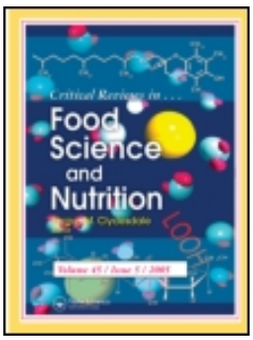

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The Acceptability Limit in Food Shelf Life Studies

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Despite its apparently intuitive nature, the acceptability limit is probably the most difficult parameter to be defined when developing a shelf life test. Although it dramatically affects the final shelf life value, it is surprising that discussion on its nature has been largely neglected in the literature and only rare indications about the possible methodologies for its determination are available in the literature. This is due to the fact that the definition of this parameter is a consumer- and market-oriented issue, requiring a rational evaluation of the potential negative consequences of food unacceptability in the actual market scenario. This paper critically analyzes the features of the acceptability limit and the role of the decision maker. The methodologies supporting the choice of the acceptability limit as well as acceptability limit values proposed in the literature to calculate shelf life of different foods are reviewed.

Keywords Consumer, unacceptability risk, sensory dissatisfaction, label claim

1. DEFINITION

The definition of the acceptability limit is implicit in the definition of shelf life (SL). The latter is a finite length of time after production and packaging during which the food product retains a required level of quality under well-defined storage conditions (Nicoli, 2012). A proper mathematical tool for calculating shelf life is a function estimating storage time (t) based on the value assumed by a generic quality indicator (I). This function is characterized by an adequate mathematical model (f) and given parameters (λ):

$$t = f(I, \lambda). \tag{1}$$

The acceptability limit is thus the required value of the critical indicator (I_{lim}) that has to be inserted in Equation (1) to estimate shelf life:

$$\text{SL} = f(I_{lim}, \lambda). \tag{2}$$

In principle, the concept of acceptability limit is very simple. It discriminates products that are still acceptable for consumption (SL-in food) from the no longer acceptable ones (SL-out food) (Fig. 1). Despite its intuitive nature, it is a shadowed boundary that is difficult to be defined. Considering that the acceptability limit dramatically affects the final shelf life value (Guerra et al., 2008), it is surprising that discussion on its nature has been largely neglected in the literature. Similarly, limited information is available about the methodologies for its choice.

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2. END OF SHELF LIFE BUT NOT OF SAFE LIFE

Basically, there are two possibilities for a product to become unacceptable during storage. The first one is relevant to the development of a risk for consumer dissatisfaction due to poor quality appearance, low sensory, and/or nutritional quality of the product. The second one is mainly associated with safety issues potentially leading to a risk for consumer health. Unacceptability due to food intake under unsafe conditions is very critical and can be the result of the occurrence of pathogen microbes, contaminants migrating from the packaging and toxic compounds formed during storage. A number of different limit values for commercialization and consumption of food under safe conditions are indicated by regulatory bodies (EEC No. 2073/ 2005; EEC No. 2568/1991; EEC No. 2568/1991; EEC No. 72/2002). It would be a mistake to consider these values as acceptability limits to estimate shelf life. Any product overcoming during storage the safety limits indicated by the regulation is out of basic standards required for consumption. It has reached the end of its "safe life." Shelf life and safe life are, not only conceptually, but also quantitatively different, being the shelf life much shorter than the safe

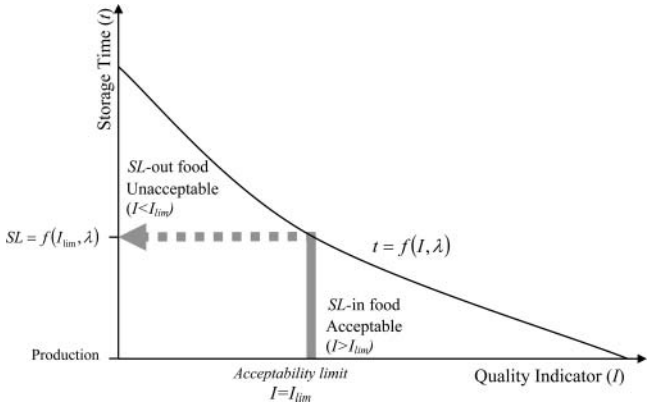

Figure 1 Acceptability limit discriminating SL-in from SL-out food.

life of the food. Before shelf life of a correctly designed and processed food, there should be only a sustainable risk for consumer dissatisfaction, and absolutely no risk for consumer health.

3. VOLUNTEER AND COMPULSORY ACCEPTABILITY LIMITS

The decision maker of the acceptability limit is the producer itself, who is completely responsible for the level of consumer satisfaction of its produce. The nature of the acceptability limit depends whether consumer dissatisfaction involves sensory or nutritional defaults. Consumers are generally well aware of their sensory dissatisfaction when eating a food. They make their own evaluation and eventually decide to award the producer with their fidelity. In this case, the producer voluntary defines the tolerable level of sensory dissatisfaction, based on a reasonable compromise among the needs of consumers, production, delivery structure, and business (Table 1).

Producers declare or label the nutrient content of the product. They are also allowed to claim the presence of bioactives to increase food functionality. In these cases, consumers are unaware of the eventual correspondence between values declared on the label and the actual ones. Producers must compulsory guarantee the conformity of the product to label data over its shelf life, even with reference to voluntary claims (Table 1). In other words, volunteer label claims result in compulsory acceptability limits.

Table 1 Legal status of acceptability limit depending on consumer awareness of the unacceptable event

Unacceptable event	Consumer awareness of the unacceptable event	Legal status of acceptability limit
Consumer sensory dissatisfaction	Yes	Volunteer
Label claim default	No	Compulsory

4. STOCHASTIC NATURE OF THE ACCEPTABILITY LIMIT

According to Nicoli (2012), a finite and countable value of a given quality indicator can be adopted as acceptability limit only based on the drastic assumption that all product items overcome the criterion for unacceptability at the same time, showing identical quality decay during storage. This is obviously a radical simplification because, under real conditions, each product is expected to exceed this limit at a different time, reflecting the intrinsic variability of the acceptance/rejection process (Fig. 2). Acceptance variability derives from the fluctuation of food production and storage conditions. Additional variability comes from the fact that the joint elaboration of the sensory perception with information from surrounding context and previous experiences is strongly individual (Costell et al., 2010). Affective, emotional, cognitive, and behavioral components of the food acceptance/rejection process actually vary from subject to subject but also from location to location and from culture to culture. In addition, for the same subject, food acceptability changes with emotional status, consumption circumstances, marketing, and advertisement strategies (King and Meiselman, 2009; Manzocco, 2012).

For these reasons, a food is never simply acceptable or unacceptable to all consumers. Any time a population of consumers eats a food, a risk of dissatisfaction arises, evidencing the stochastic nature of the acceptability limit. The acceptability limit may be not a univocal level of a given quality attribute, rather a tolerable probability of failure.

5. ASSESSMENT OF RISK FOR CONSUMER SENSORY DISSATISFACTION

The assessment of consumer sensory dissatisfaction requires the application of sensory analysis. In some companies, stability studies are performed monitoring the evolution of sensory attributes during storage. Affective analysis is also performed by evaluating consumer satisfaction on hedonic scales. Specific values of selected critical indicators (Table 2) or overall acceptability (Table 3) have been proposed in the literature to estimate shelf life.

The values reported in Table 2 were generally defined based on largely subjective and arbitrary considerations. They could have no relation with the consumer decision to eat/buy the product or not. Similarly, affective data (Table 3) only provide an intuitive information about the potential risk for consumer dissatisfaction. Any choice of an acceptability limit without clear knowledge of its relation with consumer dissatisfaction could induce mistakes in shelf life estimates.

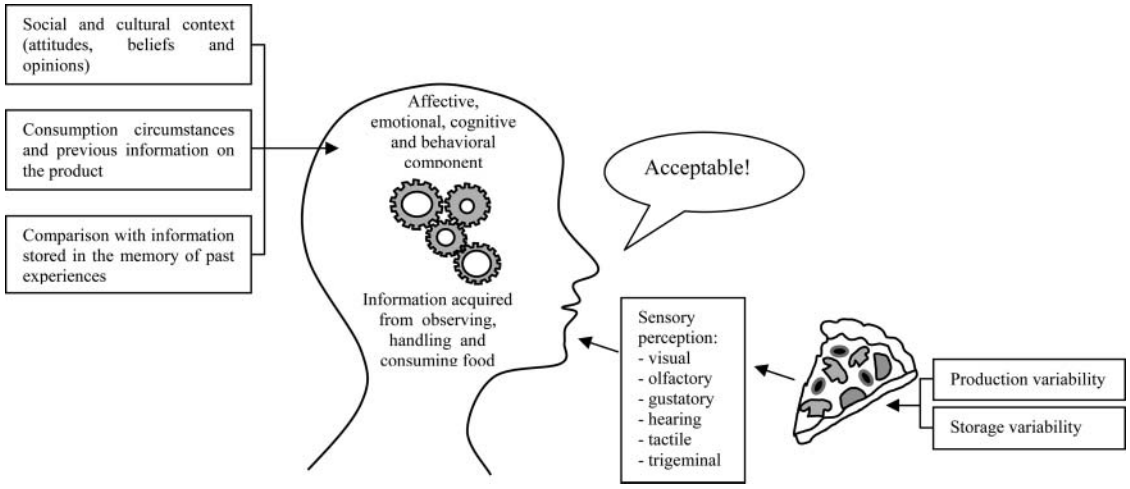

Figure 2 Variables affecting consumer acceptance or rejection of food.

Consumer sensory dissatisfaction can be identified using survival analysis methodology (Gacula and Kubala, 1975; Gacula and Singh, 1984; Hough et al., 2003; 2010). The product is analyzed during storage by asking the consumers a response of acceptability/unacceptability. Data are elaborated to obtain a risk function of consumer rejection during storage. Such methodology is used to estimate shelf life but can also be applied to support the acceptability limit choice. In this case, the acceptability limit is the percentage of food failure considered tolerable by the producer. The food company can choose to be exposed to more or less risk by selecting, as acceptability limit, a certain percentage of dissatisfied consumers. In other words, the acceptability limit is the maximum consumer percentage the company can tolerate to dissatisfy. A consumer dissatisfaction equal to 50% is generally suggested as acceptability limit. Based on product turnover on the shelves, the choice of 50% consumer rejection implies that only half of the consumers, incidentally eating the product at the end of its shelf life, will reject it. For some companies, even such a low rejection probability may represent an excessive risk. Different

Table 2 Values of critical quality indicators used in the literature to calculate shelf life of different foods

Food	Critical quality indicator	Scale	Value	References
Lettuce	Color, texture	1–5	3	McKellar et al., 2004
	Color, texture	1–5	3	Zhou et al., 2004
Mixed lettuce	Color, smell, taste, crispness, appearance	1–10	5	Jacxsens et al., 2002
Cucumber slices	Color, smell, taste, crispness, appearance	1–10	5	Jacxsens et al., 2002
Papaya fruit	Firmness, chilling injury	1–5	3	Nunes et al., 2006
Kiwifruit	Color, odor, firmness	1–5	3	Mastromatteo et al., 2011
Chicken breast	Odor, taste	1–9	6	Patsias et al., 2006
Sausages	Appearance, odor, taste, firmness	1–5	3	Nowak et al., 2007
Rainbow trout	Odor	0–10	5	Pyrgotou et al., 2010
Sea bass fillets	Color	1–4	3	Provincial et al., 2010
Cooked sea bass	Odor, taste	0–3	2	Koutsoumanis et al., 2002
	Odor	1–6	3	Provincial et al., 2010
	Odor, flavor, juiciness, firmness, appearance	0–10	5	Gimenez et al., 2005
Salmon	Color	0–4	2	Gimenez et al., 2005
	Odor	0–7	3	Gimenez et al., 2005
Cooked salmon	Odor, flavor, firmness, appearance	0–10	5	Gimenez et al., 2005
Sea bream	Color, odor, texture	0–10	6	Goulas and Kontominas, 2007a
	Color	0–3	2	Gimenez et al., 2004
	Odor	0–6	3	Gimenez et al., 2004
Chub mackerel	Color, odor, texture	0–10	6	Goulas and Kontominas, 2007b
	Color, odor, taste, texture	0–10	6	Goulas and Kontominas, 2005
	Color, odor, texture	0–5	2	Speranza et al., 2009
Bonito	Color, odor, taste, appearance	0–10	4	Mol et al., 2012
Fish burger	Odor, texture, drip loss	0–5	2	Del Nobile et al., 2009
Lobster	Color, odor	0–5	2	Gomez-Guillen et al., 2007
Shrimps	Color, odor, firmness	1–5	3	Mastromatteo et al., 2010

Table 3 Values of sensory acceptability used in the literature to calculate shelf life of different foods

Food	Scale	Value	References
Lemon verbena leaves infusion	0–15	7.5	Infante et al., 2010
Coffee brew	1–9	4	Manzocco and Lagazio, 2009
Loin steak	0–2	1	Bloomberg et al., 2011
Cooked sea bass	0–10	5	Provincial et al., 2010
Cooked salmon	0–10	5	Gimenez et al., 2005
Lobster	0–5	2	Gomez-Guillen et al., 2007
Trout soup	1–9	7	Tolasa et al., 2012

Authors actually suggest the adoption of lower percentages of consumer dissatisfaction as acceptability limit (Table 4).

Some companies apply a risk tolerance approaching zero, based on the assumption that all consumers eating the product at the end of its shelf life must found it acceptable or not significantly different from the fresh one. It is noteworthy that the development of consumer rejection functions requires large consumer panels and appropriate statistical techniques, making it still difficulty applicable by company operators. In order to meet industrial needs, instrumental, or sensory attributes, whose evolution is correlated with consumer sensory dissatisfaction, could be identified and routinely exploited to estimate shelf life. To this regard, Table 5 shows some examples of critical quality indicators demonstrated to well correlate with consumer dissatisfaction during storage.

6. ASSESSMENT OF RISK FOR LABEL CLAIM DEFAULT

The risk for label claim default can be identified monitoring the number of food items not respecting the label claim during storage. Data are elaborated following procedures analogous to those applied to estimate the risk for consumer sensory dissatisfaction: a risk function of label claim default is obtained by using survival analysis methodology. In this case, the acceptability limit is the tolerable risk of food exceeding the value claimed on the label at the end of shelf life.

Table 4 Acceptability limits used in the literature to calculate shelf life of different foods

Acceptability limit	Food	Reference
50% consumer rejection	Milk	Duyvesteyn et al., 2001
	Minced meat	Hough et al., 2006
	Fuji apples	Varela et al., 2005
	Pears	Salvador et al., 2007
	Coffee powder	Cardelli and Labuza, 2001
	Biscuits	Calligaris et al., 2007
	Bread sticks	Calligaris et al., 2008
25, 50% consumer rejection	Probiotic yogurt	Cruz et al., 2009
	Ready-to-eat lettuce	Araneda et al., 2008
	Coffee beverage	Manzocco and Lagazio, 2009
	White pan bread	Gambaro et al., 2004
	Muffins	Baixauli et al., 2008
25% consumer rejection	Pears	Salvador et al., 2007
	Fresh cut lettuce	Manzocco et al., 2012
	Apple-baby food	Gambaro et al., 2006
	Brown pan bread	Gimenez et al., 2007

Table 5 Critical quality indicators correlated with food consumer dissatisfaction during storage. The assessment methodology of the critical indicator is also reported

Food	Critical quality indicator	Assessment methodology	Reference
Sunflower oil	Oxidised flavor	Sensory analysis by a trained panel	Ramirez et al., 2001
Human milk replacement formula	Dark color	Sensory analysis by a trained panel	Curia and Hough, 2009
Powdered milk	Oxidized flavor	Sensory analysis by a trained panel	Hough et al., 2002
Duche de leche	Off-flavor	Sensory analysis by a trained panel	Garitta et al., 2004
Fresh-cut fruit salad	Brown index	Image analysis	Manzocco et al., 2012
Avocado paste	Sour flavor	Sensory analysis by a trained panel	Jacobo-Velazquez and Hernandez-Brenes, 2011
Coffee powder	Total volatile	Head space GC analysis	Anese et al., 2006
Coffee beverage	Hydrogen ion concentration	pH	Manzocco and Lagazio, 2009
Biscuits	Oxidation level	Peroxide value	Calligaris et al., 2007
Bread sticks	Oxidation level	Peroxide value	Calligaris et al., 2008
Frozen pizza	Yellow index	Tristimulus colorimeter	Calligaris and Manzocco, 2012

7. THE DECISION TREE OF THE ACCEPTABILITY LIMIT

Figure 3 schematically shows a possible decision tree of the process leading to the identification of the acceptability limit. If the product historical experience of the company is high, a rational estimation of acceptability limit, and hence of shelf life, could be made with minor error. The risk of product unacceptability can be confirmed or corrected based on failure data obtained from sales, complaint records, and quality control database collected over years of commercialization. An emblematic case is that related to foods susceptible to the development of alterative microorganisms. Even if not dangerous for health, they are potentially associated with sensory defects. Their presence is not regulated but producer associations, retail consortia, and standard agencies have provided limit values. For instance, the level of spoilage bacteria (total viable count, *Pseudomonas* spp., lactic acid bacteria, yeasts, or moulds depending on the product) in fully cooked products or in products intended for cold eating is often required to be lower than 10^6 cfu/g up to the end of shelf life. This limit

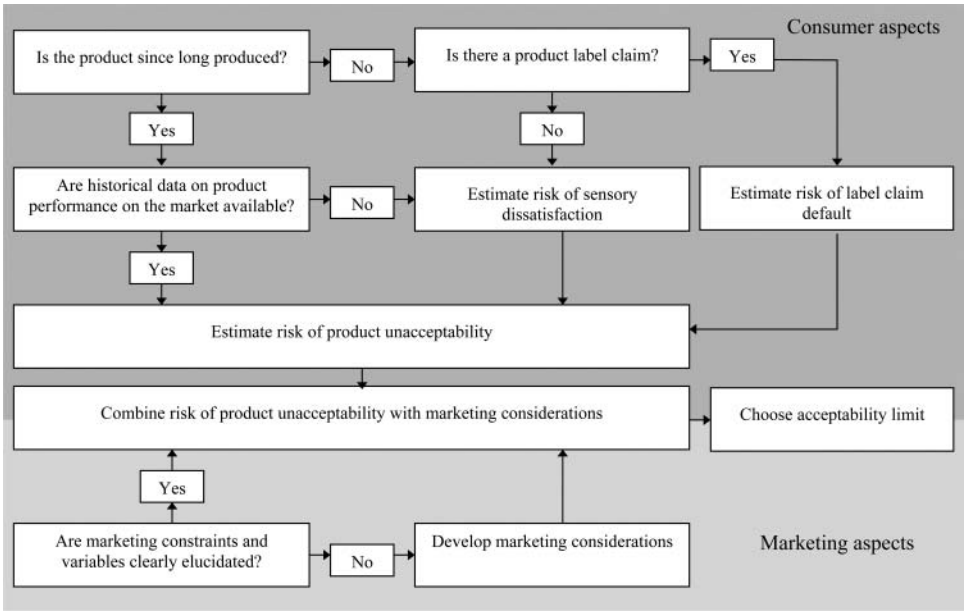

Figure 3 Decision tree for the identification of the acceptability limit (with permission from Manzocco, 2012).

derives from the historical awareness that consumer dissatisfaction becomes not negligible when counts are higher than 10^6 cfu/g.

In case, there is not an adequate historical experience, the risk for over/under estimation of shelf life increases and two possibilities arise depending on the existence of a specific label claim. If a label claim exists, the risk of product unconformity to what is declared on the label should be evaluated by a proper experimental plan. When there is no claim and the product is completely new, the risk function of consumer dissatisfaction as a function of storage time is necessarily required to choose the acceptability limit. If the product is already available on the market, emulation of competitors could be possible but risky. This hazard should be decreased by data demonstrating that the acceptability limit chosen by competitors also applies to the new production. Finally, information about product unacceptability risk should be merged with marketing considerations, including social, production, delivery system, and business constraints.

The acceptability limit is actually a quantitative value with complex and fluctuating nature. In general terms, it represents a reasonable compromise among the different needs to: (i) minimize sensory dissatisfaction of the target consumer; (ii) minimize product recalls and maximize product turnover as required by producer; (iii) maximize shelf life as required by distribution system.

The role of market constraints on the final acceptability limit choice is not negligible and sometimes becomes dominant. This is the case of frozen food undergoing oxidative reactions during storage. Although producers are aware of the sensory consumer dissatisfaction risk, they choose less conservative acceptability limits because several large retailing companies require shelf lives longer than nine months. By contrast, canned food develops a risk for consumer sensory dissatisfaction in times much longer than their actual shelf life. However, in this case, the consumer dissatisfaction risk the company is willing to tolerate at shelf life is forced to zero to increase product turnover on the shelves.

8. CONCLUSIONS

The acceptability limit is certainly the less investigated aspect in shelf life studies. This is probably because of its stochastic nature that makes it a shadowed and often mysterious boundary. While quality decay is an intrinsic food characteristic that can be univocally defined by applying kinetic modeling, the definition of the acceptability limit requires a rational evaluation of the potential negative consequences deriving from the risk of consumer dissatisfaction deriving from undesired sensory properties or label claim defaults.

Although investigations about acceptability limit are difficult, more research is needed to enlighten its theoretical aspects. This will provide a sound basis to produce acceptability limit data of easy-applicability in the food industry.

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