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## Sensory Evaluation of Cow's Milk

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# Sensory Evaluation of Cow's Milk

## Abstract

Milk contains nine of the essential nutrients at good (at least 10% of the daily value) to excellent (at least 20% of the daily value) levels recommended for human nutrition, including protein, calcium, phosphorus, potassium, riboflavin, niacin and vitamins A, D and B 12. It is well established and accepted that dairy products contribute to bone and dental health (Black et al. 2002; Rockell et al. 2005; Gao et al. 2006; Huncharek et al. 2008; Moschonis et al. 2010; Davoodi et al. 2013). Additionally, dairy products also contribute to overall health and even have protective effects against coronary heart disease, stroke, type 2 diabetes, certain types of cancer and other diseases (E lwood et al. 2005, 2007, 2008, 201 O; Kleim and Givens 2011; Davoodi et al. 2013). Thus, ensuring consumption of milk and dairy products is nutritionally relevant for a vibrant population. However, an abundant supply of milk matters little if poor quality prevents it from being consumed by those who need it. High-quality raw milk is essential, not only for the production of fluid milk but also for the production of all subsequent value-added dairy products made from milk. Because of high moisture (approximately 88% water) and nutrient composition (Table 1), milk is a highly perishable product. Although pasteurization ensures the safety of milk, the flavour quality of milk fresh from the cow cannot be improved. For instance, if milk is contaminated by microorganisms at any stage between cow and consumer, and those are allowed to proliferate (i.e., via temperature abuse), off-flavours can be produced that will persist (and sometimes become enhanced) with subsequent processing steps. Perhaps, the only exception includes the use of vacuum evaporation, which enables removal of absorbed volatile off-flavours (such as manure aroma) from milk.

## Disciplines

Dairy Science | Food Processing | Food Science | Human and Clinical Nutrition | Molecular, Genetic, and Biochemical Nutrition

## Comments

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## Sensory evaluation of cow's milk

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### 1 Introduction

Milk contains nine of the essential nutrients at good (at least 10% of the daily value) to excellent (at least 20% of the daily value) levels recommended for human nutrition, including protein, calcium, phosphorus, potassium, riboflavin, niacin and vitamins A, D and B12. It is well established and accepted that dairy products contribute to bone and dental health (Black et al. 2002; Rockell et al. 2005; Gao et al. 2006; Huncharek et al. 2008; Moschonis et al. 2010; Davoodi et al. 2013). Additionally, dairy products also contribute to overall health and even have protective effects against coronary heart disease, stroke, type 2 diabetes, certain types of cancer and other diseases (Elwood et al. 2005, 2007, 2008, 2010; Kleim and Givens 2011; Davoodi et al. 2013). Thus, ensuring consumption of milk and dairy products is nutritionally relevant for a vibrant population.

However, an abundant supply of milk matters little if poor quality prevents it from being consumed by those who need it. High-quality raw milk is essential, not only for the production of fluid milk but also for the production of all subsequent value-added dairy products made from milk. Because of high moisture (approximately 88% water) and nutrient composition (Table 1), milk is a highly perishable product. Although pasteurization ensures the safety of milk, the flavour quality of milk fresh from the cow cannot be improved. For instance, if milk is contaminated by microorganisms at any stage between cow and consumer, and those are allowed to proliferate (i.e., via temperature abuse), off-flavours can be produced that will persist (and sometimes become enhanced) with subsequent processing steps. Perhaps, the only exception includes the use of vacuum evaporation, which enables removal of absorbed volatile off-flavours (such as manure aroma) from milk.

**Table 1** Typical cow milk composition (whole, 3.25%, without added vitamin A and D)\*

Component	Unit	Amount per 100 g
Water	g	88.13
Energy	Kcal	61
<b>Macronutrient</b>		
Carbohydrate (predominantly lactose)	g	4.90
Fat (total lipid)	g	3.27
Fibre (total dietary)	g	0.0
Protein	g	2.15
<b>Minerals</b>		
Calcium, Ca	mg	113
Iron, Fe	mg	0.03
Magnesium, Mg	mg	10
Phosphorus, P	mg	84
Potassium, K	mg	132
Sodium, Na	mg	43
Zinc, Zn	mg	0.37
<b>Vitamins</b>		
Vitamin C (total ascorbic acid)	µg	3
Thiamine	µg	46
Riboflavin	µg	169
Niacin	µg	89
Vitamin B6	µg	36
Folate	µg	5
Vitamin B12	µg	0.45
Vitamin A	µg	46
Vitamin E	µg	70
Vitamin D (D2 + D3)	µg	0.1
Vitamin K	µg	0.3
<b>Lipids</b>		
Fatty acids, total saturated	g	1.87
Fatty acids, total monounsaturated	g	0.81
Fatty acids, total unsaturated	g	0.20
Cholesterol	mg	10

\*Adapted from National Nutrient Database for Standard Reference (USDA 2015).

## 2 Milk evaluation processes

Milk may be evaluated in raw (unprocessed) form, immediately after processing or at any time during storage. The primary, though not exclusive, sense used in the evaluation of milk, is the smell. However, milk quality evaluation involves almost all of the senses: sight, smell, taste and tactile.

The sequence of milk evaluation begins from the cow, when the handler checks for the presence/absence of mastitis. The handler may use a combination of udder palpation (to feel for lumps or abnormalities) and milk ejection onto a grate or into a strip cup (to observe for the presence of flocculation and/or blood). Cow handlers and milkers should be trained to understand the critical role they play in ensuring milk safety and quality. Proper use of teat pre- and post-dips, individual udder-drying cloths, cleaning and sanitizing inflations and all milk handling equipment, withholding milk from antibiotics-treated animals, attention to cow nutrition and health and denying strongly flavoured feed components (i.e., garlic, onion, mint) are all vital for ensuring high-quality milk. Miller and colleagues (2015) reported that management practices (including herd size, milking routine and bedding) play a significant role in controlling the levels of mesophilic and thermophilic spores in milk.

The milk hauler uses visual cues to evaluate whether cream or butter granules have risen to the top or if sediment has settled to the bottom of the bulk tank. Consumers also make visual evaluations. One of the reasons consumers like to purchase milk in translucent plastic high-density polyethylene (HDPE) packaging is that they like to see what they are buying; also, they can see how much milk is left in the container without having to pick it up. Consumers also look for sedimentation and flocculation on the sides of translucent containers, which are clear signs of spoilage. Another visual cue that must not be overlooked is the 'best by' or 'sell by' date printed on the carton. While some consumers simply grab the carton closest to the front of the refrigerated case at the market, many reach through the display case to procure the carton labelled furthest in the future. There are many reasons for this practice, including, but not limited to, the expectation that the milk will not be finished by the date printed, assumption that the milk will spoil by the printed date, or unfounded fear that the milk will not be safe after the printed date.

The second step in milk evaluation is generally by smelling. Milk receivers or haulers evaluate milk quality by turning off the agitator of the bulk tank, lifting the lid and sniffing the headspace of the bulk tank before pumping the milk from the tank to the truck. The hauler can reject the milk based solely on aroma quality. Cow's milk is composed of over 52 identified volatile compounds (Yue et al. 2015). A summary of aromatic compounds in milk is included in Table 2. Using a triple-channel comparative analysis combining the use of an electronic nose (E-Nose), gas chromatography mass spectrometry (GC-MS) and GC-olfactometry (GC-O), Ai et al. (2015) demonstrated that volatile flavour compounds affected consumer preference of raw whole and skim milk. Siefarth and Buettner (2014) identified 54 aromatic compounds in goats' milk, which were influenced by season and heat treatment.

Before one can identify an off-flavour in milk, recognition of what is 'normal' for milk flavour must be understood. Fresh from the cow, or freshly pasteurized, milk should have no offensive aroma. Aromatic compounds are more readily released from warm milk than from cold milk. Thus, to effectively smell milk that has been refrigerated, the evaluator

**Table 2** Recognized volatile aroma compounds in cow and/or goat milk, along with descriptors\*

Compound (also known as)	Odour descriptor
Acetic acid	Vinegar
Butan-2,3-dione (diacetyl)	Buttery
Butanoic acid (C4; butyric acid)	Green, cheesy, sweaty
Deca-2,4-dienal	Fatty, green, chicken broth-like
Decanal	Sweet, orange skin, flowery
$\delta$ -Decalactone	Coconut
$\gamma$ -Deltalactone	Peach-like
Decanoic acid (C10; capric acid)	Tallow, fatty, goat-like, leather-like
Dimethyl sulphide (methylthiomethane)	Sweaty, fatty
$\delta$ -Dodecalactone	Flowery, daisy-like
$\gamma$ -Dodecalactone	Soapy, fatty, flowery
Dodecanoic acid (C12; lauric acid)	Fatty, soapy, goat-like, faecal
3-Ethylphenol	Fatty, leather-like, medicinal
<i>trans</i> -4,5-epoxy-dec-2-enal	Metallic
2(5H)-Furanone (butenolide)	Unspecified
Hexanoic acid (C6; caproic acid)	Sour, urine-like, pungent
Hexadecanoic acid (C16; palmitic acid)	Fatty
3-Hydroxy-2-butanone	Fatty
2-Methylbutanoic acid	Sweaty, cheesy
3-Methylbutanoic acid (isovaleric acid)	Sweaty, cheesy
4-Methyloctanoic acid	Musty, urine-, stable-like
3-Methylphenol ( <i>m</i> -cresol)	Leather-like, medicinal
3-Methylthiopropional (methional)	Cooked potato-like
Nona-2,6-dienal	Fatty, cucumber-like
Nona-2,4-dienal	Fatty, green
$\delta$ -Nonalactone	Sweet, peach-like
$\gamma$ -Nonalactone	Peach-like
Nonanal	Fatty
Non-4-enal	Green, fatty
Non-2-enal	Fatty, green, body odour
Nonanoic acid (pelargonic acid)	Fatty, faecal, male goat-like
$\gamma$ -Octalactone	Coconut-like
Octanoic acid (C8; caprylic acid)	Rancid, medicinal, fatty, musty
1-Octanol	Fruity
Oct-2-enal	Green, fatty, plastic-like
Oct-1-en-3-one	Mushroom-like, metallic
Pentanoic acid (valeric acid)	Sweaty, cheesy
Phenylethan-2-ol (phenethyl alcohol)	Flowery, fruity, sweet
Tetradecanoic acid (C14; myristic acid)	Fatty

\*Compiled from Ai et al. (2015) and Siefarth and Buettner (2014).

should place approximately 15 mL of milk into a waxed or plastic (not paper or foam) cup. The evaluator is advised to place one hand over the cup and the other hand around the bottom of the cup, so that the warmth of the lower hand can penetrate the cup, enabling volatile aromatic components to fill the headspace, trapped by the upper hand. Swirling of the cup facilitates aromatic release. The evaluator should place his or her nose close to the upper hand, lift the hand from the top and immediately sniff the headspace. Fresh milk, if full of fat, should have a clean aroma of milk fat. Any deviation from this suggests potential defects. Various off-flavours (namely acid or sour, barny, cooked, cowy, feed, fruity/fermented, garlic/onion, malty, oxidized, rancid) can be readily recognized just by sniffing the milk. Reading Section 3 may help the evaluator create a mental database of potential off-flavours, to help in future identification. Better yet, evaluators can utilize recipes, such as those included in Table 3 or in *The Sensory Evaluation of Dairy Products* (Costello and Clark 2009), and practice sniffing and tasting various intensities of the defects to aid in identification.

While off-flavours will be most readily noted by sniffing the headspace, off-flavours will be noted retronasally, if the evaluator takes a sip, swirls the milk around the mouth, expectorates and breathes out through the nose.

It is also very common for consumers to smell milk. Although not trained to identify aroma compounds, each consumer has his or her own definition of what is considered offensive; thresholds and tolerance levels vary among consumers. While some consumers are forgiving of an occasional offense, others may steer clear of a particular brand of milk if it offends, particularly if it spoils before the code date printed on the carton. Some consumers discard containers once they reach the printed 'best by' or 'sell by' date, without even sniffing, while others continue drinking milk beyond the date as long as it smells 'OK'. Thus, it is in the best interest of companies to conduct shelf-life tests and to monitor product sensory quality throughout shelf-life.

Taste refers to the basic sensations acquired from stimulation, on the tongue, by general classes of tastants, including sweet, sour, salty, bitter, umami (savoury) and fat (fatty). While the basic acid or sour and fatty tastes often have aromatic components associated with them, the basic tastes, sweet, salty, bitter and umami can only be recognized by tasting the milk. The basic tastes are commonly associated with locations on the tongue, but taste sensation varies among humans. Flavour is a broader term, referring to the combined sensation of taste and aroma. Fresh 'normal' milk should taste slightly sweet, umami and fatty, with no offensive flavour or aftertaste. Upon tasting, the first thing that an evaluator should notice is the natural sweetness of milk, since lactose is the primary solid component in milk (approximately 5%). The sweet sensation can be noted readily on many parts of the tongue and may be associated with a warming feeling. The basic taste of umami, which is associated with proteins, is often described as 'brothy'. Milk with less fat (low-fat (1%) or skim milk) will have a more pronounced umami taste than milk with more fat (reduced fat (2%) or whole milk (at least 3.25% fat)).

In many facilities, taste/flavour quality is evaluated throughout production runs. Staff take cartons off the processing line, to the laboratory, where a variety of quality and regulatory compliance tests are run throughout a shift. It is a great practice to have trained sensory personnel in milk quality control/quality assurance laboratories. Such personnel can identify potential quality issues early, and potentially circumvent customer complaints. Regulatory compliance tests, including, but not limited to, bacterial limits, temperature recording, proximate analysis, somatic cell count, drug residues, phosphatase, etc., are beyond the scope of this chapter. The reader is encouraged to

**Table 3** Recipes\* for production of samples for milk off-flavour identification

Off-flavour	Description/recipes/notes
No defect	Fresh, wholesome whole or 2% milk should have no offensive aroma, and should taste slightly sweet, fatty and umami. There should be no offensive flavour or aftertaste. When purchasing from a store, milk packaged in paperboard may have no defect, but milk in glass or HDPE will likely be oxidized. Skim milk and low-fat (1%) milk will lack the fatty taste and will have more pronounced sweet and umami tastes.
Acid/sour	Add 1–2 mL of cultured buttermilk to 1 L of milk. Alternatively, add 3 mL of a 10% lactic acid solution to 1 L of milk.
Bitter	Add 1–2 mL of a 0.25% quinine sulphate solution or a 0.25% caffeine solution to 1 L of milk.
Cooked	Purchase UP or UHT milk. Alternatively, boil 500 mL of milk and bring to 1 L volume with 'no defect' milk.
Feed	Add 5 mL 'alfalfa tea' (steep alfalfa or Timothy hay 5 min in boiling water) to 1 L of milk within 6 h of tasting (aroma dissipates over time).
Flat	Use 'no defect' low-fat (1%) or non-fat milk or combine 500 mL skim milk with 500 mL 2% milk. Alternatively, add up to 20% water to 1 L of milk.
Foreign	Anything that should not be in milk, but not otherwise identified by one of the other off-flavour categories, is foreign. To 1 L milk, add (1) 0.25 mL iodine sanitizer or 1 mL bleach solution (1 mL/1 L water) within 1 h of tasting (unstable); (2) 0.1 mL vanilla or other flavour; (3) 1 g sugar (or 0.25 g of a high-intensity sweetener); (4) 0.25 mL fish oil; (5) 0.25 g vitamin pre-mix.
Fruity/ fermented	Add up to 3 mL pineapple juice, apple juice or V8 Splash® Tropical Blend juice to 1 L of milk.
Garlic/onion	Add 0.25 mL of garlic or onion juice to 1 L of milk.
Lacks freshness	Dissolve 1–2 g of stale (stored) non-fat dry milk (NFD) in 1 L of milk. Alternatively, cut a sanitized green pepper and place it into approximately 200 mL milk. Fish the pepper out of the milk after 30 min and bring to 1 L volume with 'no defect' milk. Another option is to taste milk stored 7 days past the code date, but other off-flavours may be noted (fruity/fermented, bitter).
Light oxidized	Buy milk in any plastic or glass container or place 'no defect' milk into a glass or plastic container and expose to fluorescent or UV light for 15 to 30 min.
Malty	Dissolve 1 g malted milk powder (Carnation® or other brand) in about 200 mL of milk that has been warmed in a microwave for 20 seconds; swirl or mix with a sanitized spoon; bring to 1 L volume.
Metal oxidized	Add a cleaned and sanitized copper penny to 1 L milk; allow oxidization for at least 4 h; filter out the penny before serving. Alternatively, add 1 mL 0.25% copper sulphate to 1 L of milk at least 4 h in advance of serving.
Rancid	Add 0.2 g kid lipase to 1 L milk and allow to hydrolyze for at least 4 h under refrigeration. Alternatively, add 10 g grated Romano cheese to 500 mL milk and refrigerate overnight. Filter cheese out of milk (4–6 layers of cheesecloth or 1 coffee filter) and bring to 1 L volume with 'no defect' milk.
Salty	Add approximately 0.25 g table salt to 1 L 'no defect' milk.
Unclean	Combine at least two of the following off-flavours and bring to 1 L volume: bitter, fruity/fermented, acid/sour, malty, rancid.

\*Recipes can be adjusted up or down to train varying intensities of off-flavours.



reference the *Grade 'A' Pasteurized Milk Ordinance* (USDHHS et al. 2011) for details. Microbiological tests that may be conducted as indicators of milk quality, including, but not limited to, standard plate count, coliform count, laboratory pasteurization count, preliminary incubation count, direct microscopic count and psychrotrophic/psychrophilic or spore pasteurization count will also not be covered in this chapter. The reader is encouraged to reference the *Standard Methods for the Examination of Dairy Products* for detailed methodology (Wehr and Frank 2004). Some processors 'hold back' products at various stages of production runs, for storage in-house and for sensory and/or microbial evaluation throughout the stated shelf-life. Shelf-life testing will be elaborated upon in a later section of this chapter.

Tactile issues are least likely to be experienced in milk because of the likelihood that consumers will use their other senses. Visually, if milk has coagulated (by acidification or proteolysis), rejection will occur well before the milk is tasted. However, if coagulation is not visually noted (for instance, if someone drinks spoiled milk directly out of a paperboard carton), the milk will likely taste either sour (acidification) or fruity/fermented and/or bitter (proteolysis). Age gelation, resulting from the natural plasmin enzyme system in milk, can be an issue in ultrahigh temperature (UHT) processed milk stored beyond 6 months or at elevated temperatures (Chavan et al. 2011).

### 3 Off-flavours in milk: categories, causes and remedies

There are four basic categories that off-flavours in milk can be divided into, namely absorbed, bacterial, chemical and delinquency. Preventing absorbed off-flavours generally involves good cow nutrition (appropriate feeds, balanced rations) and management (ventilation, health monitoring, manure management) practices. Preventing bacterial off-flavours hinges on the good training of staff that prepare teats for milking and proper maintenance of equipment, temperature control, proper selection of application of cleaning and sanitizing chemicals, and prompt milk processing. Preventing chemical off-flavours involves keeping milk away from light and reactive metals, avoiding excessive agitation and using appropriate processing controls. Preventing delinquency off-flavours relies on attentive care by all who handle milk, from cow to consumer.

#### 3.1 Absorbed

If cow paddocks or resting areas are not properly maintained, and if manure is not cleared away, the aroma of manure may be absorbed into the milk and be perceived by consumers. The barny off-flavour, described as 'faecal', is readily observed by aroma.

The cowy off-flavour is described as medicinal, acetone or ketone aroma/flavour. The off-flavour indicates that cows in the herd are suffering from acetonæmia or ketosis, a result of abnormal fat metabolism when energy demands exceed energy intake.

Because of the absorbent nature of milk fat, strong feed flavour compounds may be absorbed from the blood into milk. The off-flavour, which can be described with a variety of terms, including, but not limited to, 'grassy', 'alfalfa', 'green', 'tea', 'grain' or 'molasses', is not objectionable to all consumers.

Closely related to the feed off-flavour, garlic/onion off-flavours are absorbed into the milk if cows are exposed to wild onions or garlic. Garlic/onion off-flavour is readily noted

by its aroma. While some may not even notice, an unpleasant aftertaste can linger for those who are sensitive to the off-flavour.

Lacks freshness is a general term to capture any off-flavour that is not well described by any of the other terms. However, the word 'stale' or 'taste like the smell of the refrigerator' have been used to describe lacks freshness. Lacks freshness may be of absorbed or bacterial origin. Milk may absorb aromas from strongly flavoured foods in the refrigerator. Psychrotrophic bacteria, including *Pseudomonas*, *Paenibacillus*, *Bacillus* and *Microbacterium* species, may produce off-flavours associated with lacks freshness. Lacks freshness can be smelled. The stale flavour may not clean up readily.

## 3.2 Bacterial

The acid/sour taste has been described as sharp, piercing and even cooling sensation; it is commonly experienced on the sides and top of the tongue. In dairy products, acid describes the taste of lactic acid, while sour includes volatile components associated with the lactic acid bacteria (LAB) that produce not only lactic acid but also volatile components such as diacetyl in such products as cultured buttermilk, sour cream, cream cheese, etc. 'Sour' is perhaps the most common specific sensory description for spoiled milk by consumers. However, acid/sour is a rare off-flavour in milk. The reason for this disconnect is likely that consumers do not have an established vocabulary to describe milk defects and the word 'sour' has been carried through generations. Souring is the result of fermentation of lactose into lactic acid by LAB, including, but not limited to, species of *Lactococcus*, *Lactobacillus*, *Streptococcus* and *Leuconostoc*. Depending on the genus, LAB are most active at temperatures ranging from as low as 25–35°C (mesophilic species) to as high as 35–45°C (thermophilic species), and most grow slowly at temperatures as low as 4°C. The U.S. Food and Drug Administration's *Grade 'A' Pasteurized Milk Ordinance* (USDHHS et al. 2011) for interstate milk shipment requires that milk be cooled to below 7°C within 2 h of the complete milking of the last cow. Since all fluid milk in the United States must meet Grade 'A' standards, when present in raw milk, LAB proliferation is slowed down by the cold temperatures required by the PMO. Additionally, LAB are killed by pasteurization, which is also required for fluid milk sold across state lines, and even within many states' borders. Although pasteurization kills LAB, it will not improve the flavour of milk if the defect (acid/sour) is already present. Because of these two practices, milk does not sour as readily today as it did in the early years of transporting milk to consumers. However, it should be noted that post-pasteurization contamination of milk with LAB enables formation of the sour/acid off-flavour in milk.

Fruity/fermented is one of the most common off-flavours in milk that has been stored beyond its code date. Fruity/fermented off-flavours result from ethyl ester formation by esterases from thermotolerant psychrotrophic bacteria, especially *Pseudomonas*, including, but not limited to, *Pseudomonas fragi*. Other species that predominate in milk stored too long, and that produce fruity/fermented off-flavours, include Gram-positive psychrotrophic *Paenibacillus*, *Bacillus* and *Microbacterium* species (Fromm and Boor 2004). Fruity milk may smell like apples, pineapples, mangos, strawberries and so on, while fermented milk smells like fermented fruit or sauerkraut. Fruity/fermented milk may taste dirty and tends to leave an aftertaste.

Similar to acid/sour, the malty off-flavour results from temperature abuse of raw milk. The microorganism responsible for this off-flavour, *Lactococcus lactis* ssp. *maltigenes*, grows

by its aroma. While some may not even notice, an unpleasant aftertaste can linger for those who are sensitive to the off-flavour.

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Similar to acid/sour, the malty off-flavour results from temperature abuse of raw milk. The microorganism responsible for this off-flavour, *Lactococcus lactis* ssp. *maltigenes*, grows

well at temperatures above 18°C. *Lactococcus lactis* subsp. *lactis* biovar. *diacetylactis* has also been implicated in malty flavour compounds, including 2- and 3-methylbutanal and 2- and 3-methyl-1 1-butanol (Mutukumira et al. 2009). Although the microorganisms are killed by pasteurization, the malty flavour will persist once produced. The malty off-flavour can be readily sensed by sniffing. Although not terribly objectionable in aroma, it is a clear sign of bacterial degradation; counts will be in the millions per millilitre. Malty smells and tastes like the milk left over after eating a bowl of breakfast cereal (toasted barley, corn, oat or Grape Nuts® cereal).

Milk that is 'unclean' tastes dirty. It generally smells bad and leaves an unpleasant aftertaste. The unclean off-flavour results from activity by psychrotrophic and/or mesophilic bacteria. While outgrowth of psychrotrophic bacteria is expected at refrigeration temperatures, an outgrowth of mesophilic bacteria indicates temperature abuse. If left long enough (e.g. ~15 days beyond code), most milk will eventually turn unclean.

### 3.3 Bacterial/chemical

Bitterness typically has a slower onset than the other basic tastes, is noted at the back of the tongue and throat, can give a dull or throbbing sensation, and tends to linger longer than the other basic tastes. The sensitivity to or threshold for bitterness varies widely among humans; some people are 'bitter blind' while others are particularly offended by the off-taste. Fresh milk should never taste bitter, unless cows are fed certain feedstuffs. However, bitterness is one of the most common defects in milk that has been stored beyond its code date, because of proteolysis. Proteolysis may be initiated from two sources: native plasmin enzyme system and bacterial origins. The term 'plasmin enzyme system' refers to a family of proteins, specifically plasminogen (an inactive form, or precursor of plasmin), and two plasminogen activators (which enable conversion of plasminogen to plasmin), plasmin, plasmin inhibitors and plasmin activator inhibitors (Metwalli et al. 1998; Ismail and Nielsen 2010). Plasmin and plasminogen are highly heat stable, which is why bitterness and age gelation occur even in UHT milk. Because milk is rapidly cooled, and because many microorganisms that survive pasteurization are proteolytic, the dairy industry has naturally selected thermotolerant spore-forming psychrotrophic microorganisms to dominate in dairy environments and dairy products over time.

Although enjoyed in some types of cheeses (Asiago, feta, blue, Romano), rancid is one of the most objectionable off-flavours to occur in milk. With oils and nuts, 'rancid' often refers to oxidative rancidity, but in the context of milk, the term rancid refers to hydrolytic rancidity, resulting from the cleavage of fatty acids from the glycerol backbone of triacylglycerols (triglycerides) by the enzyme lipoprotein lipase. Short-chain volatile free fatty acids, including butyric (C4), caproic (C6), caprylic (C8), capric (C10) and lauric acid (C12), contribute to the baby vomit-like smell. The enzyme lipase is a natural component of milk, but is also a component of many bacteria. Generally, lipase is separated from its substrate, milk fat, by the protective milk fat globule membrane. The rancid off-flavour is induced when the milk fat globule membrane is compromised and lipase has access to fatty acids to catalyse hydrolysis. Causes of rancidity include (1) overly rapid cooling or freezing, (2) foaming, (3) homogenizing raw milk and (4) adding raw milk to pasteurized-homogenized milk. Lipase is destroyed by the heat of pasteurization, but lipolytic damage done to milk before pasteurization will not be improved by pasteurization. Additionally, if milk is contaminated with psychrotrophic bacteria that produce lipase, the off-flavour

is likely to manifest during storage. Although the acid degree value (ADV) has been used as a measure of free fatty acids, and an indirect measure of milk hydrolytic rancidity, Duncan and Christen (1991) demonstrated that ADV does not measure the short-chain fatty acids that contribute to the threshold sensory detection of rancid off-flavour.

### 3.4 Chemical

The term cooked can be described as 'eggy', 'sulphur', 'custard', 'steamed' or 'barista milk'. There is a wide range of consumer tolerance or acceptability for the off-flavour 'cooked'. Most fluid milk in the United States is high-temperature short-time (HTST) pasteurized (at or above 72°C, held thereat for at least 15 sec) and some is low-temperature long-time (LTLT) pasteurized (at or above 63°C, held thereat for at least 30 min). At those temperatures, milk is only mildly cooked. Milk naturally contains sulphur-containing amino acids. In the raw form, proteins in their native structure do not present aromatic sulphur compounds. However, when cooked, proteins unravel, enabling exposure and volatilization of the sulphur compounds. UHT milk, in particular, contains significantly higher concentrations of hydrogen sulphide, methanethiol carbon disulphide, dimethyl trisulphide and dimethyl sulfoxide than raw or pasteurized milk (Vazquez-Landaverde et al. 2006). In a study specifically designed to address the concern about cooked flavour, Gandy and others (2008) demonstrated that consumers ( $n = 298$ ) preferred milk pasteurized at 79°C to milk treated at 77, 82 or 85°C on 'day zero', but differences were not as notable beyond six days of storage. Some clusters of consumers liked the cooked flavour of milk treated at 82 or 85°C, but others did not (Gandy et al. 2008). For many, cooked is a pleasing aroma/flavour, and it does not become objectionable until milk is ultra-pasteurized (UP) or UHT pasteurized. UP and UHT pasteurized milk must be thermally processed at or above 138°C for at least 2 s, either before or after packaging (USDHHS et al. 2011). The main difference between UP and UHT is packaging; UHT milk is either thermally processed and then packaged aseptically or thermally processed in the package (commercially sterile milk). UHT milk has an unrefrigerated, unopened shelf-life of approximately 6 months. UHT milk is not common in the United States, in part because of the strong cooked flavour, but outside the United States, UHT milk is common and popular (Chavan et al. 2011). Further, minimal processing, a current trend in the United States limits the appeal of UHT. Modern technologies, including microfiltration, high hydrostatic pressure, pulsed electric fields and ultrasound, have been considered as adjuncts to pasteurization, but have not found industrial application to date.

The most common off-flavour in milk in the United States is light oxidized, because so much of the milk is packaged in translucent HDPE plastic gallon and half-gallon containers. Unfortunately, milk in HDPE packaging, as well as milk packaged in glass, is prone to light oxidation. Light-oxidized off-flavour has been described as 'wet cardboard', 'burnt feathers', 'burnt hair', 'mushroom', 'old vegetable oil' and even 'plastic-like'. Light-induced oxidation (or 'sunlight flavour') results from chemical reactions initiated by light and facilitated by riboflavin and possibly another photosensitizer, upon amino acids and/or unsaturated fatty acids (Chapman et al. 2002; Webster et al. 2009). Havemose et al. (2004) demonstrated that protein oxidation occurs independently of lipid oxidation, and milk from cows fed grass silage is more vulnerable to lipid oxidation, while milk from cows fed corn silage is more vulnerable to protein oxidation. Chemically, accumulation of dityrosine can serve as a marker for protein oxidation, and accumulation

of lipid hydroperoxides, pentanal, hexanal and heptanal can serve as markers for lipid oxidation (Havemose et al. 2004, 2006; Hedegaard et al. 2006). Chapman et al. (2002) demonstrated that trained panelists could note oxidized off-flavour in milk after exposure to light for 15 to 30 minutes, while untrained consumers notice the oxidized off-flavour after 54 minutes to 2 h of light exposure. It was also reported that approximately 50% of the plastic milk containers remain in lighted dairy cases for at least 8 h (Chapman et al. 2002). Webster et al. (2009) demonstrated varied effectiveness of overwraps against oxidized off-flavour when milk was subjected to fluorescent light. For instance, iridescent film material that blocked certain wavelengths of light was not very effective at preventing the off-flavour. Only aluminium foil was effective at blocking all UV and visible wavelengths of light and at preventing the off-flavour. Hexanal, pentanal and heptanal concentrations in milk increased, and riboflavin concentration decreased, in all packaging scenarios except when glass bottles were overwrapped with aluminium foil (Webster et al. 2009). In recent years, pigments (including but not limited to titanium dioxide) have been added to HDPE milk packaging to slow the oxidation process. Similar to what Webster et al. (2009) showed, the tinted cartons only slow milk oxidation, rather than completely preventing it. Paperboard cartons do not permit light penetration of the cartons.

The metal-oxidized off-flavour is similar to light oxidized, with an added 'tingling' or 'prickly' sensation on the tongue. Some have described the aftertaste as similar to blood (after losing a tooth). One may recognize the flavour by rubbing a bunch of copper pennies in the hands, then sniffing. Reactive metals, including copper, iron and manganese, catalyse autoxidation by way of free radical formation, autoxidation of unsaturated fatty acids in milk and production of aldehydes, ketones and other offensive off-flavours. Metal-induced oxidation is not as common today as it was in previous decades because most copper has been replaced with stainless steel. However, the presence of reactive metals in hot water used for diluting cleansers and sanitizers for dairy equipment can cause the off-flavour. Metal-induced oxidation can also result from an imbalance of minerals in the cows' diet. This happened to an Idaho farmer, in reality, in 2005. Processed milk, as well as raw milk directly from animals, tasted extremely metal-oxidized. Upon copper analysis, raw hand-milked milk measured 2.64 mg/L copper, though raw milk copper is supposed to be approximately 0.02 mg/L (Lopez et al. 1985). Although no feed or mineral ration changes were made by the farmer, calculation errors were made by the nutritional supplement supplier such that the nutritional supplement had 702 ppm copper and 2468 ppm iron; they should have been 285 ppm copper and 190 ppm iron. After the farmer obtained a properly balanced mineral ration from a new supplier, the cows produced more milk, milk flavor improved, and reproductive problems were rectified.

Spontaneous oxidation is a general term used to describe an oxidized off-flavour that tastes like a cross between light-induced and metal-induced oxidation, resulting from unknown source(s). Milk neither exposed to reactive metals nor light, which tastes oxidized within a few days of production, is called spontaneous oxidized. Cow diet, seasonal changes and/or lack of balance between pro- and anti-oxidants in milk may be involved in spontaneous oxidation but no single source has been conclusively implicated (Granelli et al. 1998; Havemose et al. 2006; Juhlin et al. 2010; Testroet et al. 2015).

The salty taste is noted typically, though not exclusively, on the tip and sides of the tongue and can provide a warming sensation. Although milk naturally contains a number of salts (Table 1), milk is not perceived as 'salty' unless there is a breakdown of

**Table 4** Off-flavours in milk, along with descriptions, causes and remedies

Off-flavour	Description	Cause	Remedy
Absorbed	Barny	Faecal aroma, unclean flavour.	Poorly maintained barn aromas transmitted to milk by cows inhaling air laden with volatile compounds characteristic of a barnyard.
	Cow	An unpleasant medicinal odour and/or chemical aftertaste.	Accumulation of ketone bodies in milk; a sign of physiological malfunction in cows (acetonaemia/ketosis).
	Feed	Aroma and/or flavour and/or aftertaste of alfalfa, grass, corn silage, molasses or herbs.	Aromatic compounds in feed are transmitted to milk.
	Garlic/onion	Aroma and/or flavour and/or aftertaste of garlic or onions.	Aromatic compounds absorbed into milk after cows consume wild garlic or onions.
	Lacks freshness	Milk tastes 'stale'.	Storage of milk next to cut/chopped onions or garlic in refrigerator. Milk may have absorbed flavours from foods (e.g., green peppers) in refrigerator. A bacterial cause may also be at work (i.e., psychrotrophic bacteria).
Bacterial	Acid/sour	Acid/sour is a basic taste and may be experienced as a tingling sensation on the sides of the tongue.	LAB convert lactose to lactic acid at warm temperatures (>10°C/50°F). A buttery aromatic component is notable if diacetyl is also produced by the bacteria. Post-pasteurization contamination is the primary cause of sour/acid milk today.
	Fruity/fermented	The fruity/fermented aroma may be like apples, sauerkraut, pineapples, strawberries, etc.	Certain psychrotrophic bacteria (e.g. <i>Pseudomonas fragi</i> ), produce volatile compounds, including ethanol, coupled with enzymatic action upon lipids during extended storage.
	Malty	The malty aroma resembles Grape Nuts® or other malted grain-based cereal.	Contact with improperly sanitized equipment contaminated with <i>Lactococcus lactis</i> ssp. <i>maltigenes</i> followed by temperature abuse (18°C).
	Unclean	A lingering unpleasant aftertaste that may involve multiple off-flavours/aromas.	High numbers of heat-tolerant psychrotrophic microorganisms are transferred into milk from unclean equipment/utensils, multiply and produce off-flavours with storage.

Bacterial/chemical	<p><b>Bitter</b> Bitter is a basic taste and yields a somewhat numbing sensation on the back of the tongue.</p> <p><b>Rancid (hydrolytic)</b> May smell like baby vomit, a male goat, or Romano or feta cheese. The flavour may seem unclear, and lingers.</p>	<p>Protein degradation (proteolysis) by enzymes (proteases) generates bitter peptides and amino acids. The natural heat-stable plasmin system in milk generates bitter peptides and amino acids with extended storage. Spore-forming psychrotrophic bacteria (grow at 7°C) endure pasteurization and their enzymes cause bitterness, especially with extended storage. Weeds in cows' diet may also impart bitterness.</p> <p>Hydrolysis of aromatic fatty acids (butyric, caproic, caprylic, capric lauric acids) by the enzyme lipase, which is naturally present in milk and can be microbially derived. Lipase is inactivated by pasteurization. However, overly rapid cooling, excessive agitation or homogenization before pasteurization disrupt the protective milk fat globule membrane, increasing susceptibility to rancidity.</p>	<p>Ensure proper cleaning and sanitizing to minimize the number of proteolytic microorganisms.</p> <p>Handle milk carefully, avoiding over-agitating and homogenization of raw milk. Do not mix raw milk into homogenized milk.</p>
Chemical	<p><b>Cooked</b> A somewhat nutty, custard-like (cooked eggs) aroma and mildly sweet taste. Excessive heating can lead to burnt hair or burnt feathers aroma.</p> <p><b>Oxidized, light-induced</b> Milk oxidized by light may smell/taste like wet cardboard, wet paper or even cooked cabbage.</p> <p><b>Oxidized, metal-induced</b> Milk oxidized by metal may smell/taste like a copper penny.</p> <p><b>Oxidized, spontaneous</b> Tastes like a combination of light- and metal-induced oxidation, but of different origin.</p> <p><b>Salty</b> Salty is a basic taste experienced on the front and sides of tongue.</p>	<p>Heating milk above standard pasteurization temperatures. Sulphide compounds may arise with excessive heating (UHT pasteurization may yield scorched off-flavour).</p> <p>Sunlight/UV light exposure leads to breakdown of sulphur-containing proteins or lipid oxidation (autooxidation). Aldehydes and/or ketones are formed.</p> <p>Oxidation of unsaturated fatty acids occurs after contact with copper or other metals.</p> <p>The source is not completely understood, but it appears to be diet related. A combination of high polyunsaturated fatty acids and low vitamins A and E have been implicated.</p> <p>May be present in the milk of cows with mastitis or in late lactation because of the increase of milk secretion cell (alveoli) membrane permeability.</p>	<p>Process milk at the recommended time/temperature combinations to ensure safety and desired shelf-life.</p> <p>Package milk in containers that block light (paperboard). Tinted plastic packaging only partially blocks light, to slow oxidation.</p> <p>Prevent milk from contacting copper and/or other unprotected metals.</p> <p>Avoid drastic changes to cow diet, milk foaming or extremes in temperature.</p> <p>Properly treat cows exhibiting mastitis and follow withholding times before introducing their milk to the bulk tank.</p>
Delinquency	<p><b>Flat</b> Flat milk lacks creamy aroma or full-bodied flavour.</p> <p><b>Foreign</b> The foreign term is used when milk had an odour or flavour not associated with pure milk.</p>	<p>Adulteration of milk with water will dilute the full-bodied flavour of milk.</p> <p>The defect may result from contamination of milk with chemical sanitizers, detergents, medications, etc. Using the wrong packaging (2% milk) on a flavoured milk line (vanilla milk) would be another example. Use of poor-quality vitamin solution can yield a foreign off-flavour.</p>	<p>Prevent adulteration of milk with water. Run a cryoscope (freezing point) analysis regularly.</p> <p>Properly drain holding tanks of water, cleanser and sanitizer before use. Be alert to line changes to ensure proper packaging.</p>



the semipermeable membrane that maintains a salt balance between blood and milk. If a cow has mastitis, the semipermeable membrane becomes more permeable to salt, and the composition of salt ions in milk increases. Salty is a rare defect in commercial milk because cows with mastitis are generally caught and treated, and their milk is not commingled in the bulk tank.

### 3.5 Delinquency

Flat is essentially a lack of aroma/flavour. Upon smelling, the milk may lack the expected fatty aroma; upon tasting, the milk may seem 'watered down'. Flat results from two sources: added water or reduced fat. Because fat provides good flavour to milk, 1% and non-fat milk taste 'flat' compared with 2% and whole milk – that is expected. Flat is only a concern if it results from added water. Leaving rinse water in a bulk tank or a line will yield flat milk. Some processing plants test milk for added water, using a cryoscope, before off-loading milk from tankers.

Similar to flat, the foreign off-flavour is a result of delinquency by someone at the farm or in the processing plant. Foreign is a catch-all term to describe any off-flavour that can be explained by any foreign object or chemical that is not supposed to be in milk. An exception would be vitamins, as vitamins A and D are permissible for addition to whole milk, and required for reduced fat, low-fat and fat-free milk. The foreign 'vitamins' flavour can be described as tasting like carrots. A 'fishy' off-flavour can result from incorporation of omega-three fatty acids into milk. A chlorine or iodine flavour can result from the misuse of sanitizers (improper drainage). A plastic off-flavour could result from spent gaskets running through a line. It is even possible that white milk may have a vanilla or coffee or other flavour if someone forgot to switch out the packaging on the line.

### 3.6 Summary of off-flavours, their causes and their remedies

Table 4 provides a detailed summary of the defects associated with the different categories of off-flavours, along with how to diagnose and prevent the occurrence of such off-flavours.

## 4 Sensory shelf-life testing

The code dates printed on the top of milk cartons are not arbitrary; they are selected by individual companies within a confidence interval of assurance that the milk will taste good through that date. Unfortunately, many consumers interpret 'best by', 'best if used by' and 'sell by' dates as 'expiration' dates, and assume, wrongly, that milk will taste bad, or harm them on that date. By definition, the code date signifies the last date at which the product can be sold for full price. In practice, many stores remove products from shelves within a week of that date, especially for refrigerated products. Sadly, most of those products enter the waste stream.

The shelf-life of any milk is dictated partially by microbial quality and partially by enzyme activity, which are influenced by cow and season, raw milk quality, processing conditions, packaging materials, temperature abuse and exposure to light. While milk with low

microbial counts may have limited shelf-life if enzyme activity is high, milk with poor initial microbial quality will only get worse with time.

For decades, a number of raw milk tests, including the somatic cell count, standard plate count, ropy milk test, coliform count, Gram-negative non-coliform count, laboratory pasteurization count, preliminary incubation count, coagulase-negative staphylococcal count, environmental streptococcal count, direct microscopic count, psychrotrophic/psychrophilic or spore pasteurization count, bioluminescence, impedance microbiology, limulus amoebocyte lysate, direct reflectance colorimetry, Virginia Tech shelf-life procedure and the Moseley keeping quality test, have been used to help predict milk shelf-life (White 1993). Jayarao et al. (2004), who conducted somatic cell count and 10 different bacterial counts, showed that such tests could serve as indicators of, and facilitate monitoring of, herd udder health and milk quality. They showed that dairy herds that used automatic milking detachers, sand as bedding material, dip cups for teat dipping instead of spraying and practiced pre- and post-dipping had significantly lower bulk tank and/or bacterial counts (Jayarao et al. 2004). Later, Miller and colleagues (2015) sampled bulk tank milk from 33 farms in New York every month for one year. They reported that low mesophilic spore levels were associated with large herd size, use of sawdust or sand bedding, and not fore-stripping during the pre-milking routine; low thermophilic spore levels were associated with large herd size, use of straw bedding, spray-based application of the post-milking disinfectant and dry massaging the udder during the pre-milking routine (Miller et al. 2015). However, the reader is cautioned that raw milk tests do not always effectively predict the sensory or microbiological shelf-life performance of commercially pasteurized fluid milk (Martin et al. 2011), and should be accompanied with sensory quality evaluation.

Pasteurized milk microbial testing is routinely conducted. Not only is testing required for Grade 'A' milk, with clear bacterial limits (<20000 total aerobic bacteria per mL and <10 coliform bacteria per mL), but microbial counts can be indicative of contamination at various stages in the milk collection and processing stream. In a study to characterize spoilage bacteria in pasteurized milk collected from three commercial dairy plants, Fromm and Boor (2004) identified the predominant spoilage microorganisms as Gram-positive, heat-resistant, psychrotrophic rods including *Paenibacillus*, *Bacillus* and *Microbacterium* species, which caused undesirable flavours in milk. Ranieri and Boor (2009) obtained pasteurized 2% milk from 18 dairy plants from 5 geographical regions of the United States and characterized 589 bacterial isolates with DNA-sequence-based subtyping methods. More than 58% of the isolates were Gram-positive spore-forming isolates; 84% of those characterized within 10 days of production were of the genus *Bacillus*; and more than 92% of isolates characterized at 17 days of shelf-life were of the genus *Paenibacillus*. Similarly, Martin et al. (2011) characterized isolates from pasteurized milk of four New York State processing plants over a 1-year period into three predominant genera: *Pseudomonas*, *Bacillus* and *Paenibacillus*. Most recently (Ivy et al. 2012), out of 1288 isolates obtained from raw and pasteurized milk and from dairy farm environments, two major clusters predominated: the genus *Paenibacillus* (737 isolates, including the species *Paenibacillus odorifer*, *Paenibacillus graminis* and *Paenibacillus amylolyticus*) and *Bacillus* (467 isolates, including *Bacillus licheniformis*, *Bacillus pumilus* and *Bacillus weihenstephanensis*). These microorganisms, which survive pasteurization and are psychrotolerant, are associated with a variety of bacterial off-flavours, including bitter, fruity/fermented, rancid and unclean. Control strategies to reduce the introduction of these microorganisms will be essential to increase the shelf-life of milk.

To complicate matters, contrary to what might be expected, reduction of pasteurization temperature leads to lower bacterial outgrowth in pasteurized fluid milk during refrigerated storage. Martin et al. (2012) enumerated bacteria in HTST commercially pasteurized fluid milk over refrigerated shelf-life. Milk was pasteurized at 79.4°C for 15 months, followed by 15 months at 76.1°C. Mean total bacterial counts were significantly lower immediately after processing and after 21 days of storage in samples pasteurized at 76.1°C than those pasteurized at 79.4°C. Additionally, bacterial growth was lower throughout shelf-life for products pasteurized at the lower temperature. The authors hypothesized that at the higher temperature, lactoperoxidase (a naturally occurring enzyme in milk that is bacteriostatic against Gram-positive and Gram-negative bacteria) was inactivated at the higher temperature (Martin et al. 2012). No sensory evaluation of products was conducted to evaluate sensory shelf-life, but authors encouraged pasteurization at temperatures near the minimum specified by law.

Because raw and pasteurized milk microbiological testing are only indirect measures of milk quality, it is more appropriate to estimate and validate sensory shelf-life using actual sensory evaluation.

The sensory shelf-life of raw milk in the United States is typically close to seven days. Pasteurization kills all pathogenic bacteria and many spoilage bacteria, extending the shelf-life, but thermophilic spore-forming bacteria survive, and the plasmin enzyme system remains functional. The shelf-life of packaged LTLT or HTST pasteurized milk or pasteurized-homogenized milk in the United States is expected to be approximately 14–21 days. UP milk has a shelf-life of approximately 35–45 days, and UHT milk can last for approximately six to nine months on the unrefrigerated shelf before enzymatic breakdown (by the plasmin enzyme system) reduces the quality significantly.

While some companies select a code date based on these ranges, the more prudent behaviour is to conduct shelf-life studies in-house to confirm product shelf-life before product release. To properly set code date, companies must conduct at least three shelf-life studies on different lots of milk, on all products and all packaging types, to determine the mean time to failure for each product. Sufficient numbers of unopened packages of products must be stored, at one or more temperatures (e.g., 4°C and/or 6°C and/or 8°C), and evaluated on the expected code date (e.g., 21 or 35 days) and one week beyond the expected code date (e.g., 28 or 42 days) to confirm the quality is acceptable for seven days beyond the printed code. When initially selecting the proper code date, milk may be tasted on several days around the predicted code date (e.g., days 18, 21, 24, 27, 30 and 33), in order to properly select the appropriate code date. This necessitates storage of a lot of milk initially, but helps producers select a proper code date. Two negative consequences necessitate careful selection of code date: if shelf-life is set too short, companies will lose money in unsold product; if shelf-life is set too long, companies will lose customers in rejected product and lost future sales. Consider the two scenarios in boxes.

Staff must be effectively trained to recognize off-flavours, tolerance for severity of off-flavours must be agreed upon, and point of failure must be clearly defined by the company before conducting tests in order to set and confirm the appropriate code date to maximize shelf-life and limit customer complaints. Along with trained staff, untrained consumers are sometimes recruited to help determine product shelf-life. Using a combination of trained panelists and consumers, Richards et al. (2014) utilized multivariate accelerated shelf-life test to show how high temperature storage negatively affected shelf-life of low-fat UHT milk. While the shelf-life of UHT milk was 211 days at

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## Milk shelf-life scenario 1

### Description:

To be conservative, and to ensure the highest quality of milk for all consumers, Amy's Dairy sets the code date of 2% milk at 14 days. As per order, 100 cartons of 2% milk are delivered to Hal's Grocery, two days after production. Hal's Grocery staff are directed to pull all unsold product off the shelf within four days of the code. On that day, 20 are shipped back to Amy's Dairy, and discarded.

### Interpretation/consequence:

Customers of Hal's Grocery only have a window of eight days to buy Amy's Dairy milk. Amy's Dairy loses money in discarded product. Staff at Hal's Grocery may decide they made a mistake in purchasing 100 cartons and order 80 for subsequent shipments. Thus, that is loss in product (waste) and loss in potential future revenue for Amy's Dairy.

### Lesson:

If the staff at Amy's Dairy conducted a sensory shelf-life study and discovered product quality was high for 28 days, a 21-day code would be appropriate. With 15 days in which to buy the Amy's Dairy milk, perhaps 20 more cartons could sell, which would align the order by Hal's Grocery with the sales, reduce waste and contribute positively to Amy's Dairy' revenue.

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## Milk shelf-life scenario 2

### Description:

A new processor, DariFresh sets the shelf life of their ultra-filtered pasteurized milk at 40 days. On day 35, customer complaints start coming into the grocery store and the company hotline.

### Interpretation/consequence:

The shelf life of the milk is closer to 30 days than 40 days. Customers have many products to select from and may turn away from DariFresh for a short time, or worse, permanently, because of their bad sensory experience.

### Lesson:

DariFresh should have conducted in-house sensory shelf-life tests to select the appropriate code date that is neither too long nor too short.

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25°C, it was shortened to 73 (+/-3) and 27 (+/-3) days when stored at 35°C and 45°C, respectively (Richards et al. 2014).

In addition to conducting an in-house study before setting code dates on packages, prudent companies also track product quality throughout shelf-life. Whether setting or confirming shelf-life to conduct a sensory shelf-life study, unopened cartons are pulled

from the production line(s) and are held in one or more refrigerated cases (e.g., 4°C and/or 6°C and/or 8°C and/or 10°C). While 4°C is an appropriate milk storage temperature to maximize shelf-life, it is not very reflective of the average temperature that milk experiences during its shelf-life. A temperature between 6°C and 8°C is more reflective of home refrigerator temperatures or the average temperature milk experiences during shelf-life. A temperature of 10°C is abusive, and hopefully not reflective of home refrigerators, but may reflect the kind of abuse milk undergoes short-term at points during shelf-life; 10°C storage in-house would cause accelerated spoilage of milk. By holding milk at an elevated temperature, the dairy plant, with scheduled sensory evaluation, discovery that a product may not taste good through the code date can be caught before customer complaints occur. Such a discovery may enable a company to proactively pull a product, or put a product 'on sale' to flush that product out of stores more rapidly than if at full price.

In the scenario summarized in Table 5 (and used for sensory shelf-life case studies 1 and 2), a fictional company makes three kinds of products: whole, 2% and skim milk, processed daily in that order. Incoming raw milk is separated, standardized and simultaneously pumped to two different processing and filler lines: one for HTST gallon HDPE containers and one for UP quart-sized paperboard cartons. The gallon size of each product is most popular; they sell faster, so HTST pasteurization is appropriate. The quarts sell more slowly; a longer shelf-life is desired, so UP is used. In this scenario, the company

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## Sensory shelf-life case study 1

### Description:

A trained QA/QC staff member evaluated milk samples stored according to the scheme in Table 5. All samples were criticism-free on day 14. However, by day 21, when HTST products were evaluated, all tasted slightly fruity/fermented.

### Interpretation:

The off-flavour should be verified by at least one other trained staff member. The off-flavour is indicative of the presence of high numbers of psychrotrophic bacteria, which suggests cleaning/sanitation issues either at the farm and/or processing facility. The type of microorganisms responsible for the off-flavour can be verified with plating of milk samples. Improving sanitation practices at one or both places may be necessary.

### Response:

Plant personnel should be notified that a milk quality problem has been encountered and measures should be taken to immediately remedy the situation so milk spoilage is not propagated in subsequent batches. Since the milk is already in stores, a decision has to be made on how to handle that milk. Because no off-flavour was noted in the same milk stored for 14 days, and the off-flavour was only slight in milk stored at 8°C for 21 days, putting the milk on sale is an option. Removing remaining milk from stores may be an appropriate response, to avoid losing repeat customers. Since the same milk was used to make the UP products (though the processing temperature was higher for UP), UP products should also be placed on sale or removed from stores.

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## Sensory shelf-life case study 2

### Description:

A trained QA/QC staff member evaluated milk samples stored according to the scheme in Table 5. All milks, evaluated through day 14, were criticism-free. On day 21, the milk in gallon containers received no criticism. However, when the UP paperboard quart containers were evaluated on day 21, all tasted slightly acid/sour. A second trained staff member confirmed the defect.

### Interpretation:

Because LAB are responsible for the acid/sour defect, and LAB are killed by pasteurization, the off-flavour is indicative of post-pasteurization contamination. Since the defect was only noted in milk packaged in paperboard cartons, it suggests cleaning/sanitation issues at the filler. The source of the problem can be verified with equipment swabbing and microbiological plating.

### Response:

Measures should be taken to immediately remedy the situation. Both production lines should be swabbed to confirm if LAB contamination is isolated to one line. Because no off-flavour was noted in the same milk stored for 21 days, and the off-flavour was only slight in milk stored for 21 days, putting milk on sale is a good option. Removing remaining milk from stores may be an appropriate response, to avoid losing repeat customers.

**Table 5** Example sensory shelf-life evaluation scheme for a fictional company that produced whole milk, 2% milk and skim milk processed with high temperature short time (HTST) or ultra-pasteurization (UP)

Product	Predicted shelf-life	Evaluation days for samples stored at 8°C
Whole milk HDPE gallon (HTST)	21	14, 21
Whole milk paperboard quart (UP)	35	21, 28, 35
2% milk HDPE gallon (HTST)	21	14, 21
2% milk paperboard quart (UP)	35	21, 28, 35
Skim milk HDPE gallon (HTST)	21	14, 21
Skim milk paperboard quart (UP)	35	21, 28, 35

predicts a 21-day shelf-life for the HTST milk. They hold three unopened containers, from the end of each production run, in storage at 8°C. For the UP milk, the company predicts a 35-day shelf-life. Similarly, four containers are stored at 8°C. For the container types, the evaluation schedule differs, such that HTST products are evaluated on days 14 and 21 and the UP milk samples are evaluated on days 21, 28 and 35.

Obviously, the scheme outlined in Table 5 is not feasible for all milk-processing facilities. In this scenario, with only six products produced at a facility, quality control/quality

assurance staff would open and evaluate three cartons on days 14, 28 and 35, and six on day 21, not including the other lots of milk that would also need tasting on the same days. The scheme can be modified to meet the needs of any given facility. For instance, milk can be evaluated less frequently. The important point is that every facility must routinely evaluate products to ensure consistent, high quality to consumers.

## 5 Conclusion

Providing safe, wholesome, high-quality milk to consumers is an immense responsibility. One of nature's most perfect foods, milk is a source of nine essential nutrients to humans. It also serves as a great growth medium for bacteria and is susceptible to breakdown by native enzymes. Any miss-step in milk handling, from cow to consumer, contributes to reducing the quality of milk. Although microbiological and chemical tests have been and will continue to be utilized to help predict and track milk quality, ultimately, sensory evaluation is key – consumers will be the ultimate judges and they will adjudicate with their money. As milk producers and processors, it is our job to practice care at every step and understand how to guarantee the best tasting products in order to ensure milk's consumption in future generations.

## 6 Where to look for further information

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