

Flavor description and classification of selected natural cheeses

Delores H. Chambers¹, Edgar Chambers IV¹ and Dallas Johnson²

¹*The Sensory Analysis Center, Department of Human Nutrition, Kansas State University, Justin Hall, Manhattan, KS 66506-1407, USA*

²*Department of Statistics, Kansas State University, Dickens Hall, Manhattan, KS 66506, USA*

Abstract

Intensities of 30 flavor attributes were measured for 42 cheeses. Rated intensities of flavor characteristics generally fell in the low to moderate range for all cheeses. Some of the flavor characteristics (dairy fat, dairy sour, dairy sweet, sharp, astringent, bitter, salty, sour, and sweet) were present in all cheeses, and some (cooked milk, animalic, goaty, fruity, moldy, mushroom, and nutty) were specific to only a few of the cheeses evaluated in this study. The flavor of each of the 42 cheeses is described. Similarities in flavor were observed among many of the individual cheeses. Therefore, a clustering scheme was developed to show the overall flavor relationships among the cheeses. Those relationships are schematically represented by a tree diagram. Proximity on the tree diagram indicates a high degree of flavor similarity among the types of cheese.

Introduction

In most countries, consumption of cheese has been on the rise over the past decades (Richards, 1989; Magretti, 1996; Havrila, 1997; Hoeberrmann, 1997; Anonymous, 2002). Increasing evidence exists between the positive relationship of calcium consumption and prevention of disease such as osteoporosis (McBean, 1998). In addition, the increased availability and appreciation of specialty cheeses by those individuals willing to expand their culinary horizons (Meehan & Cowan, 1998) has increased consumption of these types of products, along with the more common domestic cheeses. Differentiation of one cheese type from another has thus assumed more importance, both from the consumer perspective and from the marketing/manufacturing perspective, as each manufacturer seeks to distinguish his product from others in reliable ways, as well as to increase the quality and uniformity of the product.

Considerable research on the chemical composition of cheese has been conducted in recent years (Aston and Creamer, 1986; Barlow *et al* 1989; Biede and Hammond, 1979a; Rothe *et al*, 1982; Vangtal and Hammond, 1986). However, authors have been largely unsuccessful in correlating sensory characteristics with the chemicals that are found in various types of cheese. Biede and Hammond (1979b) suggested that this failure to correlate cheese composition with flavor notes resulted from interactions between chemicals which could affect the flavors. Mulder (1952) theorized that "cheese" flavor did not result from one chemical, but from a unique combination of chemicals at specific concentrations. Paulsen *et al* (1980) suggested that sensory flavor terms, at least those

used in their study, were too limited to represent cheese flavor comprehensively. Heisserer and Chambers (1993) attempted to overcome the deficit in sensory description by establishing 30 defined and referenced sensory flavor descriptors for cheese.

Over 2,000 natural cheeses have been named and identified (Pearl *et al*, 1978), including "original" cheeses, as well as "imitations" of originals. Establishing suitable criteria for cheese classification is difficult because of the wide variety of cheeses (Pearl *et al*, 1978) as well as the differences among the various types of cheese (Kosikowski, 1982). Methods of classification include systems based on method of processing, consistency (e.g., hard or soft cheeses), and country of origin (Davis, 1965; Pearl *et al*, 1978); general appearance, chemical analysis (Carpino *et al*, 2002; Salles *et al*, 2002), microbiological properties (Davis, 1965), and milk source used for manufacture (National Dairy Council, 1986).

Specialty cheeses may have unique flavor properties, but they still have some flavor characteristics that are common to all cheeses. White and White (1991) described, in general terms, the flavors of 50 cheeses, but did not develop detailed flavor descriptions or attempt to establish a classification scheme based on those flavor properties. Murray and Delahunty (2000) described a system for Cheddar cheeses. The problem with many classification schemes is that they give little information about flavor. For example, classification based on moisture allows very different cheeses such as Romano and Stilton or Mozzarella and Limburger to be classified in the same category. A classification group called "mold-ripened" consists of Brie and Camembert, as well as Roquefort and Gorgonzola, with the pairs having few flavor or textural characteristics in common. Classification based on milk source presents the same problem; "Lite" Cheddar is very different from "Lite" Swiss, yet both are made from part skim cow's milk.

The purposes of this study were to 1) characterize the flavor of a wide variety of natural cheeses using well-defined sensory flavor descriptors and 2) develop a classification scheme for cheeses based on their flavor properties.

Materials and Methods

Samples

Forty-two cheeses were selected to represent various milk sources, countries of origin, and a range of fat, moisture, and microbial ripening properties (Table 1). All cheese samples were received and stored at 4°C for less than 6 weeks prior to assessment.

Panelists

Professional panelists of The Sensory Analysis Center at Kansas State University (Manhattan, KS) participated in this study. The five highly trained, experienced panelists had completed 120 hr of training in sensory analysis, had a minimum of 1000 hr of general sensory testing, and had experience testing dairy products.

Table 1. Cheese varieties, abbreviation, country of origin, milk source, and fat and moisture contents.

Cheese	Country	Milk Source	Percent Fat	Percent Moisture
Asiago	Italy	Cow	31.4	33.1
Bel Paese	United States	Cow	30.0	43.3
Blue Cheese	Denmark	Cow	30.0	51.5
Blue Cheese	United States	Cow	30.2	49.2
Bond-ost	United States	Cow	32.1	42.2
Brick	United States	Cow	32.6	40.5
Brie	France	Cow	32.8	50.4
Butter Cheese	West Germany	Cow	27.9	44.0
Camembert	Austria	Cow	24.5	52.6
Cheddar-Lite	United States	Cow (part skim)	19.9	46.8
Cheddar-Mild	United States	Cow	31.4	38.8
Cheddar-Mild Longhorn	United States	Cow	33.1	37.7
Cheddar-New York	United States	Cow	32.8	40.1
Cheddar-Sharp	United States	Cow	34.9	36.0
Cheddar-Vintage	United States	Cow	33.2	37.5
Chevre	France	Goat	20.1	57.4
Colby	United States	Cow	30.9	41.9
Danish Cream Havarti	Denmark	Cow	36.2	39.2
Edam	Holland	Cow	27.0	41.1
Emmentaler	Switzerland	Cow	31.9	35.9
Feta	Greece	Sheep	19.6	58.0
Fontina	Sweden	Cow	29.6	39.4
Gorgonzola	United States	Cow	30.8	53.5
Gouda	Holland	Cow	30.9	39.0
Gruyere	Switzerland	Cow	34.0	35.2
Jarlesburg	Norway	Cow	29.4	42.0
Kreme Kase-Lite	Denmark	Cow (part skim)	18.3	47.8
Limburger	West Germany	Cow	22.1	49.9
Manchego	Spain	Sheep	40.3	27.5
Monterey Jack	United States	Cow	32.7	41.4
Mozzarella	Italy	Buffalo	24.9	60.8
Mozzarella	Italy	Cow	26.4	46.6
Mozzarella	United States	Cow (part skim)	21.9	44.1
Parmesan	Italy	Cow	31.4	26.2
Port du Salut	France	Cow	23.4	48.4
Provolone	Italy	Cow	27.9	45.2
Romano	Italy	Cow	32.1	31.2
Roquefort	France	Sheep	32.1	36.6
Sap Sago	Switzerland	Cow (skim)	2.3	48.6
Stilton	England	Cow	32.9	39.4
Swiss	United States	Cow (part skim)	33.2	39.1
Swiss-Lite	United States	Cow (part skim)	19.3	43.7

Preparation and test procedures

General preparation of cheeses for flavor testing was described by Heisserer and Chambers (1993). Kosikowski (1982) suggested that cheese was at its optimal flavor at 21°C; thus cheeses were tested at room temperature. Samples, labeled with 3-digit codes, were served to panelists in individual booths. Panelists scored the intensity of flavor descriptors (30 attributes) present in each cheese on a 15-point numerical scale with half-point increments, from 0="none" to 15="extremely strong". Four replicate judgments

were made. A completely randomized design was used to determine the serving order for each cheese during testing sessions, with approximately 11 cheeses analyzed per session.

Association of Official Analytical Chemists (AOAC, 1984) procedures were used to determine the percentage moisture in four replicate samples. Fat content was determined using a modified Babcock method (Wilster, 1969) on triplicate samples.

Statistical Analysis

Analysis of variance and average linkage cluster analysis were conducted using SASTM software (SASTM version 8.0, SAS Institute, 1999, Cary, North Carolina, USA).. Mean attribute ratings for each cheese were used for cluster analysis. A tree diagram as suggested by Munoz and Chambers (1996) and used by Prell and Sawyer (1988) showing the interrelationships among the various cheeses was developed from cluster analysis. A similar procedure has been used to classify saltwater fish based on their flavor characteristics (Prell and Sawyer, 1988).

Results and Discussion

Flavor characteristics of cheese

Some flavor attributes were common to all cheeses. For example, dairy-related attributes (dairy fat, dairy sour, and dairy sweet), fundamental tastes (bitter, salty, sour, and sweet), and sharp and astringent were found in every type of cheese tested. The intensity of each attribute was substantially different depending on cheese type, and ranged from barely detectable to moderately intense.

Some attributes, such as buttery, butyric acid, and waxy were found in most of the cheese types. In general, those attributes all had low intensities. Several attributes were specific to only a few types of cheese. For example, cooked milk character was found only in Brie, Camembert, and Limburger. Animalic, decaying animal, fermented fruity/winey, fish oil, fruity, moldy, mushroom, pineapple, sauerkraut, soy sauce, and sweaty were found in only a few cheeses and usually were the most characteristic notes in each specific cheese. Attributes such as goaty, nutty, biting, and pungent were present in approximately half of the cheese types. Scores for the various flavor attributes defined the intensity of the character of each cheese. Descriptions are representative of the cheese type, but may not exactly define each individual cheese of that type, depending on differences in brand, maturation, production method, or storage conditions.

Asiago: had some of the highest "dairy" characteristics and was one of the most butyric of all cheeses tested, even though it was rated as only slightly butyric. Asiago was one of the sweetest cheeses, had some of the highest sourness, and was perceptibly fruity and nutty.

Bel Paese: was moderately buttery and dairy fat-like, with a slight butyric note. It had a detectable sweetness and had the lowest saltiness scores of all cheeses studied. Ratings for other attributes found in this cheese were primarily mid-range for all cheeses tested. White and White (1991) described Bel Paese as acidic and creamy, but indicated that the flavor was similar to sweaty feet rather than butyric.

Blue Cheese (Danish): had among the highest dairy fat, dairy sour, moldy, sharp, astringent, bitter, salty, and sour characteristics of all the cheeses in this study. A slight sweaty flavor was evident, one that was found in only a few other cheeses. Animalic, goaty, nutty, biting, and pungent notes were detected by the panelists, although the intensities were slight. White and White (1991) indicated that methyl ketones were responsible for the fruity character of this type of cheese.

Blue Cheese (United States) was a sharp, moldy, dairy fat-like cheese. Like Danish Blue,

it was higher than most cheeses in bitter, salty, and sour attributes. It also had perceptible nutty, mushroom, fermented fruity/winey, animalic, biting, and pungent notes.

Bond-ost: was high in dairy notes: buttery, dairy fat, and dairy sweet. It had among the least intense ratings for sourness, astringency, and butyric acid-like character of any of the cheeses. More than most other cheeses, it was characterized by the lack of, rather than the presence of, certain flavor characteristics.

Brick: ratings for Brick were among the highest of all cheeses tested for dairy flavor notes of buttery, dairy fat, and dairy sweet. Brick cheese was one of the nuttiest and waxiest cheeses, although those attributes were slight in intensity. Mouthfeeling attributes of sharp, astringent, biting, and pungent were less intense for Brick than for most other cheeses tested.

Brie: was characterized by its mushroom, moldy, and dairy sweet attributes. Brie also had a slightly nutty and a cooked milk note that was found in only two other cheeses. Brie was more bitter and more pungent than most cheeses. It exhibited very slight animalic and goatly attributes, as well, and was in the group of cheeses with low scores for attributes such as sour, salty, and sharp. Brie was similarly described by White and White (1991) as creamy, nutty, and mushroom-like, with a slight acidic note.

Butter Cheese: had among the highest scores for dairy attributes such as buttery and dairy fat. This cheese was not sweet and had more sour character than most other cheeses with high dairy notes. It also had a slight, but perceptible, nuttiness.

Camembert: like Brie, Camembert was characterized as a dairy sweet, mushroom-like, and moldy flavored cheese. Also like Brie, it had a cooked milk flavor, but its slight fish oil flavor was unique. It had a slight nutty character, with goatly and animalic notes. White and White (1991) described Camembert as similar in flavor to Brie.

Cheddar "Lite": had mid-range ratings for most of the attributes detected, such as the dairy attributes (buttery, dairy sweet, and dairy sour), astringent, and sharp. As was the case with most cheddar cheese, dairy fat character was at the high end of the range for the cheeses studied here. Although mean values were not numerically the same, this cheese was not statistically significantly different from Mild Longhorn Cheddar for any flavor attribute.

Cheddar (Mild): had a higher buttery character and was rated lower in sharpness and astringency than any of the other cheddar cheeses. It had little sweet taste, but was in the middle range for the attributes sour, salty, bitter, butyric, and dairy sweet.

Cheddar (Mild Longhorn): had a high dairy fat note, and was rated significantly higher than mild cheddar for dairy sour, sour, astringent, and sharp attributes. As with the other Cheddars, Mild Longhorn Cheddar was only perceptibly sweet.

Cheddar (New York): was one of the least dairy-like of the Cheddar cheeses, although it was more dairy-like than many other cheeses. It had one of the highest scores for butyric and was the only Cheddar cheese that was scored significantly higher than zero for nuttiness. It had a higher score than most cheeses for astringent, but was only in the middle of the range of scores for sour and sharp attributes.

Cheddar (Sharp): contrary to its name, Sharp Cheddar was in the middle range of all cheeses for the attribute sharp. This cheese had higher intensities of dairy fat and sour than most cheeses, but was not different from most Cheddar types. The dairy attributes: buttery, dairy sweet and dairy sour were rated in the mid-range of cheeses, as were the astringent, sour, salty, and bitter.

Vintage Cheddar: this particular cheddar was aged for over 24 months, and was rated significantly higher than any other cheddar and most other cheeses for the attributes sharp and biting. Vintage Cheddar could be characterized as dairy-like, with sour and astringent

notes.

Chevre: was the only cheese in this study that was made from goat's milk. It had the highest goaty flavor and was rated among the highest for dairy sour flavor, sour taste, and astringency of all cheeses studied. Chevre had very low dairy flavor notes (other than dairy sour), and some of the lowest ratings for buttery, dairy fat, and dairy sweet notes of any cheese. Chevre was very low in waxy flavor, as well.

Colby: was similar in flavor to the Cheddar-type cheeses, and was rated high for dairy fat and dairy sweet attributes. Other attributes generally found in Cheddar were present in Colby at intensities in the middle of the range. Colby was sweeter than the Cheddar cheeses and was ranked in the mid-range of sweetness for all cheeses studied.

Danish Cream Havarti: was characterized by a significantly higher rating for butteriness than any other cheese in this study. It also had a slight nutty note and tended to have more sweetness than other cheeses. Other attributes, such as astringent, sour, and sharp, were in the mid-range for all cheeses in this study.

Edam: was moderately salty and moderately buttery, with a perceptible nutty character. White and White (1991) indicated that the brining treatment used in production of this cheese was responsible for the salty taste. Dairy attributes were mid-range, while Edam was rated higher than most of the other cheeses in waxiness.

Emmentaler: was characterized by its dairy sweet, pineapple, and waxy flavors. As with the other Swiss-type cheeses, it had a nutty flavor. White and White (1991) indicated that a nutty flavor was characteristic of a good Emmentaler. Bitter, salty, and sour tastes were low and sweetness was high in this cheese. Astringency and sharpness were rated low.

Feta: a cheese made from sheep's milk, had a unique sauerkraut flavor. Feta was one of the saltiest and sourest cheeses, which was not surprising, because it is a brined cheese. The intense dairy notes found in many other cheeses in this study were lacking in Feta cheese, and it had slight goaty, biting, and pungent flavors.

Fontina: in comparison with many of the other cheeses, Fontina was higher only in the dairy sweet attribute, while being slightly nutty and perceptibly goaty. The sharp and sour notes were rated within the low range of scores for all cheeses in this study.

Gorgonzola: was similar to other blue/green mold-ripened cheeses. It was moderately moldy, sharp, and salty. This description is similar to that of White and White (1991). Dairy characteristics were rated in the moderate range. Gorgonzola had a slight goaty note and, compared with other Blue cheeses, it was waxier, less biting, and pungent.

Gouda: was higher in the dairy attributes, especially the buttery note, than most other cheeses evaluated here. It was mid-range for other attributes common among other cheeses, except that Gouda had a higher butyric acid character than most. It also had a slight nutty character and a waxy note that was described previously by White and White (1991).

Gruyere: could be considered a sweet cheese; it was higher than most cheeses in both sweet taste and dairy sweet, and was low in bitterness. It also was one of the few cheese to have a pineapple note as well as a slight nutty note. A slight goaty character also was detected in this cheese. White and White (1991) indicated that certain Gruyeres may have a putrid character. Although the Gruyere in this study did not have a putrid note, it was slightly butyric-like.

Jarlesburg: was characterized by its slight fruity, nutty, and pineapple notes, and was rated statistically significantly higher than any other cheese for the sweet taste attribute. Most of the dairy-type notes were mid-range for all cheeses evaluated in this study. Jarlesburg cheese was rated lower than most for saltiness and sourness.

Kreme Kase "Lite": was not high in most flavor notes, compared with other cheeses. It

was mid-range for the dairy attributes, as well as other notes that were common to most cheeses. It did have a slight fruity, nutty character and was one of the few cheeses in which a fermented fruity/winey note was detected. Kreme Kase "Lite" also had one of the highest scores for waxy flavor, although this attribute was rated as low intensity.

Limburger: was different from all of the other cheeses included in this study. It was described as decaying animal-like, animalic, and as having a sweaty character. In fact, Limburger was rated significantly higher than any other cheese for the attributes of decaying animal, sweaty, bitter, and pungent. It also scored high for sharp and astringent notes in comparison with the other cheeses. Limburger was one of the cheeses (all white surface-mold ripened) that had the cooked milk attribute. This cheese was rated low for most of the dairy attributes, perhaps because they were dominated by the strong flavors characteristic of Limburger.

Manchego: a cheese made from sheep's milk, was higher in dairy sweet character than most of the cheeses studied, and was ranked mid-range for other dairy attributes. Manchego had a goaty character and was slightly nutty and pineapple-like, as well as being one of the waxiest, least bitter cheeses. This cheese was ranked mid-range for other taste characteristics.

Mozzarella (Buffalo): this Mozzarella, made from buffalo milk, was rated lower than most cheeses for dairy fat character, and was rated significantly lower than all other cheese for sharpness. Butyric acid, although slight, was more prominent in this cheese than most other cheeses. This Mozzarella was slightly waxy and scored lower than most cheeses for bitterness.

Mozzarella (Italian): had one of the highest scores for dairy sweet, sweet taste, and nutty attributes. It was one of the least dairy-like (other than dairy sweet) and was lower in butyric, sharp, and astringent notes than most cheeses.

Mozzarella (United States): the attributes of U.S. Mozzarella were almost all mid-range for all cheeses studied here. Scores for salty and sour attributes were lower than most and the cheese had a slightly nutty flavor. It was also rated low in astringency. U.S. Mozzarella was not characterized by any one particular attribute.

Monterey Jack: had a high buttery characteristic. It was ranked mid-range for sharpness, astringency, other dairy characteristics, and taste sensations. Monterey Jack also had a slight nuttiness.

Parmesan: had a complex flavor. Among the dairy attributes, it was low in buttery and dairy fat, scored in the middle of the range of all cheeses for dairy sour, and scored higher than most cheeses for dairy sweet and sweet taste. It had slight notes of animalic, nutty, pineapple, sweaty, biting, and pungent. It was goatier than most cheeses, although the intensity was low.

Port du Salut: in relation to many of the other cheeses, Port du Salut was rated high in buttery and several other dairy-type attributes, and was rated higher than most of the cheeses studied here for bitterness. Several attributes were present at only slight intensities, including animalic, goaty, and decaying animal.

Provolone: was significantly more butyric than any other cheese, as well as goatier than any other cheese, with the exception of Chevre and Stilton. Ratings were in the mid-range for cheeses studied here for the dairy attributes and for sharpness and astringency, but Provolone was rater more sour than many cheeses. Provolone usually has a smoky character, but this particular provolone was an unsmoked type.

Roquefort: was described as a moldy, sharp, salty cheese. This cheese had higher scores than most cheeses for dairy sour, sour, salty, bitter, astringent, and sharp attributes. Although some attributes were only slightly present, animalic, butyric acid, fermented

fruity/winey, goaty, mushroom, biting, and pungent did contribute to the overall flavor of the cheese. Roquefort was saltier than the other blue/green mold-ripened cheeses.

Romano: was low in dairy notes, especially buttery and dairy fat. It was one of the sharpest and most astringent cheeses evaluated. This cheese was characterized by attributes such as butyric, goaty, and biting that were not as common in many of the other cheeses. Romano cheese had slight animalic, sweaty, and pungent flavor notes as well. Salty and bitter attributes were rated higher than for many other cheeses in this study.

Sap Sago: was characterized by its unique soy sauce flavor. It also was significantly higher in animalic, biting, and astringent attributes than any other cheese. It was higher than all cheeses other than Limburger for sweaty and pungent notes and was one of two cheeses that were highest in the goaty attribute. Sap Sago was rated higher than most cheeses for bitterness and saltiness, as well.

Stilton: had higher dairy fat and dairy sour attributes and was at the low end of the range for buttery and dairy sweet attributes. This cheese could be characterized by its moldy, sharp, and sour attributes. Ratings for goaty, animalic, biting, and pungent attributes were at the high end, although they were only of slight intensity, of the range for all cheeses studied. Compared with other blue-type cheeses, Stilton was higher in animalic, goaty, and fermented fruity/winey characteristics and was slightly more moldy than most. White and White (1991) described Stilton as having a sharp, acetic, and slight bitter character. Those authors also indicated that it had a cowshed-like aroma, which may be similar to the animalic note in this study.

Swiss (United States): this cheese was a sweet, nutty, fruity cheese compared to most others in this study. It was in the low range for astringency and sharpness. It was more butyric and waxy than Jarlesburg, more buttery than Emmentaler, and less pineapple-like than either Jarlesburg or Emmentaler, the other closely related cheeses.

Swiss (Lite): also was a sweet, nutty, fruity cheese. It had dairy sweet and sweet taste notes that were in the high range of those recorded for all cheeses in this study. This cheese was nuttier than any of the other cheeses evaluated. Ratings were mid-range for buttery and dairy fat attributes and lower than most cheeses for dairy sour, sour taste, and sharpness.

Classification of cheese based on flavor properties

A specific classification scheme for cheese was difficult to formulate as the flavor properties of most types overlapped extensively. Sap Sago and Limburger were described as individual cheeses that, in fact, had few "cheese-like" flavor properties. The interior blue/green mold-ripened cheeses also were similar to each other and formed a different class from other cheeses. Similarly, Camembert and Brie formed a single class of cheese. Beyond those obvious classes, the overlap of flavor properties was more pronounced and division into specific categories proved less useful. Rather than assigning cheeses to specific classes, a tree diagram (Figure 1) was developed that indicated the overall relationships of the cheeses to each other. Cheeses that are on the same branch and shown close to each other could potentially be substituted for that cheese. For example, U.S. Swiss and Swiss Lite, which are both on the same branch and are shown close to each other, are quite similar. In contrast, Brie which is 4 branches away and quite a distance from provolone are very dissimilar.

In the tree diagram, the major and minor branches show various groupings or categories of cheese. Some branches have only one cheese, for example, sap sago and limburger are individual cheeses that are dissimilar to other cheeses in the study. Vintage

cheddar, part of a main branch leading to many other cheeses, still is shown as an individual cheese off that main branch. An example of a branch with several cheeses is the blue green mold-ripened cheeses which are a main branch all their own.

Limburger and Sap Sago were very different from the other cheeses in the study. Both had "extreme" flavor attributes; either they had among the highest scores of the cheeses for a particular attribute or the scores were low or very slight. Sap Sago has clover leaf powder added to the curd that gives it a pungent, sharp flavor (U.S.D.A., 1969) that is different from other cheeses. Generally both Sap Sago and Limburger lacked dairy attributes and were high in various non-dairy attributes. They were characterized by attributes few other cheeses possessed. For example, Sap Sago had a flavor similar to soy sauce, while Limburger had a sweaty flavor. These attributes may have been so intense that they masked others.

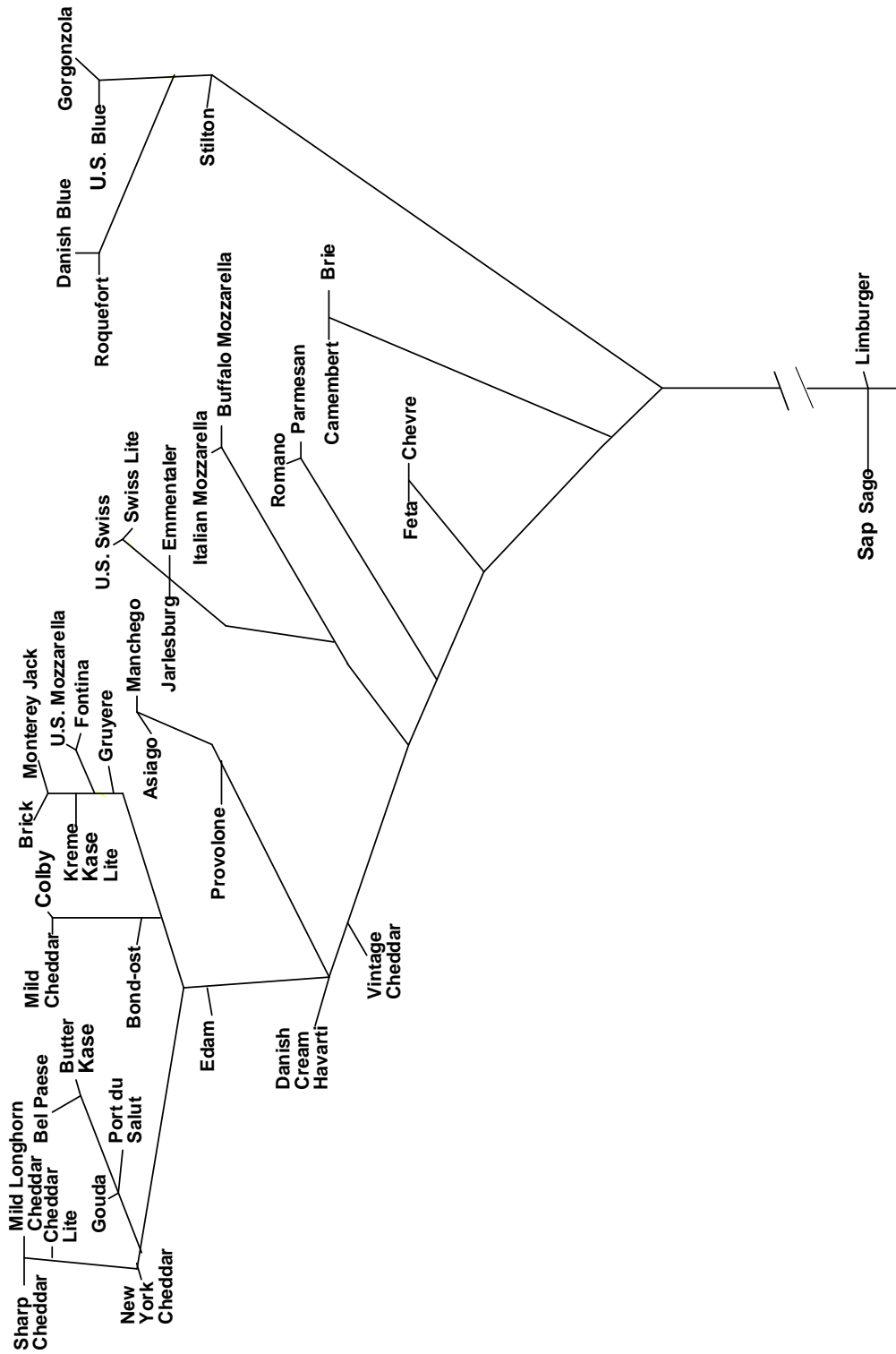
The second group included the blue/green mold-ripened cheeses (e.g., Danish Blue, U.S. Blue, Roquefort, Gorgonzola, and Stilton) primarily characterized by their mold flavor. Cheeses in this group generally had higher fundamental ratings (i.e., bitter, sour, salty) than most other cheeses and were sharp, astringent, goaty, biting, and butyric acid-like, with almost no dairy sweet, buttery, or nutty attributes. Stilton branched from this group quicker than the others, probably because it had slightly more intense animalic, goaty, moldy, biting, and bitter attributes and less saltiness than the others. Gorgonzola and U.S. Blue had very similar flavor descriptions, except that U.S. Blue had slightly more intense animalic and biting attributes. Danish Blue and Roquefort were similar, but the Danish Blue had slightly less sweaty character.

Brie and Camembert, both surface-ripened cheeses, were closely related to each other with respect to sensory attributes. Both cheeses had mushroom, moldy, nutty, and cooked milk characters. Karahadian *et al* (1985) indicated that the slight nutty, mushroom character has sparked interest in these cheeses among U.S. consumers. Brie was more mushroom-like and had slightly more goatiness and pungency than Camembert, but Camembert had a fish oil character not found in Brie. Karahadian *et al* (1985) indicated that 3-octanol (our reference for moldy) was partly responsible for the mushroom-like or green plant-like aroma in these cheeses.

Feta and Chevre occupied the next branch of the tree diagram. Chevre, made from goat's milk, and Feta, from sheep's milk, lacked the "dairy" character of many of the other cheeses. These two cheeses had a much more intense sour note and very slight dairy sweet attributes. Chevre had a more goaty character than did Feta.

Romano and Parmesan formed a branch near that of Feta and Chevre and also were low in dairy flavor. Both were in the high range of cheeses for astringency and bitterness, although Romano was saltier and Parmesan was sweeter. They both had many other similar attributes, such as animalic, butyric, biting, and pungency, although Romano was slightly higher than Parmesan for several of those flavor notes. Parmesan was fruity and pineapple-like, characteristics not noted in Romano.

Figure 1. Schematic diagram of cheese relationships based on flavor characteristics



The Italian Mozzarellas comprised a group of related cheeses, which formed a small side branch with the Swiss-type cheeses. As a large group, this set of cheeses could be characterized as sweet and nutty, although the intensity of each attribute varied with individual cheese type. Vangtal and Hammond (1986) suggested that these flavors were the result of the presence of acetic and propionic acids, and Biede and Hammond (1979a) suggested the nutty aroma was caused, in general, by fatty acids. Jarlesburg, U.S. Swiss, "Lite" Swiss, and Emmentaler all were significantly higher than any of the other cheeses for nuttiness. In addition, all except Jarlesburg were rated low in saltiness. The Swiss-type cheeses had much more nutty and fruity flavors than did the Mozzarellas. Mozzarella cheeses generally were rated mid-range for dairy-type attributes and had only slight sourness and astringency. One important distinction of the Mozzarella side branch was that the U.S. Mozzarella did not group with the Italian Mozzarella cheeses. The two Italian types, made from different milk sources (cow and buffalo) grouped together, but the U.S. Mozzarella made from cow's milk was quite different.

Vintage Cheddar, a singular group, had cheddar characteristics such as dairy sour and dairy fat, but it had the sourness and astringency of the cheeses that had already branched from the tree. Danish Cream Havarti also was slightly biting, which was not typical of the Cheddars. Barlow *et al* (1989) indicated that the amount of lactic acid increased with age in Cheddar cheese. Vintage Cheddar had aged over 24 months and that may be the reason for the high dairy sourness, astringency, and sharpness.

Danish Cream Havarti branched by itself at the same time that Provolone, Asiago, and Manchego branched. It was significantly higher than any other cheeses for buttery flavor. Also, the other dairy notes generally were higher than in most cheeses, giving Danish Cream Havarti some similarities to the Cheddar types. However, it had lower sharpness and astringency than the cheddars and was slightly nuttier than was typical of many cheeses in this study.

Provolone, Asiago, and Manchego had higher goaty notes than many other cheeses in the study. Provolone was more butyric than any other cheese, which may be the reason it branched separately from Manchego and Asiago. Asiago was in the high range for butyric acid, and Manchego was in the mid range for the butyric attribute. All of these cheeses had more sharpness than Danish Cream Havarti, which had many other similar notes, such as nutty.

Edam had a high buttery note and was in the mid range for dairy, astringent, and sharp notes that were similar to many other cheeses located near it on the tree. However, Edam also had a perceptible nuttiness and was much higher in saltiness than other similar cheeses, which may have caused it to branch by itself.

Near Edam was a large group of cheeses that were divided into several smaller groups. One of the main branches had a small cluster that included Kreme Kase "Lite", Brick, Monterey Jack, U.S. Mozzarella, Fontina, and Gruyere. Those cheeses did not have any specific character. They were in the mid range for most of their detectable attributes, such as the dairy attributes, astringency, and sharpness. They all had a slightly nutty note and several of them had a perceptible fruity note, as well.

A small group related to those cheeses consisted of Bond-ost, Mild Cheddar, and Colby. These three cheeses were "dairy"; each had buttery and dairy fat notes that were in the high range for all of the cheeses studied. The other dairy attributes were in the mid range, except for a low dairy sour character in Bond-ost. Other than the dairy attributes, these cheeses did not have any special characterizing notes; only Colby had a very slight nutty note. Vangtal and Hammond (1986) indicated that cheeses that do not develop much other flavor usually have a buttery flavor.

The last main branch of the tree diagram included three groups. New York Cheddar formed a group of its own and was mid-range for most dairy attributes, but had high sour and butyric flavor ratings compared with the other related cheeses.

One of the smaller branches on this portion of the tree consisted of Gouda, Port du Salut, Butter Cheese, and Bel Paese. Those cheeses were primarily "dairy", being in the high range for the dairy attributes and all having a slightly nutty character. Astringent, sharpness, and the taste factors were mid-range of all cheeses evaluated. Bel Paese and Butter Cheese were the two most closely related cheeses in this group, which is not surprising because Butter Cheese marketed in Germany is very similar to Bel Paese (U.S.D.A., 1969). Port du Salut was similar in all main attributes, but also had barely perceptible levels of animalic, decaying animal, and goaty attributes.

Sharp Cheddar, "Lite" Cheddar, and Mild Longhorn Cheddar comprised the last small branch on the tree. These cheeses were all high in dairy fat, and other dairy attributes were rated mid-range for all cheeses evaluated here. As a group, they had higher ratings than most other cheeses for sharpness and were low in sweetness.

Cheeses at the base of the tree had few "cheese" attributes. The branches nearest the base were characterized by attributes other than "dairy" and had unique flavors not typical of all cheeses. As the tree progressed upward, cheeses on the branches became more dairy-like, having attributes or intensities of attributes that were specific to their small group. At the ends of the branches, cheeses had more blends of attributes that were common to almost all the cheeses with no particular note dominating.

Conclusions

An objective flavor description using a set of well defined sensory attributes was developed for a wide variety of cheeses. This should enable cheese researchers to more adequately describe the flavor of particular cheeses. Cheeses can be judged and discussed on flavor attributes that are characteristic of that particular cheese rather than on ambiguous qualities such as "unclean" and "overmatured", or subjective qualities such as "like-dislike". Manufacturers and researchers can use descriptive flavor data to help correlate specific chemicals present in individual cheese types with the sensory flavors of that cheese, and manufacturers can use these data to set quality standards for their cheese.

The diagrammatic scheme developed shows the overall relationships among cheeses. This scheme is useful for understanding the similarities or differences in flavor properties of various cheeses. Consumers could examine a simplified tree before making the decision to purchase an unfamiliar type of cheese.

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