Beiträge zur Tabakforschung International · Volume 12 · No. 3 · February 1984 DOI: 10.2478/cttr-2013-0537

Factors Influencing Tobacco Leaf Quality: an Investigation of the Literature*

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SUMMARY

This paper comprises a review of the published literature (1936–1979) dealing with the relationship between the chemical constituents of tobacco and smoke and tobacco and smoke quality. Various components thought to be influential in determining quality are identified; conclusions of researchers regarding the effects of these components are recorded and discussed. A summary table is presented which details the nature of the relationship between these constituents and tobacco quality.

ZUSAMMENFASSUNG

In einem zusammenfassenden Überblick wird die in den Jahren 1936 bis 1979 veröffentlichte Literatur über die Beziehungen zwischen den chemischen Bestandteilen von Tabak und Rauch einerseits und der Tabak- und Rauchqualität andererseits dargestellt. Verschiedene Komponenten, denen in den betreffenden Aufsätzen eine Bedeutung für die Qualität zugeschrieben wurde, werden hinsichtlich ihrer Wirksamkeit im einzelnen behandelt, wobei die Schlußfolgerungen der Autoren aufgeführt und diskutiert werden. Die in den einzelnen Arbeiten angegebene Bedeutung der Bestandteile für die Tabakqualität wird in einer zusammenfassenden Tabelle bewertend charakterisiert.

RÉSUMÉ

Cet article donne un vaste panorama de la littérature publiée au cours des années 1936 à 1979 concernant les relations existantes entre d'une part les composants chimiques du tabac et de la fumée et d'autre part la qualité du tabac et de la fumée. Différents composants auxquels ces articles accordent une signification eu égard à la qualité, sont traités dans le détail du point de vue de leur efficacité, les conclusions des auteurs étant citées et discutées. L'influence de ces composants sur la qualité du tabac telle qu'elle est indiquée dans les différents travaux est présentée et spécifiée dans un tableau récapitulatif.

* Received: 7th September 1982 — accepted: 21st October 1983.

INTRODUCTION

A great deal of research has been conducted over the years regarding the relationship between the chemical constituents of tobacco and smoke and tobacco and smoke quality. This paper attempts to survey the literature in the area of cigarette tobacco, noting the effects of various components thought to be influential in determining quality. This review encompasses studies reported between 1936 and 1979, including many foreign contributions. Studies that have not been cited directly here are included in a general "Bibliography". This paper is intended to serve as a starting point from which to conduct future investigations of the topic.

Unfortunately, one of the major obstacles in attempting

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to correlate the results of these various investigations remains the lack of consensus on a definition of quality. This is an issue with which *Coresta* * has wrestled for many years. *Akehurst* + has suggested that quality may be "that for which the buyer pays money". *Tso* ++ gives the following definition: "Many essential chemical and physical characteristics are being used to judge quality. In flue-cured tobacco these characteristics may be classified into three areas:

1. *Visible and detectable criteria:* size, uniformity, finish, foreign matter, damage, color, texture (grainy, soft), body (thickness, density), maturity, odor and flavor;

2. *Physical criteria:* filling power, shatter resistance, equilibrium moisture content, strip yield, combustibility and stalk position; and

3. *Chemical criteria:* nicotine, sugar, petroleum ether extracts, mineral components, alkalinity of water-soluble ash, total N, protein N, α-amino N, starch, non-volatile acids, and total volatile bases.

Most of these characteristics may also be used to judge the quality of other tobacco types. The ultimate judgment, however, is based on smoking taste and odor, generally known as strength, aroma, mildness or sharpness".

This paper is concerned with investigations of the latter aspect of quality, i.e. chemical criteria. However, the many researchers working in this area often do not bother to define what they mean by quality, but merely proceed to speak in terms of "quality" as a self-evident attribute. The problem is further complicated because the research involves many different types of tobacco, grown in many different areas under many different types of agricultural conditions. Furthermore, tastes have varied not only around the world but throughout time. In addition to these other factors, the influence of stalk position must also be considered. Thus, investigators offer necessarily contradictory and confusing evidence with regard to the effects contributed by the chemical constituents in question, rendering conclusive judgments impossible (see Summary Table 1).
Often it is not an absolute quantity of a substance which is important, but the relative amount of the particular constituent and its balance with other factors. Attempts to develop quality indices relating these elements have resulted in a myriad of formulas which cannot be applied uniformly to tobacco of different types or regions. Nor can they be applied unchanged over time, since the increasing sophistication of analytical tools and methods presents data that continue to become more precise. Indeed, as *Akehurst* ** has stated, "undoubtedly the behavior of tobacco leaf in manufacture and smoking is the result of numerous interactions between a large number of compounds, but to pick out a small number and express their relationship as a general quality index is only likely to be of limited local usefulness".
Thus, this paper does not attempt to draw firm conclusions regarding the effects of specific substances on the nebulous attribute referred to as tobacco "quality". Nevertheless, it does serve both to identify those components of tobacco thought to be influential in determining quality and to focus on the complexity of their interactions.

CHEMICAL COMPONENTS AND QUALITY

Acids

Acids are an important constituent of tobacco. They help regulate the pH of tobacco, thus indirectly influencing smoke aroma and taste. Acids in general have been reported to have varying degrees of association with quality, including no association at all. *Kallianos* has stated that confusion may exist because acids predominate in tobacco as salts and the taste effects come from thermal degradation of the salts (26).
High acid concentrations have been found in light-bodied leaves, low concentrations in heavy-bodied leaves (1). *Shmuk* reports that high acid content indicates high ash content which has been correlated with poorer taste and combustibility. He also states that acid fractions do not influence aroma, but do improve and mellow the taste (66).
There seems to be no consistent relationship between total organic acids and quality (26, 56, 58, 63), though several sources have indicated that non-volatile carboxylic acids (especially malic, citric, oxalic and malonic) have an inverse relationship with taste (26, 49, 66). Volatile organic acids such as formic, acetic, propionic or isobutyric, however, are especially important in contributing to smoke flavor and aroma (1, 2, 26). Non-volatile acids are also quality producing agents (3), as are aromatic acids, especially benzoic acid and phenylacetic acid (67). However, water-soluble acids have not been consistently linked to quality (63).
Fatty acids have a significant relationship with quality. The major higher fatty acids are: palmitic, linoleic, linolenic, stearic, oleic, myristic and lauric. Ethyl and methyl esters of the higher fatty acids are smoothing; some esters of the lower fatty acids add fruity, winey and waxy flavors (13). *Davis* and *Kallianos* have each suggested that low molecular weight fatty acids contribute significantly to smoke flavor, quality and aroma (13, 26).

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\+ Akehurst, B. C.: Tobacco; Longman, London and New York, 1st edition, 1968, p. 457.
++ Tso, T. C.: Physiology and biochemistry of tobacco plants; Dowden, Hutchinson & Ross, Inc., Stroudsburg, Pa., 1972, p. 305.

** Akehurst, B. C.: Tobacco; Longman, London and New York, 1st edition, 1968, p. 448.

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Alkaloids

Alkaloids contribute to smoke flavor (2) and have a significant positive correlation with taste (25). They are a common determinant of quality (22). In general a lower alkaloid content indicates higher quality; higher concentrations lead to stronger "gustatory" sensations (66). Alkaloids have been negatively related to mildness and palatability, positively correlated with "smoking density" (38).

Nicotine, the most important alkaloid in tobacco, determines the physiological strength of tobacco and smoke (1, 66) and therefore has a significant positive correlation with taste strength (25, 66). Nicotine salts are thought to be particularly important for determining sensory strength (65).

Reports on nicotine's role in determining tobacco quality vary. Free nicotine and bound nicotine apparently have different effects on flavor (2). Some sources indicate a definite negative correlation between nicotine and tobacco quality (17, 68); others classify nicotine as a quality producing chemical (3); still others cite no consistent relationship between nicotine content and quality (20, 58, 63). It has been suggested though, by both *Ahmad* (3) and *Chakraborty* (11), that it is the balance between nicotine, nitrogen and sugar in the leaf which regulates the quality of the smoke, indicating that too much nicotine can be as undesirable as too little (49).

Nicotine appears in high concentrations in Burley tobacco, low in flue-cured and lowest or in-between in Oriental. It seems to have a positive effect on the quality of air-cured tobacco and a negative effect on that of flue-cured (12).

Nornicotine, another important alkaloid, has been negatively correlated with quality (15).

Carbohydrates

Carbohydrates are significant chemical constituents of tobacco. In general they contribute to smoke flavor (2, 66) and have a positive influence on tobacco quality (1, 17, 19, 50, 55, 56, 66). However, increasing the carbohydrate concentration does not lead to further improvements in quality unless accompanied by the harmonious interaction of other components (1, 66). For example, sugars, which most sources indicate have a positive correlation with quality and taste, appear in higher concentrations in desirable leaves, but they do not imply high quality unless enough waxes and resins are present (56, 61). Sugars often must be added to tobacco to balance acidic and alkaline substances (1), however too much sugar can lead to a biting or pungent smoke (56, 61). In other words, there can be too high as well as too low a level of carbohydrates.

Carbohydrate content varies with tobacco type, being high in flue-cured tobacco, low in Burley and Maryland, and in-between in Oriental (1). Carbohydrate content has been related to a biting taste in Japanese tobacco smoke and is also an influential contributor to the taste of Turkish tobacco smoke (17, 56).

Soluble carbohydrates add to smoke acidity, increase moisture content and retard burning (1), but too high a soluble carbohydrate content weakens the smoke (1, 20). *Pyriki's* 1958 study showed that soluble carbohydrates, especially monosaccharides, constitute important factors in many quality indices (57). On the other hand, structural carbohydrates, according to *Abdallah*, have a negative influence on smoke, although they do improve combustibility and filling power (1). Cellulose is also important in promoting combustibility (1), but it has an inverse relationship with quality in general (20, 56).

Both *Shmuk* and *Abdallah* agree that pectins have a negative influence on tobacco quality (1, 66). *Shmuk* has stated that not only are pectins negatively correlated with taste, but methyl alcohol, "a component of the pectic substances", has an especially strong negative correlation (66). However, in a 1959 paper, *Pyriki* reported that pectins may act positively on tobacco, much the same as sugars do (56). In 1963, *Pyriki* devoted a rather extensive paper to investigations of the relationship between tobacco quality and pectins, but was unable to establish any definite relationship (53).

The role of starches in determining tobacco quality is also questionable. Although *Ahmad* reports a quality producing effect (3), others describe no consistent relationship (58, 63).

Carbonyl Compounds

Carbonyl compounds such as aldehydes and ketones appear to have a dual effect on aroma. According to one Russian source, the quality of tobacco aroma increases with increasing amounts of carbonyl compounds, especially the non-volatile carbonyls (14). Another Russian study reports that, while non-volatile carbonyl compounds do have a positive influence on aroma, volatile carbonyl compounds contribute an unpleasant odor (32). Like other carbonyl compounds, it seems that some aldehydes have quality producing effects, while others are negatively related to tobacco quality. According to *Abdallah*, both aldehydes and ketones contribute to smoke flavor (2) and determine reducing power (1), which *Shmuk* maintains correlates with taste and aroma (66). Additional evidence comes from a 1973 communication in which *Kamenshchikova* and *Mokhnachev* reported that the formaldehyde content of tobacco decreased as the tobacco quality declined (27).

Ether and Petroleum Ether Extracts

Petroleum ether extracts from tobacco consist mostly of fatty and resinous materials, essential oils, paraffin hydrocarbons, some organic acids, higher alcohols, and

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Table 1. Literature references (1936–1979) concerning the relationship between tobacco components and quality.

	Relationship		
	direct	inverse	inconclusive
Acids			66
total organic			26, 56, 58, 63
non-volatile carboxylic		26, 49, 66	
volatile organic	1, 2, 26		
non-volatile organic	3		
aromatic	67		
water-soluble			63
fatty acids	13, 26		
Alkaloids		66	
nicotine	3	17, 68	20, 58, 63
nornicotine		15	
Carbohydrates	1, 17, 19, 50, 55, 56, 66		
sugars	56, 61		
solubles	1	1, 20	
structural		1	
cellulose		20, 56	
pectins	56	1, 66	53
methyl alcohol		66	
starches	3		58, 63
Carbonyl compounds			
non-volatile	14, 32		
volatile		32	
aldehydes	1, 2, 27		
ketones	1, 2, 27		
Ether / petroleum ether extracts	24	11, 23, 58, 63	23, 49
essential oils	28, 29, 58		
Inorganics / inorganic salts		66	
chlorides		11, 23, 24, 66	
magnesium salts		8	
calcium salts		48	
potassium	48, 66		
potassium chloride		9	
potassium salts	1		
iron		6	
iron : manganese		6	
phosphorus			16, 18, 47
Nitrogenous compounds	31	15, 23, 46, 51, 58, 66 68	
total N	3	58, 63	
protein N		58, 63	
insoluble N	3	58, 63	
amino N	3		
soluble N			58, 63
Phenols / polyphenols	2, 26, 56, 63		49, 58
chlorgenic acid	7, 8, 26		
rutin	7, 8, 26		
lignin		49, 56	
Proteins		1, 66	
soluble	22		
amino acids	2, 31		
Volatile bases	2, 66		
ammonia		1, 66	
Volatile oils	1, 66		
Waxes / lipids / terpenes	13, 54		49
resins	1, 5, 28, 35, 54, 56, 66		49
esters of phytosterol		1, 13	
esters of solanesol		1, 13	
phytosterol			13
solanesol			13
duvatrienediol			13
paraffin hydrocarbons		1	13
soluble hydrocarbons	68		

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phenols. The extract comprised of essential oils favorably influences quality (58). In general, the more essential oils there are, the better the quality (28, 29). The relationship between the neutral essential oil fraction and the basic fraction probably determines leaf quality (28).

Hsieh has argued that theoretically there should be a positive correlation between petroleum ether extracts and quality, but this has never been demonstrated (23). On the contrary, *Phillips* and *Bacot* found no direct relationship (49), while several other sources have reported a negative relationship (11, 23, 58, 63). *Hsieh* has also stated that a higher level of ether extracts indicates better quality (24), but *Phillips* and *Bacot* again found no direct relationship between the two (49).

Inorganics and Inorganic Salts

Shmuk reports that high concentrations of inorganic salts are undesirable for tobacco quality and combustibility (66). Chlorides depress combustion (9) and generally retard burning (1, 60, 62), therefore low chloride content correlates with high combustibility which favors good taste (66). *Hsieh* has found that high grades of tobacco seem to have lower concentrations of chloride (23, 24). A recent study on flue-cured tobacco from India, Thailand and Brazil also found an inverse relationship between chloride content and quality (11).

Sabir, studying flue-cured Iraqi tobacco, found that both calcium and magnesium salts improved the moisture content of tobacco (60), but generally, though magnesium and calcium salts play an important role in the burning process (1, 9), they are thought to be inversely related to quality (48).

Potassium correlates highly with high combustibility (1, 60, 62, 66) which favors good quality and good taste (48, 66). Potassium salts also favor combustion (1). Potassium chloride in large amounts inhibits combustibility, but small amounts of potassium chloride, especially in the presence of calcium and magnesium, promote combustion (9).

In a study of flue-cured tobacco conducted during the 1970's, *Araiba* and *Honda* found low iron content and a low iron-to-manganese ratio to be desirable for producing good aroma and taste in tobacco (6).

Another inorganic, phosphorus, has been related to the biting taste in Japanese tobacco smoke. It is reported to have both a positive relation and no correlation at all with quality (16, 18, 47).

Nitrogenous Compounds

Nitrogenous compounds, another important group of chemical constituents found in tobacco, have been cited as indices to the strength, smoking, and blending quality of Burley tobacco (34). Generally, nitrogenous compounds are thought to be inversely related to quality (15, 23, 46, 51, 58, 66, 68). As nitrogen content decreases, it leads to a milder, yet poorer, taste (30). Nitrogenous materials have been related to a biting taste in Japanese tobacco smoke (17). Nitrogen is also unfavorable for burning (62). It has been reported that total nitrogen, protein nitrogen and insoluble nitrogen are unfavorable for quality in Indian flue-cured tobacco (58, 63).

However, *Ahmad* has indicated that total nitrogen, amino nitrogen and insoluble nitrogen are quality producing agents for flue-cured tobacco (3). Soluble nitrogen has not been related to quality (58, 63).

Leffingwell's 1976 paper provides a comprehensive review of the role of nitrogen in determining tobacco quality. The browning reactions which involve nitrogen compounds contribute significantly to tobacco flavor and aroma (31).

Phenols and Polyphenols

Abdallah and *Kallianos* both report that phenols may contribute to smoke flavor, quality and aroma (2, 26), however, the relationship between quality and complex phenolics is unknown. They may serve as precursors of flavorants (26).

Polyphenols contribute to smoke flavor (2), but like many other substances they appear to have a confusing relationship with tobacco quality. Some sources cite no consistent relationship between polyphenols and tobacco quality (49, 58). Others indicate polyphenols are a positive factor in determining quality as long as they are present in smaller concentrations than soluble carbohydrates (56, 63); higher concentrations can produce negative effects (66). In a study reported in 1966, *Akaike* and *Yamada* found that polyphenol content and quality grades ran parallel, except when they were inversely related with rutin in cutter and leaf of bright yellow tobacco (4).

In a comprehensive review of phenolics presented at the 1976 Tobacco Chemists' Research Conference (Nashville, Tenn.), *Kallianos* reported that rutin and chlorogenic acid seem to correlate directly with flue-cured tobacco quality (26). Earlier, *Arsenyan* also reported positive correlations between those substances and tobacco quality (7, 8). He found that levels of both chlorogenic acid and rutin decreased with decreasing quality of Oriental leaf (8).

Phillips and *Bacot* found that lignin content increases in tobacco as the plant ages; very high concentrations often indicate over-ripeness (49). In the 1950's, *Pyriki* and others reported an inverse relationship between lignin content and tobacco quality (49, 56).

Proteins

Like many other substances, the effects of protein on tobacco quality are complex. In general, albumin and other proteins have a negative influence on tobacco quality, especially on taste. However, some protein content is needed for full taste, taste strength, and a degree

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of bitterness (1, 66), and, in fact, *Grob* asserts that soluble proteins are a common determinant of quality (22).

Proteins impart an unpleasant odor when burning, though small amounts have been shown to have a positive effect on aroma (1, 66). Amino acids are precursors of aroma (1) and are thought to contribute to smoke flavor (2). In flue-cured tobacco at least, two amino acids, alanine and glutamine, may directly correlate with smoking quality as indicated by a high negative correlation coefficient. *Leffingwell* also reports that proline content is high in quality flue-cured tobacco (31).
Protein content is high in Burley tobacco, low in flue-cured, and in-between in Oriental (1).

Volatile Bases

In general, volatile bases influence only flue-cured tobacco quality (15) by contributing to flavor (2) and indicating body or strength (66).
Shmuk states that ammonia is a very important negative indicator of tobacco quality (66). Although some ammonia content is necessary to provide sensation, ammonia does promote harshness and is a negative factor in general (1).

Volatile Oils

Volatile oils have a positive influence on quality and contribute to flavor and aroma (1, 66).

Waxes, Lipids, and Terpenes

Waxes and lipids constitute a large and important group of substances found in tobacco leaf and smoke. In his 1976 paper, *Davis* (13) stressed the importance of the pyrolytic products of waxes and lipids in determining smoke quality and aroma. Isoprene-derived lipids, especially ionones and related compounds, which are the degradation products of carotenoids, do seem to affect quality. While *Phillips* and *Bacot*, in a 1953 study, found no direct relation between waxes and tobacco quality (49), *Davis* more recently reported that both waxes and lipids seemed to contribute directly to smoke aroma and quality (13), and *Pyriki* emphasized the role of waxes and resins in reducing sharp tastes in smoke (54).

Phillips' and *Bacot's* 1953 report accented the role of resins in determining the amount of aroma produced, but found no direct relationship between resin content and aroma quality (49). However, most sources indicate that resins and their pyrolytic degradation products are positively correlated with quality, aroma and taste (1, 5, 28, 35, 54, 56, 66). In Iraqi tobacco, an average resin content is best in terms of quality (20).

Both *Davis* and *Abdallah* report that esters of phytosterol and esters of solanesol have slightly negative influences on aroma (1, 13). According to *Davis*, neither phytosterol nor solanesol seems to affect quality, though solanesol may contribute to diterpenes in smoke and thereby influence smoke aroma indirectly. Duvatrienediol, a diterpene, has not been associated positively with smoke flavor or aroma (13).
Davis also asserts that paraffin hydrocarbons have no direct relationship with leaf quality, though some reports indicate they have a negative effect on smoke flavor and aroma (1, 13). Soluble hydrocarbons have been positively correlated with quality (68). An unsaturated hydrocarbon, neophytadiene, reportedly may enhance aroma and taste and contribute to quality, but no conclusive evidence has been presented thus far (13).
Davis' 1976 paper (13) provides a thoroughly comprehensive review of the role of waxes and lipids in determining smoking quality and aroma.

Table 1 attempts to summarize those components of tobacco which generally have a direct relationship to quality, those which generally have an inverse relationship to quality, and those for which no definitive conclusions have been reached as far as their role in determining tobacco quality is concerned. The numbers denote the references which have reported on these relationships.

INDICES QUANTIFYING TOBACCO QUALITY

Because the relationship between the many components of tobacco and tobacco quality is so complex, numerous researchers have attempted to devise formulas to relate various combinations of important substances to tobacco quality. Many of these involve the ratio of the sum of quality-producing substances to the sum of quality-inhibiting substances. However, it is difficult to apply these indices uniformly to tobaccos of different types or regions. In a study of some chemical quality indices, *Ramakrishnaya* et al. (58) state that indices should only be used to compare tobacco grown under identical conditions of soil, climate and production practice, as these factors affect chemical composition.

Nevertheless, many researchers have continued to try to develop workable quality indices (see Summary Table 2). The three foremost were developed by *Brückner, Pyriki,* and *Shmuk.*

Brückner, in 1936, proposed using the ratio between the sum of quality-promoting substances multiplied by four hundred and the sum of quality-restricting substances. Thus he added together sugar, starch, oxalic acid, tannins, and resins, multiplied them by four hundred, and divided them by the sum of cell membrane substances plus ash plus citric acid plus nitrogenous compounds plus pH value (10):

$$\frac{(\text{sugar} + \text{starch} + \text{oxalic acid} + \text{tannins} + \text{resins}) \times 400}{\text{cell membrane substances} + \text{ash} + \text{citric acid} + \text{nitrogenous compounds} + \text{pH value}}.$$

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In 1958, *Pyriki* (1) published his quality index which was derived from the sum of total reducing substances plus resins plus waxes, multiplied by four hundred and divided by the sum of ash, nicotine, protein, ammonia and residual nitrogen:

$$\frac{(\text{total reducing substances} + \text{resins} + \text{waxes}) \times 400}{\text{ash} + \text{nicotine} + \text{protein} + \text{ammonia} + \text{residual N}}.$$

Shmuk's quality index, published in 1953, consisted of the ratio between soluble carbohydrates and proteins. In his monumental work on the chemistry and technology of tobacco (1), he discusses several other equations which may relate to tobacco quality. A high nicotine number, which is derived from dividing the percentage of total nicotine by the percentage of free nicotine, indicates high quality. Likewise, a high nitrogen number, the quotient of nicotine nitrogen over ammonia nitrogen, indicates high quality. The polyphenol number, which compares the percentage of polyphenolic substances expressed in terms of glucose to the total quantity of reducing sugars, gets higher as tobacco quality gets lower (66).

In a paper published in 1961, *Pyriki* (52) discusses several other attempts to develop quality indices for tobacco. He states: "The quality numbers which have been achieved long ago and which are the basis of tobacco analysis resemble each other fundamentally because they are based on the determination of more or fewer tobacco content substances which are compared according to their quality promoting or quality-decreasing influence". *Pyriki* mentions that "the quality number of *Molinari* and *Kuhn* which was proposed a few years ago, as well as the quite recently made public quality number of *Aksu* and *Enercan* both depend on the same basis. The latter is supposed to be valid for Turkish tobaccos of the Aegean district". *Pyriki* also cites the work of *Trifu*, who proposed that tobacco quality could be determined by comparing the ratio between the total reducing substances of smoke and the total nitrogen of smoke. *Pyriki* reports that *Bodnar* and *Votiszky* suggested a "smoke number" based on the microdetermination of tobacco smoke alkalinity according to *Nagy*. *Jeney* and *Nemeth* also developed a similar "smoke number". *Shmuk* number, *Pyriki* number, *Molinari* and *Kuhn* number, and *Trifu* number all decrease as tobacco quality decreases. The *Jeney* and *Nemeth* number increases as tobacco quality declines (52).

In 1971, *Sanaullah* (61) briefly reviewed early work in the area of tobacco quality. He cites *Reiser's* 1937 "qualitative value", the *Shmuk* number, *Pyriki's* work on relative quality, *Dezelic's* 1949 coefficients for mildness percentage, polyphenol number and harmonic value. *Sanaullah* also mentions the commercial quality index developed in 1961 by *Aksu* and *Enercan* as well as *Dzhalal Shafik's* 1965 index of physiological strength. For Oriental tobacco, *Sanaullah* uses the pH value as an index to quality, with a low pH indicating better quality (61).

A study on Spanish tobaccos found that the ratio of CaO to K_2O was "near 1 for good tobaccos. The time of burning was in direct proportion to the quotient K_2O/Cl; for good tobaccos it is > 5, for passable 3–4, and for poor < 3" (64).

Rodriguez (59) presents a tentative index for determining the quality of Cuban tobaccos, i. e.

for alkaline tobacco:

$$\frac{(\text{nicotine} \times 100) + (\text{resins} + \text{waxes}) \times 10}{\text{total N} - \text{nicotine N}},$$

for acidic tobacco:

$$\frac{\text{sugars} + \text{nicotine} + (\text{resins} + \text{waxes}) \times 10}{\text{total N}}.$$

Chakraborty and *Kameswara* (11) discuss the importance of the sugar/nicotine balance in determining tobacco quality. *Murty* et al. (39) also examine the ratio of reducing sugars to nicotine, reducing sugars to total nitrogen, and reducing sugars to protein as indices of tobacco quality.

Table 2. Classification of quality indices with reference to tobacco or smoke composition.

Index	Classification derived from: tobacco constituents	Classification derived from: smoke composition
Ahmad		×
Aksu & Enercan	Turkish	
Araiba	×	
Bodnar & Votiszky		×
Brückner	×	
Chakraborty & Kameswara	×	
Dezelic	×	
Fujiwara & Kurosawa	×	
Gopalakrishna	Burley	
Harlan & Moseley		×
Jeney & Nemeth		×
Kovalenko	Flue-cured	
Mokhnachev et al.	×	×
Molinari & Kuhn	×	
Muramatsu et al.	×	
Murty	×	
Obi	Flue-cured, Japanese, Burley	Flue-cured
Pyriki	×	
Reiser	×	
Rodriguez	Cuban	
Sanaullah	Oriental	
Sabir	×	
Shmuk	Flue-cured	
Trifu		×

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Ahmad (3) states that the "nitrogen-nicotine-sugar balance, in general, regulates the smoke quality of tobacco".

Obi et al. (40) have worked on several possible avenues for evaluating tobacco quality from its chemical constituents. They compared the products of the pyrolytic degradation of sugars and resins (F) to the products of the pyrolytic degradation of cellulose (E), and reported: "The general consideration of the F/E value in connection with several properties of tobacco leaves supported the following possibilities for the quality index of tobacco leaves: index of the combustibility of tobacco leaves and tar content in smoke, index of aroma and (or) taste and (or) strength of flue-cured tobacco leaves, and index of harshness or irritation of Japanese domestic and Burley tobacco leaves".

Obi et al. (41 to 45) discuss the relationship between "K value" (K = 100 F/E) (see preceding paragraph for E and F values) and smoke aroma and taste as follows:

For aroma and/or taste at a confidence coefficient of 95 percent:

$$Y_1 = 0.068X - 2.65 \pm 0.3,$$

where

Y_1 = aroma and/or taste,
X = K value.

For aroma plus taste at a confidence coefficient of 95 percent:

$$Y_2 = 0.128X - 4.34 \pm 0.33,$$

where

Y_2 = aroma plus taste,
X = K value,

or, at a confidence level of 95 percent:

$$Y = 0.068X - 2.65 \pm 0.30 \quad (75 < X < 156),$$

where

$Y = 2.0 - 2.5 \ (X \leq 75)$,
$Y = 8.0 - 8.5 \ (X \geqq 156)$,
Y = aroma and/or taste,
X = K value.

They further (45) refined their equations to derive the K_M value * which "was established as a new coefficient for the evaluation of smoking quality of flue-cured tobacco leaves as follows":

$$K_M \text{ value} = \frac{(\text{isoprene} + 2) \times (2{,}5\text{-dimethylfuran})}{(\text{acetaldehyde} + \text{acetone} + \text{acrolein}) \times 100}$$

In another study by *Muramatsu, Obi, Shimada* and *Sakurai* (35), dryness was postulated as an indicator of tobacco quality. Dryness, or D value, was computed from the ratio of isoprene plus the products of the pyrolytic degradation of resinous substances to 2-methylfuran plus 2,5-dimethylfuran.

Muramatsu et al. (36, 37) also report on two additional quality coefficients, i.e. K_{PA}, "based on the pyrogram of powdered tobacco, obtained with a fixed pyrolytic temperature (550 °C) and time (15 s)" and K_{PN}, "based on the pyrogram of powdered tobacco leaves in N".

Mokhnachev and *Kamenshchikova* (33) developed the elaborate equations below to determine the relationship between tobacco constituents and flavor as well as between smoke constituents and flavor. However the calculated data and the real data may vary as much as ± 20 %.

Constituents of tobacco in relation to:

Flavor =
0.064 resins+ — 0.013 carbohydrates + 0.017 proteins + 0.017 water soluble substances + 0.009 alcohol soluble substances + 0.008 substances of acid nature in aqueous tobacco extract — 0.014 nicotine + 0.0002 alkaline substances in aqueous extract — 0.303 carbonyl compounds (non-carbohydrate) in aqueous extract + 0.109 methanol in aqueous extract.

Taste =
0.060 resins — 0.009 carbohydrates + 0.020 proteins + 0.016 water solubles + 0.007 alcohol solubles + 0.008 acidic substances in aqueous extract — 0.009 nicotine + 0.001 alkaline substances in aqueous extract — 0.227 carbonyl compounds (non-carbohydrate) in aqueous extract + 0.095 methanol in aqueous extract.

Constituents of smoke in relation to:

Flavor =
— 0.0096 wet condensate++ + 0.1844 volatile acids + 0.1667 nicotine + 11.3409 volatile phenols + 0.9866 methanol + 0.1553 carbonyl compounds (non-carbohydrate).

Taste =
— 0.0087 wet condensate + 0.1944 volatile acids + 0.1490 nicotine + 10.9868 volatile phenols + 0.9796 methanol + 0.1532 carbonyl compounds (non-carbohydrate).

The *Kovalenko* coefficient, which was developed in 1935, compares the percentage of reducing sugars, expressed as glucose, to the percentage of total nitrogen (49).

* K value modified

\+ mg/g of absolute dry tobacco
++ mg/g absolute dry burnt tobacco

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Fujiwara and *Kurosawa* (17) report that: "The ratio of reducing sugar to total N gave a better indication of quality than the *Shmuk* quotient ..." .

In a study of some chemical quality indices, *Ramakrishnayya* et al. (58) found "good agreement among the *Shmuk* numbers, *Kovalenko* coefficients, and the grade of tobacco".

However, as *Gopalakrishna* at al. (21) point out in their 1977 paper, both the *Shmuk* number and *Kovalenko* coefficient were developed using flue-cured tobacco. In their paper, they attempt to develop a quality index for Burley tobacco and conclude: "The correlation coefficient of protein N to quality was found to be −0.5621 and this appears to be suitable as an index of quality of Burley tobacco".

Sabir (60) cites the ratio of protein N (multiplied by one hundred) to total N as an index of tobacco quality.

Harlan and *Moseley* (34) state that "the ratio of nicotine to total volatile bases is particularly useful as an index of the palatability of smoke".

Finally, *Araiba* et al. (6), as mentioned earlier, feel that the iron to manganese ratio may be another indicator of tobacco quality.

Obviously, there is a plethora of indices referenced in the published literature. It is assumed, however, that research groups either apply these selectively or integrate them partially with their own formulas for analyzing tobacco. These "formulas" are considered trade secrets, for the most part. But it is likely that they examine balances of constituents similar to those described above.

Table 2 represents an attempt to classify various quality formulas based on whether they were derived from looking at tobacco constituents or smoke composition.

CONCLUSIONS

Of the many considerations involved in quality evaluation, ultimate judgments seem to have relied on subjective assessments of smoke aroma and taste. This subjective aspect, applied to widely varying types of tobacco, combined with a general vagueness as to the meaning of the term "quality" itself, renders a survey of research in the area of tobacco quality necessarily inconclusive. Nevertheless, it should be useful as a review of work performed in the field from the mid-1930's to the late 1970's.

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