

## Quality-Based Clustering of Food Products for Customized Food Logistics

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### Abstract

Perishability and quality deterioration over time makes food differ from industrial products. The objective of this research is to describe the food quality from a logistics perspective and specify which characteristics of food products are necessary to consider in designing food logistics. These characteristics include food sensory factors, food safety factors, packaging, and the interaction of all these factors with the surrounding environment which can occur related to the logistics processes.

According to the results, food products are suggested to be divided into 6 major groups based on their similarity in the interaction with surrounding environment factors affecting the products during logistics activities. These groups are Vegetables, Fruits, Biennial vegetables, Chilled & Super-Chilled, Frozen, and Ambient. Subsequently, the sensitivity of each group was analyzed with regard to the environmental factors they are exposed to during logistics, such as e.g. temperature variations, humidity, or pressure and vibration.

The results of this study can increase the knowledge and know-how for more efficient and safer food transports while minimizing the risk of damage to the food products during transport.

**Keywords:** *Food logistics, food quality, metabolic activity, chilled food, frozen food, ambient food*

### 1 Introduction

The logistics of food products are different from the logistics of other products because these products undergo continuous quality changes throughout the supply chain [1]. Such changes, in particular a constant deterioration process after the production stage, are characteristic of perishability [2]. Food quality is determined by biological variations, environmental conditions and time where the latter two may be influenced by logistics activities such as type of packaging, way of loading, and the availability of temperature-controlled vehicles and warehouses [3]. Such influence cannot stop the process of quality deterioration but affect the speed by either slowing it down e.g. through low temperature or increasing it by e.g. poor handling. Therefore, the perception of product quality in the food supply chain cannot be restricted to the properties of the product but also extends to the supply chain agents, processes, and activities.

The problems facing food logistics are concerned with many different factors. Nonetheless, they also extend to such factors as the low profit margins involved, the requirements of carrying large quantities in as short time as possible, or the market saturation in Europe – exacerbated by the limited growth potential of a stagnating population. Yet the primary concern is the quality of food itself since customers in Europe have grown more sophisticated in their demands, and many even select stores based on the quality of fruit and vegetables [4]. The concerns of customers encompass such issues as healthiness of their purchased foods as well as shelf life and time required to prepare meals. For fruit and

vegetables in particular, demands have increased on their appearance, leading to a rejection – and therefore waste – of products that are not only edible but of good quality in every other respect. The increased interest in processed foods has also affected the market. Research surveys continue to suggest that “taste”, as a sensory quality is the single most important criterion people use for food selection [5], yet some groups of consumers focus more on nutrition, shelf life, and environmental concerns [6].

There is no uniformly accepted definition of food quality and only a basic understanding of the concept, which is still predominantly based on technical criteria and producer-focus, particularly with respect to costs and productivity. While some standards of quality have been established, logistics providers mainly rely on producer information – or their own empirical knowledge – on how to transport, handle and store various food products in such a way that they retain their quality. [9] Producer requirements (e.g. permitted range of temperatures) can sometimes be too strict. Exceeding the range of temperature slightly may for example not damage the product, still the product will be rejected by the retailer and therefore wasted. An important question is consequently how to develop a scientific guideline of requirements for logistics providers, taking into account parameters such as choice of transportation mode, way of loading, inventory policies, etc.

Food products are already grouped for logistics purposes mainly based on temperature requirements, i.e. frozen, chilled, and ambient. Although there are many similarities for the logistics of products in these different groups, simply focusing on temperature may not guarantee food quality as that may be affected by other critical environmental factors relevant in logistic activities. These encompass e.g. humidity, pressure, and vibration and temperature variation. Therefore, the objective of this research is to identify different food clusters and critical environmental factors through analyzing the food quality deterioration in relation to these. The results can be used as input in developing customized food logistics solutions.

It should be noted that within the scope of this work, the term logistics will be interpreted in a narrower focus and concentrate on the aspects of transport, storage, and handling since these directly affect the maintenance or deterioration of the quality of food products.

This paper starts by explaining the state of the art in food quality and will be followed by an explanation of the methodology employed. In the next step, those food characteristics which are relevant in food quality are determined. These factors then form the basis for grouping the products in the next section. After that, each product group is discussed in relation to different critical environmental factors, and the possible combinations of the products of different groups are considered in the results while consequences for logistics are raised in the discussion.

## **2 Methodology**

To determine the food product-specific requirements on logistics, we chose food quality and its deterioration as the starting point since it is the major concern when it comes to logistics. The rate of food quality deterioration is dependent on how the logistics solutions manage to deal with the surrounding environment in relation to the specific requirements of the food product.

The study consists of four main steps:

1. Determination of relevant food characteristics important in food quality deterioration and the critical environmental factors impacting food quality deterioration
2. Grouping of food products based on their similarity in quality deterioration
3. Risk of quality deterioration in each food group based on its interaction with determined critical environmental factors

The first step was to identify the food characteristics and critical environmental factors which are relevant in food quality deterioration in logistics. The relevant food characteristics were determined through a number of face to face interviews and brain storming sessions with experts at the Swedish Institute of Food and Biotechnology (SIK), specifically 2 interviews each with experts on Sensory and Flavour Science each for about an hour and 1 interview with an expert in Structure and Material Design department for an hour. Furthermore, three workshops were held in which an expert from the Microbiology and Process Hygiene department participated aside from three separated interviews each for an hour. Such a selection of experts with their variety of expertise was intended to cover all different aspects of food quality including sensory characteristics, biological characteristics, safety factors and the issue of shelf life. The interviews were held by a food supply chain expert from the Sustainable Food Production department of SIK. Alongside these interviews, a comprehensive overview of the food quality literature was performed using recommended resources by the experts in all those areas.

Food products were thereafter grouped based on these factors by the team mentioned above through a review of literature on fresh horticultural, chilled, frozen, and ambient products. This grouping was checked and approved by the interviewed experts from different departments.

The critical environmental factors impacted by transport, handling and storage were discussed and determined in three joint workshops of food experts from SIK and logistics experts at the department of food logistics, at the Division of Logistics and Transportation, Chalmers University of Technology. Each workshop lasted for three hours, and two experts from Sustainable Food Production department of SIK as well as an expert from Microbiology and Process Hygiene were involved.

In the last step, each food group was discussed with its relevancy to each critical environmental factor in the continuation of these joint workshops, and the results are presented in a matrix (table 2). This matrix describes the level of quality deterioration risk for each product group relevant to each surrounding environmental factor.

### **3 Frame of reference**

#### **3.1 Food quality**

Of particular importance for food products is the question of food quality and how to maintain it during transport, storage and handling. Below are the specific physical conditions which need to be in place during transport, storage and handling to retain quality, e.g. temperature or atmospheric composition, etc. [7].

Food quality can be distinguished in two ways [8]: (1) *intrinsic factors* describing physical properties that can be measured directly and are objective, such as flavor, texture, appearance, shelf life, or nutritional value; and (2) *extrinsic factors* encompassing e.g.

biotechnologically altered properties, the production system, or the type of packaging material used.

### 3.1.1 Food characteristics

Using this definition, the intrinsic factors can also be described as food characteristics, the internal elements making up this half of food quality.

These include the sensory characteristics, which are the obvious aspects by which a customer can judge a product, such as texture, flavor, taste, and aroma as well as its physical appearance (shape, color, stability). Also included are the biological characteristics: metabolic processes (oxidation/reduction), respiration, senescence and ripening, dormancy and regrowth. Resulting from the condition of both sensory and biological characteristics are the safety factors, i.e. the shelf life or product life as a time issue and the characteristics of micro-organisms in the food product.

Agricultural food products are particularly marked by having large variations in their product quality, e.g. due to seasonal differences or the methods used in planting and growing. Variations and changes continue after the harvest as bioactive substances are affected by climatic conditions during post-harvest storage that can change textural properties, altering both the product's gas exchange qualities as well as its water content. Identifying product-specific thresholds, it should be easier to maintain the quality of horticultural products after harvest [8]. Other food products, such as meat and poultry, are dependent on temperature control to keep the presence of micro-organisms that could damage food safety within regulatory levels. [9] Furthermore, it is of note that the sensory qualities of meat products can be affected by such factors as the feed which the animal was raised on as well as the age or sex of the animal itself [10,11]. Similarly, meat products can be affected by the type of handling both pre- and post-slaughter such as the storage and freezing conditions.

### 3.1.2 Critical environmental factors

The food characteristics are not static entities but dependent on their environment, i.e. the extrinsic factors mentioned above. While these factors in the original definition also include aspects such as methods of production or processing, that list is condensed here to the critical environmental factors occurring in logistics activities.

- **Temperature and temperature variations:** Keeping a product at a certain temperature is a complex task as the various materials have to be considered as well as the arrangement of the products and airflow. Hence, temperature variations can occur even with a refrigeration system running at a constant temperature if such aspects are not considered.
- **Humidity:** The presence of moisture is the primary source for micro-organisms to take hold and grow, equally it allows enzymatic and chemical reactions to occur. Nonetheless, food products require certain specific levels of moisture to maintain their quality and may thereby limit its availability for e.g. microbial growth, as measured by the water activity of a food.
- **Pressure and vibration:** : Impacts of pressure and vibration based on the structural stability.

### 3.3 *Grouping of the products*

The first step in grouping of the products is to start with their metabolic activity as it affects the quality deterioration and furthermore determines the requirements that are placed on the logistics solution. Based on the metabolic activity it is possible to distinguish two groups, those with metabolic activity (living organisms) and those without metabolic activity (non-living organisms). Then each group is divided to three subgroups based on the similarity of the quality deterioration behavior.

The first group of products can be both packaged (with or without modified atmosphere-packaging (MAP)) or without packaging but the second group is nearly always packaged in the European market. (Exceptions here are some meat products which are sold fresh and unpackaged, some frozen types of fruits such as various berries, frozen shrimps which might be sold in packages of the size of customer expectations, or fresh bread which is either sold directly without packaging or is shipped from the manufacturing site to retail shops in various forms of packaging.) Nonetheless, since the focus is on the logistics activities of transportation, handling and storage, assuming that all such products are packaged appears reasonable.

#### 3.3.1 Food products with metabolic activity

Independent of the time span from harvest to consumption, all vegetables are perishable. An ongoing challenge to growers, wholesalers, distributors, and retailers is to retard the quality deterioration by encouraging and controlling fruit ripening during the postharvest chain. However, maintaining product quality during storage and subsequent shelf life in a way that will satisfy consumers' demands implies today an integration of both crop production amendments, the stage of development at harvest as well as proper, safe, and healthy post-harvest handling of the products [8].

The maintenance of quality after the harvest is closely related to one particular ability of the harvested plant organ, i.e. its ability to maintain metabolic homeostasis for a period of suitable length, provided that the storage conditions are close to optimal.

The grouping recommended by [8] for subdividing vegetables based on similar product behavior in their metabolic activity appears to be a good fit for the concern of logistics since the behavior of the subgrouped products is similar during storage and transportation.

##### 3.3.1.1 Leaves, stems, flower buds, and inflorescences

Some of these plants, such as asparagus, broccoli, lettuce, or cauliflower, undergo a phase of rapid growth before they are harvested, giving them a limited shelf life at a high rate of perishability. Fleshy fruits, for instance tomato, cucumber, and sweet pepper, also senesce quickly after being harvested since they can no longer continue their ontogenesis.

In order to preserve leaves, stems flower buds and inflorescences as best as possible, tight temperature controls are of need. Similarly, the pressure they are exposed to needs to be regulated, and vibrations are to be kept at a minimum to avoid for example tomatoes bruising before harvest. Damage breaking a fruit's skin may allow micro-organisms to enter and multiply, damage to the cells can trigger enzymatic and chemical reactions, leading to a degradation of sensory quality [9]. These are the primary factors of concern regarding these food products.

The ideal temperatures vary for several subgroupings, such as 0–2° C for those vegetables that originate in the temperate zone. 5–8° C are suited for the aforementioned rapid-growth vegetables, while those from tropical or subtropical origin need to be kept at temperatures inbetween 12 and 25° C. The same temperature range applies to immature fruits, for example peas and bean pulses [8].

### 3.3.1.2 Fruits

**Climacteric fruits** are such with a high respiration rate during the fruit's ripening. After being picked, they are also able to continue to ripen. A prime example of climacteric fruits are bananas; they are picked and shipped green and then ripen at a later time (often in the store or at home). This group of fruits also includes apples, apricots, avocados, cantaloupes, figs, guavas, kiwis, mangoes, nectarines, peaches, pears, persimmons, plums, and tomatoes. Common to all of them is that they should be harvested prematurely as they can reach full maturity in storage and/or during transport to the retail point. Nonetheless, they are sensitive to their conditions, requiring long term storage to ensure that they do reach the end consumer in good quality and the desired ripeness [8]. Storage needs to take into particular account the saturation – or lack of such – with ethylene as well as the ratio of CO<sub>2</sub> to oxygen [9].

Citrus, grapes, and strawberries are **non-climacteric**, meaning that they ripen without ethylene. The defining point of this type is the sudden rise in respiration of the fruit which normally takes place without any external influences. After the climacteric period, respiration rates (noted by carbon dioxide production) return to or below the point before the event. For those fruits raised as food, the climacteric event marks the peak of edible ripeness, with fruits having the best taste and texture for consumption. After the event, fruits are more susceptible to fungal invasion and begin to degrade with cell death. As far as the ideal harvest time is concerned, this means that they should be allowed to ripen in the field and only then be harvested [8].

While temperatures are of some concern in this group, it is vibrations and pressure that non-climacteric fruits are most sensitive to. The same sensitivity also applies to the climacteric fruits but they, as mentioned before, require to be kept in a controlled atmosphere, including a specific temperature range (the optimum is 12–15° C). Water melons, for instance, can be safely transported in a wider range, from 12 to 25° C.

### 3.3.1.3 Biennial vegetables and egg

The plants in this group mainly consist of those with a biennial life cycle, i.e. growth ceases in the autumn with the storage organ entering an imposed or true dormant period with diminished metabolisms. Normally, storage organs are carrying meristematic tissue, which undergoes vernalization (flowering) during storage. Regrowth with a concomitant senescence of the storage tissue therefore often limits the duration of storage [8].

Biennial vegetables are in general somewhat sensitive to temperature as well as vibration and pressure but can be kept for up to six months or more at temperatures inbetween 0 and 5° C. Exceptions here are the potato group (also including snap beans) which should be kept inbetween 5 and 8° C. Onions are a special case since they are more sensitive to their exterior conditions and require CA storage for more than six months and require temperatures inbetween 12 and 25° C.

In addition, this group includes eggs. Their safety and suitability should not be diminished through factors such as storage temperatures, time, and humidity; harm can be brought to them through physical damage, considerable temperature variations, exposure to direct sunlight as well as extreme heat and moisture. They should be transported or stored at a more or less fixed temperature inbetween 12 and 25° C [12].

### 3.3.2 Food products without metabolic activity

The products in this group are divided into three sub groups of chilled and super chilled (i.e. meat and poultry, sea food and fish, dairy and Ready-To-Eat (RTE)), frozen (i.e. fruits and vegetables, meat, poultry and fish, bread and pastries, ice cream and prepared meal) and ambient (i.e. canned, dehydrated and preserved products) mainly based on their temperature requirements. Other critical environmental factors, not directly used in the grouping of the products will however be discussed later on in relation with each group. Each group is further described in detail.

#### 3.3.2.1 Chilled and super chilled

This group covers food products without metabolic activity but which have to be kept at certain refrigerated temperatures in order to preserve the intended quality of these foods. The range of products includes dairy products, meat and poultry products, sea food and fish products as well as Ready-To-Eat (RTE) products.

The primary concerns in quality maintenance are temperatures as such but also their fluctuations over time. They need to be constantly kept under similar temperature conditions. The overall temperature range reaches from 4–5° C to a maximum temperature of 8°C. Exceeding these temperature requirements can lead to premature decomposition of the food product, reducing its safety [13].

In general, RTE foods (e.g. cook-chilled and vacuum-packed) are supposed to be transported below 5° C; any temperature increase above that is to lead to their destruction or more or less instant consumption. Dairy products are carried inbetween 3 and 8° C; as microbiological growth can occur here due to the moisture content, temperatures have to be strictly maintained. The same applies to sea food and fish which commonly have limited shelf lives between a few days and a month; it is of note here that for every hour that fish is kept at 15–20 °C, the equivalent of 1 day's chilled shelf-life is lost. Changes in odor or flavor as well as in texture signal spoilage, additionally gas production in sealed packaging is a clear sign. Chilled meat and poultry products are carried at certain set temperatures (vacuum-packaged meats  $1\pm 0.5^{\circ}$  C (without freezing), chilled meats equal or below 3° C, where red meats may not exceed 7° C, poultry 4° C, and offal 3° C). Also of importance is the handling prior to and at the point of slaughter as stress or exhaustion in the animal can diminish the quality, regardless of further treatment [8,13].

#### 3.3.2.2 Frozen Foods

Similar to the previous group, these food products also have no metabolic activity and require specific – albeit considerably lower, i.e. frozen – temperatures to maintain their quality. Food products in this group encompass fruits and vegetables; meat, poultry, and fish; breads and pastries; ice cream; prepared meals. Their quality and suitability for freezing

depends on the type of product (e.g. variety of fruit, degree of ripeness) as well as on previous handling or processing (e.g. cooking, blanching, glazing).

The normal temperature that frozen foods are transported or stored at is  $-18^{\circ}\text{C}$ , allowing for temperature fluctuations of up to  $3^{\circ}\text{C}$ . Any greater degree of fluctuation is likely to lead to quality decline wherefore great care is taken to maintain the deep-frozen condition. For instance, even the way retail cabinets are stocked is important in reducing the exposure to ambient temperatures as far as possible [14].

With regard to food quality and in particular the sensory qualities important to consumers, basic characteristics can be stated for the various types of foods transported as frozen. The molecular structure of fruits and vegetables can be irreversibly damaged by freezing, thus it may result in unacceptable alterations. Accordingly, they have to be frozen and handled with appropriate care to avoid changes in sensory aspects such as color, texture, or appearance. In general, meat, poultry, and fish take far better to freezing, at least in their raw state, and may be cycled in and out of deep freezing up to five times safely [15, 10]; problems are more likely with cooked meats [15, 16]. As in the previous group including chilled meats, the handling of the animal influences the quality as does the age, sex, and breed of the animal. The temperature of frozen meats may not exceed  $-12^{\circ}\text{C}$  but is ideally kept at  $-18^{\circ}\text{C}$  or below. Breads and pastries have recently improved their own quality control schemes for maintaining quality post-freezing. The specific sensory qualities depend on the product and include frequently: light, fluffy, crisp, yeasty, and browned (appearance and flavor) [14].

For ice cream, many factors from the production stage feed into how well its quality is maintained on the way to the end consumer: The choices of ingredients or the speed of freezing impact on the size of ice crystals forming; the smaller the crystals, the less flavor and texture are damaged and the higher the quality. Stabilizers are commonly added here to prevent ice crystal formation. The aspects of the previously mentioned product types all play into frozen prepared meals as these consist of various portions of such diverse products, each with their own requirements that have to be met for the overall quality to be kept [17, 18]. Issues of interest include those involving the texture or possible separation of sauces during freezing; the alteration of sensory properties of meats in sauce; and the acceptability with respect to appearance, texture, and flavor of complex dishes after freezing [14].

Beyond product-specific aspects, the end consumption quality is also determined by the product's quality and condition at the point of freezing as well as which freezing method was selected. The packaging also plays an important part as it not only has to protect the good from outside influences but at the same time may not affect the sensory qualities, such as e.g. adding "off-flavors" to the product [10]. Further influences affecting the quality at the end are the maintenance of target temperatures during transport and storage since undue variations through e.g. freezer malfunction or inappropriate frequency of handling can lead to increased loss of sensory quality as well as premature spoilage. The longer a product is stored, the greater the likelihood of the sensory or textural qualities being affected; the shelf life of frozen foods is considered from this basis [161]. There are also considerable differences between the shelf lives of the various products; for instance, bread deep-frozen at  $-17.8^{\circ}\text{C}$  may retain its original (fresh) sensory attributes for four weeks while other products last much longer.

For the end consumer, it is important to select a product that has will last the longest at his or her home. This involves both the physical appearance but also the "best before" date; the older a product is, the less likely is it to be sold e.g. without adding sale-inducing rebates.



### 3.3.2.3 Ambient

Transport and storage at ambient conditions is generally the easiest as relatively little energy has to be expended in safeguarding temperature and other conditions. Therefore, this group may include a great diversity of temperature, relative humidity, oxygen tension, and light intensity. Nonetheless, these foods generally need to have been previously preserved in some fashion, e.g. curing or smoking, canning or dehydrating. Once the products are safe at the microbiological level entering the logistics chain, the demands on their maintenance are considerably lower than in any of the other methods [19].

Products transported in ambient conditions include bakery goods, cereal products, dehydrated fruits and vegetables, dried egg products, dry fish and fishery products, preserves, high acid canned fruits and vegetables, canned and dehydrated meat products, ultrahigh temperature milk, beverages, foods ripened or matured at room temperature such as soft or mould-ripened cheeses before fully ripened, salt, sugar, spices, nuts, and potato starch.

Nonetheless, undue temperature fluctuations or extremes are to be avoided here since they nonetheless pose a risk of damage to the food products. An example for canned and dehydrated foods is that their quality could deteriorate rapidly when kept at temperatures reaching or exceeding 38° C; the ideal temperatures though are 4 – 5° C. On the other hand, dried egg products have a safe storage period of 6 months at this temperature. Fruits and vegetables when dehydrated are preferably stored just above the freezing point, when canned they can be stored at temperatures up to about 27° C but should be kept considerably lower to better preserve their quality; protecting them from oxygen is an important factor in their maintenance. In dehydrated dairy products, the effects of temperature on shelf life are clear as going from 21° C to 32° C in effect halves the shelf life of dry whole milk in a can and has comparable effects on other products of this type. Ultrahigh temperature milk can retain its sensory qualities as well as micronutrients without refrigeration for several months, faring better than conventional heat sterilization. Bakery products are particularly sensitive to the temperatures they are carried or stored at [149].

Generally, these goods are best kept dry; particular importance on the lack of humidity is placed in the case of nuts, coffee, or cereals as well as dry fish or fishery products. Preserves also depend to a particular degree on avoiding humidity as they are kept microbiologically safe through the removal of water; hence, exposure to water would allow microbiological activities to resume.

The six food groups and critical environmental factors with the higher risk of affecting food quality relevant to each group are summarized in table 1. The flags demonstrate the risk of quality deterioration in relation to the specified environmental factor written bellow each flag. The colors are describing the intensity of the risk which is high in red and moderate in yellow.

**Table 1.** Food product groups and the relevant critical environmental factors with the higher risk of affecting food quality

With metabolic activity Temperature-controlled Packed /unpacked			WithOUT metabolic activity Temperature-controlled/ ambient Packed		
<b>Vegetables:</b> Leaves, stems, inflorescences & flower buds Te, VP	<b>Fruits</b> Te VP	<b>Biennial vegetables,                      fleshy fruits,                      pulses &amp; eggs</b> Te, VP	<b>Chilled &amp;                      Super Chilled</b> Te, TvT	<b>Frozen</b> Te, TvT	<b>Ambient                      (Uncontrolled                      environment)</b>
0-2 °C 5-8 °C 12-25 °C	- Climacteric - Non-climacteric 2-5 °C 12-25 °C	Lower limit 5-8 °C 12-25 °C - Onion - Egg: Te, TvT, VP	4-5 °C to max 8 °C - Meat and poultry - Sea food & fish - Dairy - RTE (ready to eat)	≤-18 °C - Fruits & vegetables - Meat, poultry & fish - Breads & pastries - Ice cream - Prepared	4-5°C to 21°C under 38°C - Bakery products - Cereal products - Dehydrated, canned, preserved food, ultra-high temperature milk,

**H:** Humidity  
**Te:** Temperature  
**TvT:** Temperature variations/Time  
**VP:** Vibration/Pressure

#### 4 Results

According to the analysis above, food products are divided into 6 major groups based on their similarity in quality deterioration behaviour. In this step, the quality deterioration in each product group is discussed in relation with selected critical environmental factors including humidity, temperature requirements and temperature variations, vibration and pressure.. Depending on how the product is affected by these factors, the risk of quality deterioration can be low or high (see Table 2).

In this table, both dimensions of the food product groupings and critical environmental factors are brought together to discuss the food quality in logistics

As can be seen, fresh products have a higher risk of quality deterioration when it comes to temperature abuse and vibration/pressure while chilled and frozen products are facing quality risks through temperature variations. Some ambient products are sensitive to humidity.

**Table 2.** Risk of quality deterioration in each food group based on its interaction with determined critical environmental factors

Surrounding environment characteristics	Vegetables: Leaves, stems, flower buds & inflorescences	Fruits (Climacteric/ Non-climacteric)	Biennial vegetables, fleshy fruits, pulses/eggs	Chilled & Super Chilled	Frozen	Ambient (Uncontrolled environment)
Humidity	low	low / low	low / low	low	low	high
Temperature	high	high / high	high / high	high	high	low
Temperature variations/Time	low	low / low	low / low	high	high	low
Vibration/Pressure	high	high / high	high / high	low	low	low

Those products which have more or less similar behaviour toward the critical environmental factors can be combined in logistics activities such as fresh vegetables which can accompany chilled products. Biennial vegetables can be carried in ambient conditions as they are sensitive to low temperatures. Ambient products can be transported chilled and also sometime frozen dependent on their specification; however it should be noted that this is not recommended for environmental reasons.

## 5 Discussion

As distinct as food products are in their range of characteristics at the stages of production and processing, given such variabilities as seasonality, weather effects, or pests and other biological hazards, distribution adds another layer of complexity. Transport, material handling, and warehousing need to take into account specific requirements of each food product to maintain its quality as best as possible until the point of sale.

Considering this range of possibilities, it becomes clear that customized logistics solutions have to be created which are adjusted to match the requirements of each respective food product. In this study, a basic grouping of the food products is performed as a first step to gain a better understanding of the complexity of the system and the interacting factors in designing logistics system customized for the food chain.

According to the results, food products are divided into 6 major groups based on their quality deterioration behavior, and further on, the groups are analyzed based on their reaction to the critical environmental factors selected in this study. The six product groups determined are Vegetables (including leaves, stems, flower buds & inflorescences), Fruits (climacteric/non-climacteric), Biennial vegetables (including also fleshy fruits, pulses, and eggs), Chilled & Super-Chilled, Frozen, Ambient (uncontrolled environment).

Subsequently, depending on how each product is affected by the critical environmental factors, they are categorized either as products with a high risk of quality deterioration related to each environmental factor placing higher requirements on the logistics system or those with a lower risk of quality deterioration.

There are numerous examples of how these interactions affect the quality of food products and how logistics has to control for these. In ambient conditions, cereals for instance are

highly dependent on being kept dry since humidity can deteriorate both their sensory qualities by moistening them as well as promoting the growth of microorganisms. Accordingly, food logistics for these goods have to be designed in such a way as to keep the exposure to humidity at a minimum at all stages, including loading or unloading. This is an important aspect for selecting the transport mode. Temperature control is important for canned fruits and vegetables, requiring particular care e.g. in hot regions or during hot seasons, as these can lead to loss of flavor, texture, or color. Thus it impacts the possibility of storing, and the storage has to be adapted depending on the climate at the location. Coffee can lose flavor and odor through oxidation if not properly vacuum-sealed; similarly, tea can be affected but is also sensitive to exposure to moisture, for example during loading, unloading, or storage at ports or in areas with high natural humidity requiring significant degrees of care being taken. Fresh bakery products are subject to staling, microbial growth, temperature, both excessive moisture making the product soggy and insufficient moisture leading to it hardening. Therefore, these products need to be transported quickly, with humidity and temperature kept at the desired level. While humidity, high temperatures or variations thereof can lead in dehydrated foods to browning, rancidity as well as the loss of texture and nutrients and are relevant for food logistics, the effect of light can in general be neglected as they are transported and stored in opaque packaging and in roofed warehouses.

In chilled products, temperature controls are a primary concern and need to be maintained throughout all stages to reduce micro-organism activity. Fresh fruits and vegetables can also suffer nutrient loss or wilting; they are sensitive to oxidation and bruising. Appropriate care needs to be taken in transport to keep them secure. Ice cream products can become grainy due to lactose crystallization and temperature fluctuations. Particular care needs to be taken here during loading and unloading as well as to ensure the refrigeration continues at stable temperature settings.

Frozen foods are not as sensitive to external factors as chilled food. Any damages to these products likely occurred prior to logistics in the freezing process. Nonetheless, improper handling and temperature fluctuations can lead to loss of color or flavor or cloudiness developing in frozen concentrated juices, equal losses in frozen fruits and vegetables as well as in frozen meats, poultry, and fish. The latter can suffer from oxidation while the former need to avoid the formation of packing ice. As a result, their demands on logistics concerns are mostly limited to maintaining the required low temperature. This is especially of concern as the product is handled during loading and unloading. Here, long time periods in a non-cold environment can lead to damages wherefore there is a great need to coordinate handling and transportation with each other to avoid this.

This paper contributes through our choice of considering food quality from a new perspective, that of food logistics. As such, the focus was on which factors might raise the risk of quality deterioration in each product group (as each is different based on the product characteristics). Such knowledge developed here is the first step towards generating food knowledge specific to food logistics. The results can be applied to designing different food logistics solutions.

## 6 Future research

We also aim at having more discussions within each group in terms of joint food and logistics experts' workshops. Furthermore, this clustering covers all the food products at a very general level due to the enormous variety of factors affecting the product quality of different food products. In the next step, each group can be more specifically studied based on the requirements from the logistics side (i.e. in terms of their sensitivity to temperature variations over time for frozen and chilled products). This will allow the food-related knowledge based on the matrix to be expanded.

In conjunction with those efforts, the knowledge base accumulated will serve as the basis for a detailed discussion of the implications for the design of logistics system, considering material handling, storage, transportation mode selection, and warehousing. The results of both of these approaches are to be presented in a second paper.

Another goal is to intensify collaboration with logistics providers, applying the gathered knowledge on food logistics to help improve their processes and also gain insights on the effects of such an implementation. The feedback is expected to add to the knowledge base and permit its refinement. Later publications will deal with these developments.

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