conditions should be registered and communicated to chain partners using information standards and data loggers. Then all chain partners know now the origin, quality level, the storage and travel conditions of that particular batch including the quality development Retailers should predict demand and pass this information to other chain actors enabling responsive demand driven logistics
5.	Local dynamic/adaptive logistics and quality control	Products should be harvested in uniform stage of maturity for specific market segments. If there is variation in the harvested fruits, sorting and grading on products should result in classified batches based on their quality level With the help of the different quality classes harvested, a planning/prediction can be made about how fast the product needs to go from the grower to wholesaler and also the conditions (such as temperature) needed to maintain or change the quality Inventories should be managed and allocated to customers based on quality category
6.	AgriFood Supply Chain Management	With support of information about APs and real product quality (using predictive models), the environmental conditions needed should be adjusted in the chain according to wished final development/maturity stage of fruit at arrival Quality levels of product batches and their related AP should be considered when applying SCM practices in order to deliver the right amount of product at right place at right time with the right quality. The products must be in the right stage of development and maintained at appropriate temperature to be able to present within the acceptance period by the time they arrive at retailers

Fig. 14.4 Supply chain for mangoes in the Netherlands

and are subsequently sorted on skin colour and size. Within these harvested fruits significant variation in the maturity at harvest exists, varying from immature to mature enough to ripen. Harvesting too early will result in tropical fruits sensitive to chilling injury during sea transport (Gonzalez-Aguilar et al. 2000) and will not ripen properly resulting in poor consumer quality. Harvesting tropical fruits just before the onset of ripening is crucial in determining eating quality (Brecht and Yahia 2009). Harvested too late will result in tropical fruit that either cannot withstand postharvest handling or will be overripe when arriving in Europe to be discarded in the last part of the supply chain. In total, losses due to no ripening and over ripe mangoes are very variable but can surmount to 30–50 %. Immature or overripe fruits that are sold to the consumer will create a disappointment. If these disappointments occur regularly, this will have a strong influence on the buying behaviour. This, in turn results in a lower turnover and a lower willingness to pay an appropriate price (Schepers and Van Kooten 2006). Figure 14.4 shows a simplified mango supply chain in The Netherlands.

Tropical fresh fruits take up a significant part of the fruit and vegetable segment in supermarkets. Turnover of tropical fruits in Dutch supermarkets rises every year and have now a share close to 10 % of the total fruit turnover in supermarkets. The main reason for the rapid increase in turnover of mango is the introduction of the Ready To Eat (RTE) concept that resulted in a yearly increasing mango sales volume at a 50 % increase price. The RTE concept is based on manipulation of the ripening process of tropical fruit that have been transported for 2–3 weeks in sea containers. The RTE concept at wholesalers involves storage for typically a few days at 21–23 °C. After storage the tropical fruit may be returned for additional time in the ripening chambers or packaged and marketed as RTE. An increasing percentage (up to 50 %) of tropical fruit is ripened and marketed as RTE for domestic consumption. Dutch wholesalers are increasingly ripening for Scandinavian and middle European markers. The RTE concept adds value to the fresh fruit chain resulting in increased consumer sales and minimised product waste.

Mango Quality

Apart from blemishes and size, firmness is considered to be the most important quality attribute and varies widely between batches of mangoes arriving in the Netherlands. Within and between batches there is a large variation in firmness because of their agronomic history and harvest stage. Manipulating postharvest conditions is, next to switching of cultivars and origins, the key to produce RTE mangoes in the retail shelves. Interacting factors are involved in the ripening of mangoes, which

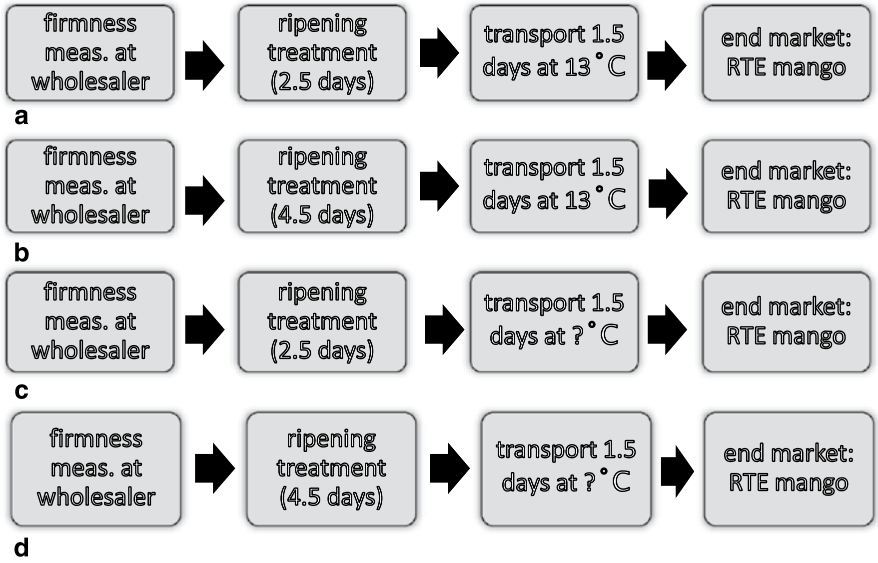

Fig. 14.5 Four RTE mango scenarios

makes good decision making complex. Temperature is the most important factor regarding softening of the mangoes, but also ethylene as mangoes are classified as being sensitive to this ripening hormone (Mattoo and Modi 1969).

QCL Analysis in the Mango Supply Chain

Consumer acceptance limits were determined by measuring firmness of mangoes and subsequent sensorial scoring of these mangoes into classes such as ‘unripe’, ‘unripe/RTE’, ‘RTE’, and ‘RTE/overripe’. Based on a kinetic firmness model, calibrated on acoustic firmness measurements gathered at different temperatures, predictions on the development of mango firmness through time at different temperatures could be established. By combining this calibrated model with the acceptance limits it becomes possible to predict the acceptance period, meaning the time it takes to become RTE until overripe.

Four RTE chains (A-D), from wholesaler to supermarket, were simulated as function of ripening time and ripening temperature based on the initial firmness (measured acoustically), consumer acceptance limits and length of the chain (Fig. 14.5). The duration of the chain was based on the time the mangoes will be at the wholesaler and the transportation time. The transportation time was based on a chain from a Dutch wholesaler to a middle-European country and was determined at 1.5 days. Ripening treatment at the retailer was either 2.5 or 4.5 days. Nowadays mangoes are transported under low temperature conditions (10–13 °C). This low temperature transport has several disadvantages: cooling during transport is expen-

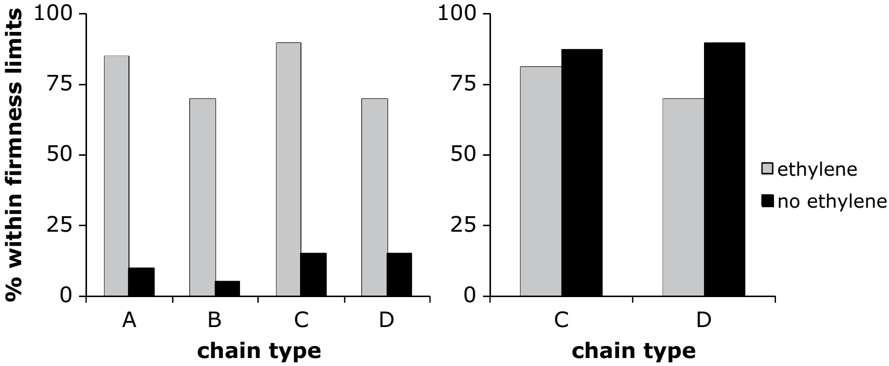

Fig. 14.6 RTE Performance using four chain scenarios (batch 1, *left hand side* plot) or two chain scenarios (batch 2, *right hand side* plot)

sive, mangoes could be suffering from chilling injury during transport and further ripening during transport is not possible. This last point could be very useful when the transportation time between the wholesaler and the end market is quite long. Ripening rooms could be limiting at the wholesaler by ripening during transport the throughput rate at the wholesaler could be increased. Therefore two of the four chain scenarios have variable transport temperatures, this allows for the mangoes to ripen further during transport.

Mangoes of batch 1 (origin Israel) were sorted on firmness at arrival at the wholesaler and gathered in four sub-batches for batch 1. Mangoes in the sub-batch with the lowest firmness were used for scenario A; mangoes in the sub-batch with the second lowest firmness were used for scenario B etc. Mangoes of batch 2 (origin Brazil) were treated the same, but now only two scenarios were simulated, scenario C and D. Half of the mangoes in every sub-batch were exposed to high levels of ethylene, the other half were not exposed. Ripening (between 17 and 20 °C) and transport temperatures (between 13 and 20 °C) were calculated using the mango acceptance model. Some of the results are depicted in Fig. 14.6, showing the percentage of the fruits within the established consumer acceptance limits at the end of the chain. For all the batches the number of fruits within the acceptance limits is around 80 % when ethylene is used. These are promising results and can be transformed into a ripening protocol.

An integrated overview of improvement opportunities when implementing the QCL concept in the tomato and mango supply chain is presented in Table 14.2.

Conclusions

Operations management in FSCN usually takes quality as given; if one approaches product quality as a dynamic issue and uses time dependent quality information more degrees of freedom come to the forefront that will improve supply chain performance significantly. We have introduced a new concept called Quality Controlled Logistics that provides means to optimize product quality and product availability in market outlets concurrently and minimizes shrinkage. Using time dependent quality information and quality change models we can now predict product quality in much more detail enabling us to adaptive control of supply chain processes and direct specific products batches—under specific environmental conditions—to specific market segments. Case studies show that QCL offers new possibilities to improve supply chain performance for fresh products. Future research aims for the further development of the diagnostic instrument and the quantification of costs and performance improvements of QCL scenarios in multiple cases.

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