A taxonomy framework to manage perishable products in cold chains

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Abstract: The interactions between perishable products and the environmental conditions experienced along the entire products' life cycle determine the quality perceived at the point of consumption. Proper storage and distribution conditions are necessary to control this relation in order to avoid food losses and disruption in the value perceived by the customers.

The adoption of refrigeration and the design of cold chains significantly reduce food losses and maintain the expected shelf life of perishable products. Although, to meet economic and environmental sustainability targets in the food supply chain management, an intensive use of refrigeration systems should be discouraged. The knowledge on products' characteristics (i.e. optimal temperature and humidity, shelf life, heat of respiration) and predictions about environmental conditions experienced, along with proper packaging solutions, could prevent the use of refrigeration without compromising the quality of products.

This paper proposes a taxonomy framework for the assessment and classification of the characteristics of different food perishable product and related supply chains. This framework aims at suggesting strategies to manage perishable products according to their optimal conservation conditions, the geography of the production phase, and the climate stresses experienced along the distribution chains.

By using geo-referenced data, product-dependent patterns are provided to support researchers and practitioners in identifying those supply chains that are particularly affected by the environmental conditions. Based on this taxonomy, the proper strategies for optimizing the observed cold chain are highlighted. This conceptual framework highlights the need of advanced approaches including environmental conditions in the model formulation to deliver high-quality products avoiding intensive use of refrigeration.

Keywords: perishable, transport, cold chain, environmental conditions, refrigeration

1. Introduction

The life cycle of perishable products is characterized by the continuous interactions with the environmental conditions. Such interactions affect the quality perceived at the place of consumption (Labuza, 1982). Therefore, the design and planning of climate-controlled environments plays a crucial role.

Three main levers can be tried to avoid perishable good losses.

Among these, the first is undoubtedly the adoption of refrigeration systems. Adequate temperature and humidity set-points at the processing plants, within the warehouses and within the transport vehicles significantly reduce the amount of products losses. By reducing the proliferation of bacteria, the chemical and biological reactions, refrigeration allows to maintain the ideal storage conditions for the products (Stoecker, 1998).

Whilst refrigeration minimizes food losses, an intensive use of cooling systems is discouraged by the fulfilment of economic and environmental sustainability targets in the food supply chain management. Refrigeration is an energy-intensive process and its infrastructural costs may be prohibitive particularly in less developed countries. Furthermore, as refrigeration is responsible of about the 15% of the overall energy consumption all over the World (Coulomb, 2008), the environmental impacts of perishable supply chains are yet alarming.

The second lever deals with packaging and other protection solutions. The use of adequate packaging solutions, along with the choice of proper insulating materials for storage rooms, facilities and transportation vehicles, combined with workers' best practice (i.e. reducing the door opening) can contribute to reduce the energy consumption.

The third lever is of management nature and deals with the proper planning of conservation and distribution operations along the perishable supply chain. Specifically, the reduction of the energy consumption for refrigeration can be achieved through a climate-driven distribution planning (Accorsi et al., 2017). According to the climate-driven framework, weather forecasts can be used to aid the following decisions:

- How to schedule the deliveries according to weather conditions;
- How to select to route toward the customers in order to encounter more favourable climate condition;
- How to choose the proper facility where to storage products according to climate conditions;
- How to assign the proper location of a product within a storage facility (Accorsi et al., 2018).

A climate-driven approach, along with proper packaging solutions, could prevent the use of refrigeration without compromising the quality of the perishable products. The effectiveness of a climate-driven approach increases both when the products are more sensible to the environmental conditions and for geographical areas experiencing seasonal critical climate conditions.

Based on these statements, this paper introduces a taxonomy framework to lead the classification of temperature-sensitive products in cold supply chains. This classification could aid practitioners to identify the strategy that obtain the best compromise between the energy consumption due to refrigeration, the logistics costs and the food losses. The classification is based on both the products' characteristics and on the geographical areas where the production phase is staged.

First, the framework classifies the products according to these characteristics with a k-mean algorithm. This classification is based on the main properties of food products (i.e. ideal temperature, ideal relative humidity, frost damages and production and sensitivity to ethylene), that typically do not include the environmental conditions that these products experience or the geographic area of provenience. First, the clustering algorithm groups the products that share similar ideal storage conditions. The obtained clusters are then assessed with geographic and climate information through a cross-map view. The obtained results could aid researchers and practitioners to identify the best strategy to implement for the management of a specific cold chain.

The remainder of this paper is organized as follows. Section 2 introduces three strategies to enhance the sustainability of a supply chain. Section 3 applies a clustering algorithm to the characteristics of the perishable food products and link the obtained clusters with geographical and climate information. In Section 4, the application of the taxonomy framework is discussed along with some suggested guidelines. Section 5 concludes the paper and introduces topics for future developments.

2. Supply chain management strategies for perishable products

Perishable products should be stored properly within environments which respect the safe conservation conditions (i.e. temperature, humidity). In such case, the quality decay of perishable products is under control and the food losses can be reduced. Otherwise, products will perish faster and the losses will rise.

This can affect the sustainability of the food supply chains according to three dimensions. The missing profits and the costs resulting by the losses (i.e. from the production to the spoilage), as well as the costs for waste management (Kim et al., 2011) influence the economic sustainability of the supply chain (1). In addition, the energy consumption and the emissions generated for refrigeration (Gallo et al, 2017) and the exploitation of natural resources (Vandermeersch et al., 2014) impact on the environmental sustainability of the supply chain (2). Lastly, the social sustainability (3) is compromised by the social consequences of the food waste, which currently represents up to one third of the total produced food (Kefalidou, 2016).

According to the literature and the common industrial practice, three main strategies are identified to reduce

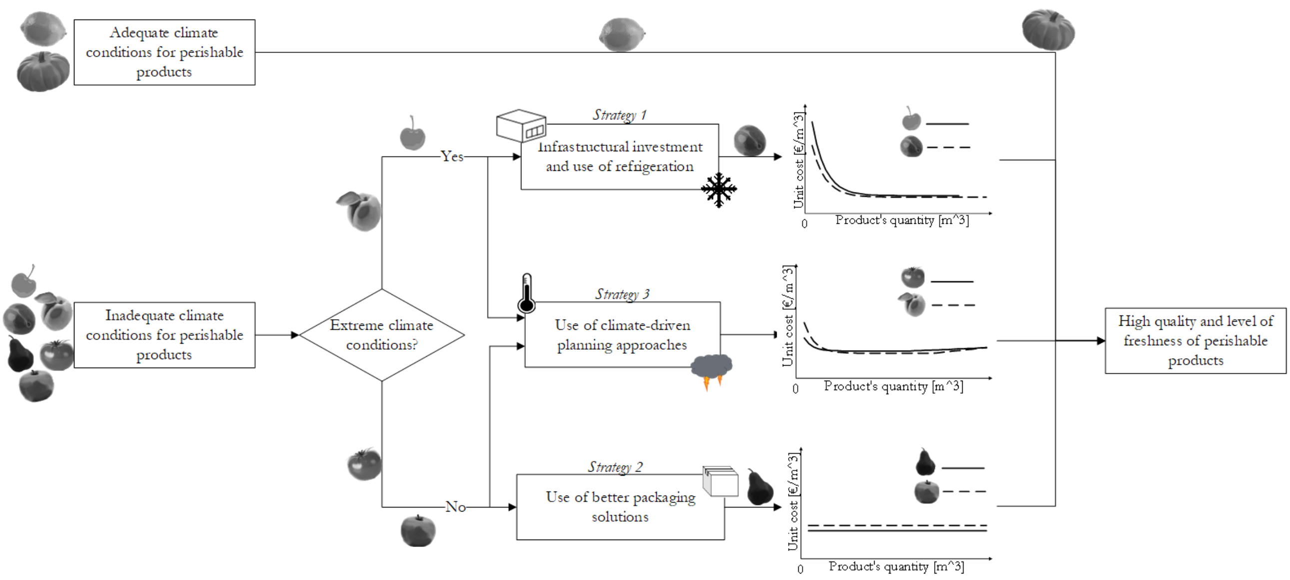

Figure 1: supply chain management strategy schema based on the environmental conditions

food waste and enhance the sustainability of the food supply chain in presence of stressing environmental conditions:

1. *Strategy 1* – Infrastructural investment. This deals with the adoption of refrigeration systems and insulating materials for either the facilities and the transport vehicles. However, such strategy leads to increase costs and energy consumptions as well (Fikiin et al., 2017);
2. *Strategy 2* – Packaging solutions. The use of innovative packaging solutions can protect products from the environmental stresses (Manzini et al., 2017) decelerating the quality degradation of food (e.g. modified atmosphere packaging, edible coatings) (Ghidelli and Pérez-Gago, 2018);
3. *Strategy 3* – Climate-driven planning. This approach is to reduce the need for refrigeration while guaranteeing the proper storage and transportation conditions for perishable products according to the expected environmental stresses experienced by perishable products along the food supply chain (Accorsi et al., 2017).

Fig. 1 schematizes these strategies. Each strategy aims at controlling the shelf-life of perishable products, but is characterized by different implementation costs and different level of effectiveness. The choice of the strategy to adopt depends on the environmental conditions experienced along the supply chain which influence the costs and the benefits associated to such decision. Fig. 1 exemplifies the trend of the cost per unit volume of product distributed over the overall perishable goods distributed. Each line represents the behaviour of a given product in agreement with the selected strategy. In these charts there are two illustrative costs trend each (i.e. a continuous curve and a dashed curve) to highlight the differences due to the specific solution adopted. Given the strategy, each product has a similar behaviour but may differ on the bases of the materials adopted for the packaging, of the investments in infrastructure or the geographic and products' characteristics of the supply chain (e.g. fresh cherries need refrigeration more than plums, so the unit cost of cherries is higher even when they present a similar trend).

The Strategy 1 guarantees the proper storage of perishable products even in presence of critical climate conditions through climate-controlled chambers (i.e. temperature, humidity) both during storage and along transportation. However, the Strategy 1 is the less convenient in term of costs, particularly when the same achievements can be obtained just with alternative packaging solutions or through climate-driven planning approaches. This strategy compels the higher fixed costs than the others due to infrastructure establishment. Nevertheless, the resulting unit costs exponentially decrease with the increase of the flow of distributed perishable products.

Strategy 2 experiences constant unit costs since the cost of packaging grows linearly with the flow of distributed products. Different packaging solutions has different constant unit cost. The cost of a packaging solution is smaller than the investments needed for the infrastructure, but it can guarantee an effective insulation of the products from inadequate environmental conditions only when these are not too critical.

Finally, Strategy 3 does not present direct costs for neither infrastructures nor of packaging materials but refer to indirect costs associated to the management of the supply chain operations. This strategy requires a new paradigm in the management of perishable products distribution in agreement with climate conditions (Accorsi et al., 2017). The climate-driven approach suggests the proper batch of the day (e.g. at the end of the day or early in the morning) when transport activities should be performed. For these reasons, this framework requires skills, information systems and management costs to be implemented. These costs decrease when allocated to a larger flow. However, when the quantity of perishable products increases, the complexity of the management strategy rises and the organisational costs increase too. The climate-driven approach reduces the needs for refrigeration, exploiting the favourable weather conditions. Therefore, it represents a cheap alternative to distribute perishable products. This strategy is appropriate either in critical environmental conditions or in moderate inadequate conditions. It is not intended to replace the other two strategies, but it may contribute to achieve the sustainability of the food chain.

The three strategies along with the original taxonomy framework introduced in the following can support practitioners to choose the best management strategy to adopt in order to achieve the sustainability of the perishable supply chain.

3. Product-based and geographic-based taxonomy for food supply chains

In this section, an original taxonomy framework is proposed. The taxonomy classifies 67 agro-food products, each of them located in ten different production regions. The ten top producing countries for each product are selected according to FAO, 2018. Then, 670 potential combinations of product and food supply chains result and are classified on the bases of the environmental conditions experienced by the perishable products.

The level of criticality of the environmental conditions for each supply chain is based on the comparison between the products' characteristics and the climatic conditions expected along the supply chain.

The products' characteristics used for the classification are the following:

- Safe temperature;
- Safe relative humidity;
- The production of ethylene, in a scale from 0 (i.e. no ethylene production) to 3 (i.e. maximum ethylene production);
- The sensitivity to ethylene, in a scale from 0 (i.e. the product is not sensitive to ethylene) to 3 (i.e. the product is very sensitive to ethylene);
- Frost damages, in a scale from 0 (i.e. the product does not experience damages due to frost) to 3 (i.e. the product is severely damaged by frost);

The secondary data used to quantify these parameters have been collected from Caccioni (2005).

3.1. A clustering approach to group similar products

In order to aid the taxonomy of the perishable products without loss of information, a clustering algorithm has been applied. It aims at grouping together the perishable products sharing similar environmental–based characteristics. The chosen clustering method bases on the *k*-means algorithm. This algorithm partitions the perishable products in *k* clusters based on their characteristics (i.e. shortlisted in Section 3). The perishable products within the same cluster might be managed with the same strategy whenever they face similar environmental stress profiles.

Firstly, the algorithm examines the elements' set. Each element (i.e. perishable product) is represented by a row of a matrix where the fields represent the classification parameters (e.g. ideal temperature, ideal relative humidity). Through an iterative process made of four steps, the elements are grouped together by calculating the centroids of each clusters and by using these to assign each element to a new cluster. The steps of the proposed algorithm are the following:

Step 1. The k-means algorithm starts with k random "means" value.

Step 2. Each element is associated to one of the k clusters by calculating the nearest of the k means.

Step 3. The means are adjusted by calculating the centroids of the clusters generated in the Step 2.

Step 4. The steps two and three are repeated until there is a convergence in the clustering results.

When the convergence is reached, k subsets of perishable products are generated. The k-means algorithm requires the number of clusters to be generated. For this paper, a set of four clusters was generated. Table 1 shows the centroids of the resulting clusters. The four clusters represent subsets of products presenting similar reactions when subjected to the similar environmental conditions

The obtained clusters roughly cover typically food sub-categories. As instance, Cluster 4 groups together garlic, onions and pumpkins, while Cluster 3 contains many exotic fruits. Cluster 3, for example, is made by the 14 products with the highest values of safe temperature, the safe relative humidity between the 85% and the 95% but are all severely sensitive to frost. Products in Cluster 2 are highly sensitive to frost, but should be stored at lower temperatures and with lower values of relative humidity.

Table 1. Centroids of the perishable products' clusters

	Min ideal temperature [°C]	*Max ideal temperature [°C]*	*Min ideal relative humidity [%]*	*Max ideal relative humidity [%]*	*Production of ethylene*	*Sensitivity to ethylene*	*Frost damages*
Cluster 1 (43/67 products)	0.12	0.16	90.12 %	94.72 %	1.37	1.09	0.28
Cluster 2 (7/67 products)	2.57	5.86	85.71 %	90.71 %	1.29	0.57	2.14
Cluster 3 (14/67 products)	9.36	12.29	87.86 %	92.86 %	1.36	1.57	2.79
Cluster 4 (3/64 products)	1.67	2.67	71.67 %	76.67 %	0.67	0.67	0.67

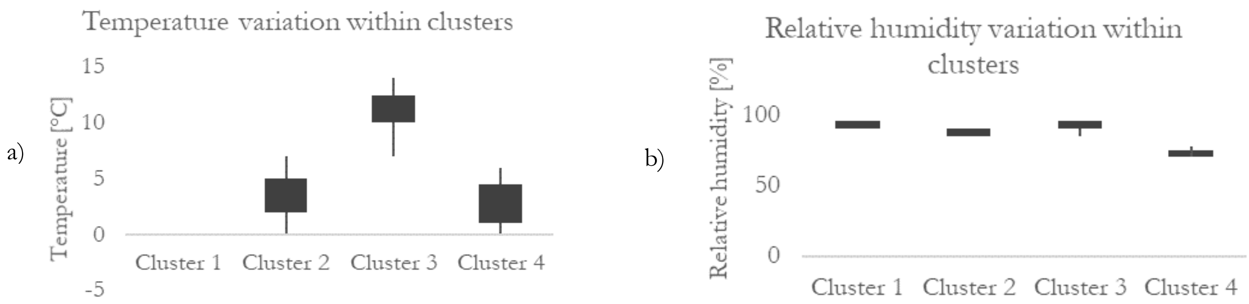

Figure 2: temperature and relative humidity data variation within clusters

Figure 2 provides a statistical analysis on the ideal temperature and relative humidity values for each cluster. The two charts, Figure 2(a) and Figure 2(b), use a box-plots chart to show the variability of the temperature and relative humidity values within each cluster. The boxes represent the values between the second quartile of the minimum ideal temperature to the second quartile of the maximum ideal temperature. The bottom error bars show the first quartile of the minimum ideal temperature, while the top error bars represent the third quartile of the maximum ideal temperature.

Cluster 1 is composed by perishable products with approximatively a value of 0°C of safe temperature (both minimum and maximum), with the 90% of minimum ideal relative humidity and with the 98% of maximum ideal relative humidity. Although this cluster groups together 43 products out of 67, the variability of the ideal temperature and the ideal relative humidity within the cluster is very low.

3.2. Supply chain classification

As previously introduced, Figure 1 shows that as the products are not subjected to critical environmental conditions proper packaging solutions, combined by climate-driven planning approaches, can avoid the use of refrigeration without affecting the products' shelf-life. The clusters resulting by the *k*-means algorithm can be related with the climate profiles of the production regions to provide managerial insights and guidelines toward the identification of the most effective strategy to adopt (see Fig. 1).

First, the ten top producing countries for each product have been identified. For each of these countries, the data about the monthly average temperature and relative humidity were collected from historical climate databases (Weather Underground, 2018). For each product, the months of production are identified according to the harvesting season. The ideal temperature and the ideal relative humidity of the products have been compared to the real climate conditions in the observed geographic regions. Figure 3 showcases the result of the analysis. The height of the histograms represents the criticality of the environmental conditions for the specific supply chain. The higher the bar, the more critical the environmental conditions experienced by the cluster's products will be. The map also highlights for each cluster which countries are the most important producers. As instance, Africa produces many products belonging to Cluster 3, but only few products belonging to Cluster 2 and 4. Products belonging to Cluster 1 are widely spread across the planet and they experience the most critical environmental stresses.

4. Discussion

The most effective strategy to manage perishable products differs based on the themselves characteristics and those

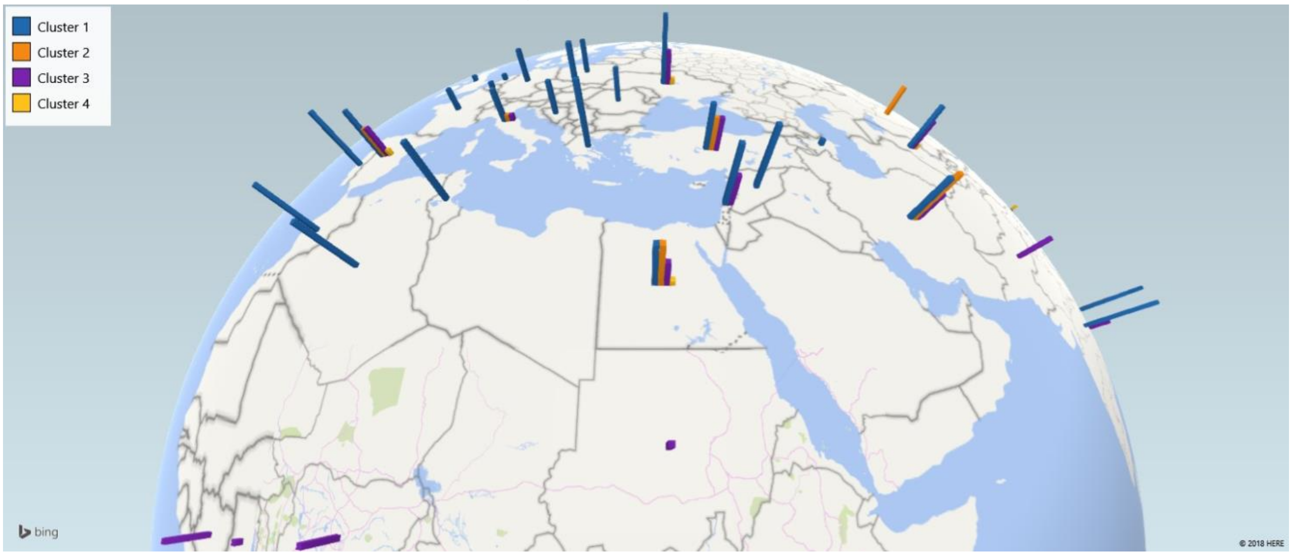

Figure 3: Criticality of the environmental conditions for clusters within the most important producer countries

of the supply chain. Since perishable products should be stored at proper environmental conditions, refrigeration represents the best strategy to minimize food losses. The maximization of all the three dimensions of sustainability (i.e. economic, environmental, social), however, discourages an intensive use of refrigeration.

The proposed taxonomy classifies the supply chain based on the ideal storage condition and on the climate profiles of the geographic areas. In view of this, given a supply chain of a perishable product, practitioners can address to the following questions through this taxonomy:

1. What is the cluster the product belongs to;
2. What is the geographic region containing the nodes of the network;
3. Are the climate conditions critical for the supply chain?

Whether the map of Fig. 3 highlights a criticality, then the proper strategy to adopt involves investments in the infrastructure and the use of refrigeration (i.e. Strategy 1). A climate-driven planning approach can reduce the criticality of the environmental conditions thus reducing the use of refrigeration also in such critical conditions.

In the geographic areas and for those products whose criticalities are less intense, the use of proper packaging solutions and climate-driven planning approaches can severely reduce the need for refrigeration (e.g. Clusters 2 and 3 in Italy does not experience critical environmental conditions, so the use of insulating materials can aid practitioners to avoid the use of refrigeration).

The framework itself provides the methods to assess the criticality of the supply chain. Given a perishable product, the implementation of the framework and the assessment of the criticality include the following steps:

1. Find out the safe storage conditions of the perishable products and its characteristics (i.e. sensitivity to ethylene and frost damages);
2. Find the cluster containing products with similar characteristics;
3. At a strategic decisional level, choose the best geographic region to locate the supply chain;
4. At a tactical decisional level, when the nodes of the chains have already been set up, find the level of criticality of the cluster in the geographic region of the chain. A mix of investments on infrastructures and climate-driven logistics should be applied whether there is a high level of criticality, otherwise better insulating materials and climate-driven should be preferred.

Table 2 highlight how the different actors could apply the taxonomy framework to better manage perishable products and what are the expected benefits they can achieve from its usage. The table presents benefits for perishable product producers, Third Party Logistics (3PL), policy makers and carriers.

Table 2. Benefits of the application of the framework

Actor	How to apply the taxonomy framework	Outcomes
Producer	Concentrate the harvesting and processing of products in the most favourable geographic areas	Reduce food losses
3PL	Choose the warehouse with the best position to stock products; Find the best strategy to manage perishable products	Reduce the total energy consumption and costs for refrigeration
Policy makers	Foster the development of regional supply chains of products with more favourable climatic conditions	Enhance the sustainability of the supply chains
Carriers	Distribute perishable products through the best routes according to the climate-driven framework	Reduce the use of refrigeration during transportation

5. Conclusions

This paper presents an original taxonomy framework for perishable products. The aim of this classification is to provide an easy and effective tool to support practitioners and decision makers in the identification of the best strategy to manage their supply chain, while improving all the three dimensions of sustainability. The knowledge of basic information on the supply chain (i.e. the characteristics of the perishable product and the climatic data in the node of the supply chain during the production seasons) can provide managerial responses to reduce the use of refrigeration without compromising the quality of the products. The analysis has been easily extended to hundreds of supply chains by applying clustering algorithm together with a three-dimensional map. This can aid researchers to find recurring patterns between similar supply chains in near geographical regions, thus highlighting the need for new models tailored not only on the type of product, but also on the geographic area of the supply chain. Future researches can include more dimensions to form homogeneous clusters of products and to evaluate the criticality of the environmental conditions.

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