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EVALUATION OF CERTAIN NUTRITIONAL AND SENSORY QUALITIES OF FRENCH FRIED POTATOES

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IOANNIS E. EVANGELOU

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Perides Markakis
Major professor

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EVALUATION OF CERTAIN NUTRITIONAL AND SENSORY QUALITIES OF FRENCH FRIED POTATOES

By

Ioannis Evangelou

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ABSTRACT

EVALUATION OF CERTAIN NUTRITIONAL AND
SENSORY QUALITIES OF FRENCH FRIED POTATOES

By

Ioannis Evangelou

Two Greek potato cultivars were par-fried, frozen, and finish-fried with 7 different frying oil combinations. Moisture, ash, fat, Kjeldahl N, non-protein N, free amino acids and ascorbic acid were determined in raw, par-fried and finish-fried potatoes. Individual sugars were assayed in raw potatoes. Total and free fatty acids were determined in olive oil and kernel olive oil. These oils, along with cottonseed oil, corn oil, sunflower oil, and palm oil were used in the trials.

Par-frying and finish-frying resulted in the following respective losses: moisture 5% and 28%; ash 22% and 55%; Kjeldahl N 21% and 31%; non-protein N 41% and 62%; free amino acids 42% and 74%; and ascorbic acid 39% and 49%. Non-protein N losses were approximately double those in total Kjeldahl N. Both cultivars contained less than 1% reducing sugars, dry basis. The fat content was: raw potatoes 0.1%; par-fried 4%; and finish-fried 11%.

A sensory panel evaluation of the finish-fried potatoes indicated that par-frying with kernel olive oil, and finish-frying with olive oil results in the best product.

DEDICATION

to my family

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INTRODUCTION

Historians and archeologists trace the cultivation of potato (Solanum tuberosum), to at least 200 A.D. on the Andean mountains. Potato, with a total yearly production in excess of 10 billion bushels, is one of the major food crops in the world.

The potato is one of the few crops that is capable of nourishing large populations with energy, high quality protein, minerals and vitamins. A hectare (2.47 acres) produces 226 kg of potato protein, a yield greater than that in wheat grain protein (200 kg/ha) or rice grain protein (168 kg/ha) (FAO, 1972).

In addition to their good nutritional quality, potatoes can be abundantly, quickly and economically produced in temperate zones. Today, there is a significant trend of increasing the per capita consumption of potatoes, worldwide, as a result of the rapid increases in processing and the greater availability of a larger variety of processed products. Frozen potato products are the fastest growing category of processed potatoes, accounting for almost one-half of all processed potatoes. In the U.S. per capita consumption of processed potatoes increased from 4.1 kg in 1940, to 51.5 kg in 1956, and reached 147.5 kg in 1972.

Commercial production of frozen French fries has increased about 800 times since 1947. Since 1970, frozen potato products have constituted 45 to 48 percent of all processed potatoes, or nearly 1/4 of the food use of potatoes in the United States (AFFI, 1969-1972). The frozen French fry industry provides a convenient product for institutional and home use, which is dependable regardless of the season of the year.

The objective of this study was a) to investigate the nutrient changes in two potato cultivars during the commercial processing of frozen French fries, and b) to conduct a sensory evaluation of the finish-fried potatoes prepared with different frying oil combinations.

LITERATURE REVIEW

A. French Fries Commercial Processing

The French fry commercial operations can be divided into the preparative and the preservative ones (Talburt and Smith, 1975), as shown in Figure 1. The preparative group includes the following:

Storage-Conditioning

Potato tubers, immediately after harvest, are stored first at 14°C for 10 days, and then they are transferred to about 4°C, with 92-94% RH and treated with sprouting inhibitors. Before processing they are conditioned, by transferring them to 14°C for 2-3 weeks to decrease the reducing sugar content.

Washing-Peeling

Unpeeled tubers are washed and then dipped in a 10-20% NaOH solution at 88°C for 60-90 sec., followed by removal of peel with high pressure streams of water, or by exposure of the tubers to infrared radiation.

Trimming-Sorting-Cutting

Peeled potatoes are conveyed over trimming and inspection belts, and then to the strip cutters where they are

PREPARATIVE OPERATIONS

STORAGE/CONDITIONING
(4.5°C, 92-94% RH/14°C for 2-3 weeks)
↓
WASH/PEEL
(10-20% NaOH Dip, 88°C, 60-90 sec)
↓
TRIM/SORT/CUT
(1.3x1.3x9.6 cm)
↓
BLANCH
(80°C, 8 min)
↓
PAR-FRY
(175°C, 60 sec)
↓
DEFAT/COOL
(vibration system)

PRESERVATIVE OPERATIONS

FREEZE
(I.Q.F. system, -30°C, 5-10 min)
↓
PACK/STORE
(-18°C)
↓
FINISH-FRY
(182°C, 2 min)

Figure 1. Unit operations in the production of French fries.

cut into strips 1/2 or 3/8 in. square.

Hot Water Blanching

Strips are usually blanched in water of 80°C, for 8 min. Blanching has several advantages including color improvement of the fried product, by decreasing the reducing sugar on the surface, and inactivating undesirable enzyme systems, improved texture of the final product and reduction of fat absorption. The disadvantage of blanching is the high nutrient losses, due to leaching (Dry blanching prevents these losses.)

Par Frying

Potato strips are fried with various frying fats, at 175°C for 60 sec. Par-frying removes any surface water adhering to the strips, so they will not stick together or onto conveyors when placed into the freezing tunnel. It also completes the enzyme inactivation.

Defatting-Cooling

Product passes over a vibrating screen, in order to drain off excess fat. Cooling reduces the load on the freezer.

The preservative operations include the following:

Freezing

The I.Q.F. (Individual Quick Freezing) is a popular system by which strips are conveyed on perforated belts

and frozen in a chamber of -30°C for 5-10 min.

Packing-Storage

The product is automatically packed in either cartons or poly bags and stored at -18°C.

Finish-Frying

French fries are fried intact at 180°C for 2 min.

B. Nutrient Composition

Specific Gravity - Dry Matter

The specific gravity and the total solids content of the potato tuber are very important criteria in selecting varieties, especially for the crisp product industry. Varieties have significant differences in specific gravity level, which is genetically controlled. Differences exist within the same variety, due to cultural and environmental conditions such as date of planting, soil type, soil moisture and temperature, location, type and amount of fertilizers, plant emergence and harvesting, pesticides, vine killing, etc (Findlen and Glaves, 1964). The earlier the planting, the longer the growing season, the higher the specific gravity. High soil moisture, excessive nitrogen applications, high temperatures and earlier harvesting decrease specific gravity. Harvest temperatures below 8°C reduce specific gravity (Findlen and Glaves, 1964).

Specific gravity affects the yield and oil content of crisps and to some extent it also influences their color. The higher the specific gravity the lower the oil accumulation in the crisps. Oily crisps are undesirable as well as costly to produce. Correlation coefficients for crisp yield and specific gravity have been reported in the literature (Findlen, 1964).

Relationships between specific gravity, dry matter (DM) and starch content of the tuber have also been reported (Simmonds, 1977; Vakis, 1978; Orphanos, 1980). Specific gravity is determined in several ways. The potato hydrometer is most widely used for potato sp. gravity determination, as it is rapid, accurate and inexpensive method.

Simmonds (1974) compared the DM content of potatoes from different countries and when allowance was made for a strong relation between maturity and DM, the following sequence, in ascending order of DM, was found:

USA < Germany < Britain < Netherlands

Mineral Content

Potatoes provide practically all essential dietary factors including minerals (USDA, 1982). True et al. (1978, 1979) found that fresh potatoes contribute significantly to the U.S. Recommended Dietary Allowance.

The factors which affect the mineral content of potatoes are: soil type, mineral content of the soil and potato

variety (Augustin, 1975). In addition, the outer cortical region has higher mineral concentration than the pith region within the same tuber.

Cooking has a negligible effect on mineral content of potato flesh, regardless of the cooking methods (True et al., 1979; Mondy et al., 1983) and potato peel contains significantly higher amounts of ash (16% of the whole tuber ash) than potato flesh (Augustin et al., 1979).

Fat Content

Surveys of the literature (Sayre et al., 1978; Lee et al., 1979) indicate that the average fat content (ether-extractible matter) of the potato is around 0.1 percent on a wet basis, with a range of 0.02 to 0.2 percent.

Early potatoes contain more lipids than late varieties. The lipid concentration of outer tuber layers is greater than of inner ones (Talburt and Smith, 1975). The fatty acids present consist of about 40% linoleic, 30% linolenic, 5% oleic, and 25% saturated acids, mainly as palmitic acid (Lee et al., 1979).

Sugars

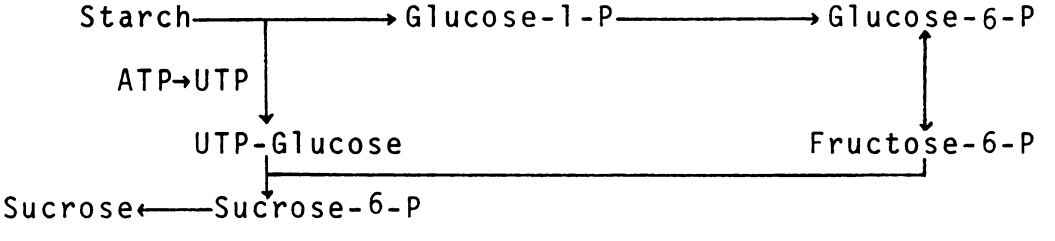
The sugars in the potato tuber are glucose, fructose (reducing sugars) and sucrose, as well as traces of maltose, xylose, sugar phosphates, raffinose, melibiose, heptulose and melezitose (Habib and Brown, 1957; Schwimmer et al., 1954).

The reducing power of potato extracts is not solely attributable to glucose and fructose. Chromatographic results indicate that there are several non-sugar components present which could conceivably react as reducing sugars. These include tyrosine, ascorbic acid, cysteine, and glutathione (Schwimmer et al., 1954).

The sugar content of potatoes varies from only traces to as much as 10 percent (dry weight). The two main factors which influence the sugar content of potatoes during post-harvest storage are variety and temperature. Also sugar content is affected during the storage by the maturity stage and pre-storage conditions (Sowokinos, 1978).

Potatoes high in sugar, taste sweet and have a poor texture after cooking. The poor texture is probably related to the low starch content associated with high sugar content. Isherwood (1973) found that a starch-sugar interconversion occurs by transferring potatoes stored at 10°C to 2°C and reverse, as the following schematic pathways show:

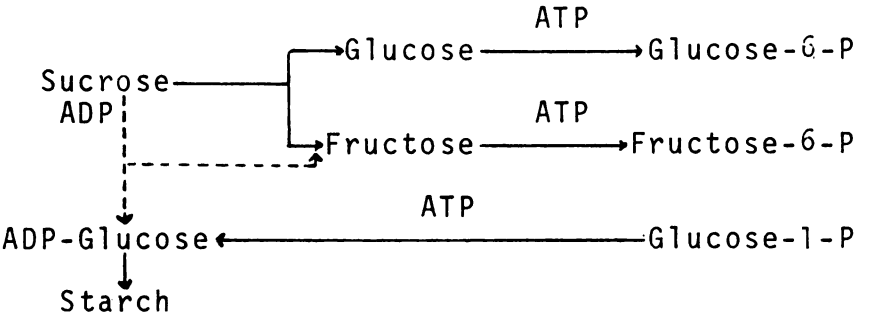
Transfer from 10°C to 2°C



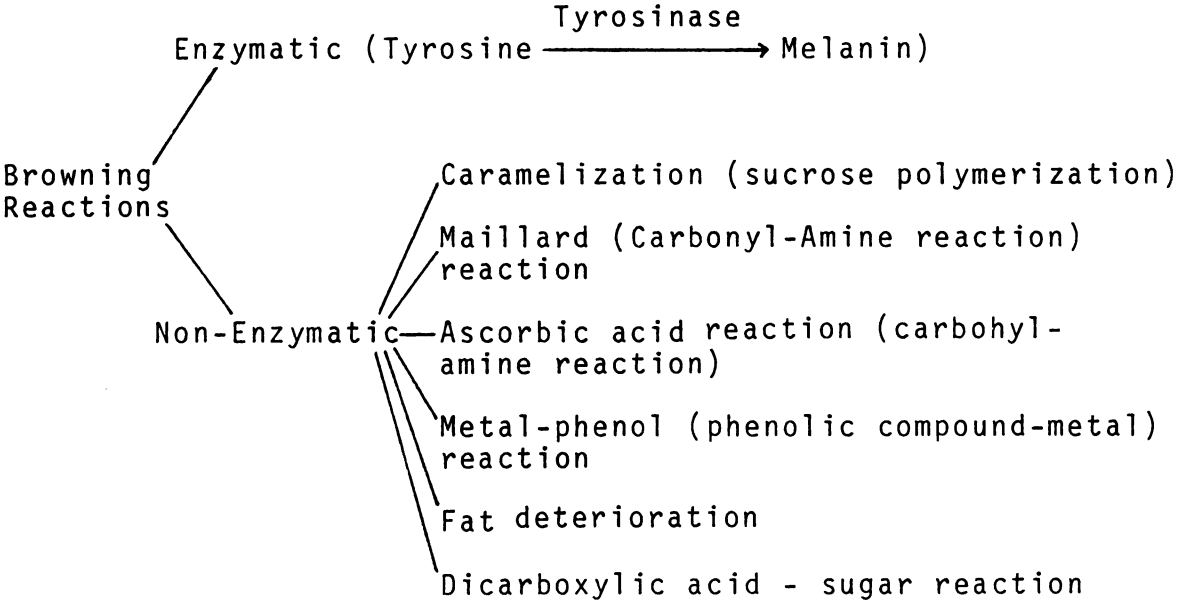
Pressey and Shaw (1966) found that the rapid conversion of starch to hexoses, at low temperatures, occurs due to a

rapid increase in invertase enzyme activity.

Transfer from $2^{o}C$ to $10^{o}C$



In the manufacture of French fries, potato chips and dehydrated potatoes, the sugar content is closely related to the color produced during the processing procedure. The source of the yellow to brown color of these products is attributed to so-called Browning Reactions which are illustrated in the following Scheme:



It has become increasingly clear in the last 20 years that the controlling factor in determining the amount of

browning is the reducing rather than the total sugar content. This suggests that the main mechanism in browning is one involving the Maillard reaction between the carbonyl groups of reducing sugars and the amino groups of the free amino acids and, perhaps to a lesser degree, of the proteins of the potato (Schwimmer et al., 1957; Hoover and Xander, 1961).

As a rule, potatoes containing more than 2.0% reducing sugars on a dry weight basis are considered to be unacceptable for processing. The correlation between reducing sugar content and browning tendency although generally good, is by no means perfect. This suggests that the already mentioned browning reactions, other than Maillard reaction, may be involved in the browning of processed potato products (Wisler, 1968).

In order to secure suitable raw material of low browning tendency, it is general practice to use potatoes which are poor sugar formers and to process potatoes in storage at periods during which they are at low sugar level and have not sprouted (Ewing et al., 1981).

The extension of storage life of potato tubers up to 10 months can be accomplished by maintaining optimum storage conditions such as temperature 3-4^{o}C, relative humidity 85-95 percent, efficient cooling, drying and heating facilities. The excessive sugar formation can be reduced by conditioning cold-storage tubers for 2 to 3 weeks at room

temperature, prior to processing; blanching of potatoes prior to frying decreases the reducing sugar content on the surface. Prediction of the storage potential of tubers can be made based on their sucrose content at harvest time (Ewing et al., 1981; Wilson et al., 1981; Rastovski, 1982; Califano and Calvelo, 1983).

Individual determination of glucose, fructose, and sucrose, the major sugars in potatoes, is becoming essential as more studies are being conducted on genetic and biochemical mechanisms of carbohydrate formation and degradation in potato tubers. Previous methods of determination include colorimetric procedures which do not distinguish between the monosaccharides, glucose and fructose, directly. Della Monica et al. (1974) quantified fructose by subtracting glucose, determined enzymatically from total reducing sugars. Sucrose was determined as the increase in glucose content, after acid hydrolysis of sucrose.

Chromatographic procedures include gas chromatography which determines the individual sugars, but requires a time-consuming derivatization step (Shaw, 1969). Currently High Performance Liquid Chromatography (HPLC) methods are the most preferable ones, since they determine the individual sugars without derivatization, and they are accurate, reproducible as well as sensitive to the 0.01 percent level (Wilson et al., 1981).

Nitrogen

Nitrogen content is not distributed equally in the potato tuber; it is highest in the periderm, and then decreases sharply in the cortex and rises again towards the pith (Herrera, 1979) (Figure 2). Throughout the tuber, total and soluble nitrogen are inversely related to specific gravity (Monday and Rieley, 1964). It is generally agreed that variations in environmental factors exert a greater influence on nitrogen content than does variety, except that early varieties tend to contain more nitrogen than do late varieties. Schuphan (1970) found that during the growth of potato tubers, the nitrogen content decreases gradually on a dry matter basis and the portion of protein is higher in the immature tuber. Protein N decreases in sprouting tubers.

The total nitrogen content can be broken down into a) true protein fractions soluble in various extracting solutions; b) insoluble protein residue, and c) non-protein nitrogen (NPN) which includes inorganic nitrogen, amide nitrogen, free amino acid (FAA) nitrogen, and basic nitrogen such as alkaloids, purines, pyrimidines, choline, enzymes, certain vitamins, quaternary ammonium compounds, etc.

Table 1 shows that potato tuber contains on the average 2.0% total protein (% Nx6.25) on a fresh weight, and it represents approximately 10.3% of the total solids of the potato (Kroner et al., 1950; Watt et al., 1963). According to Table 2, the true protein nitrogen is approximately 50%

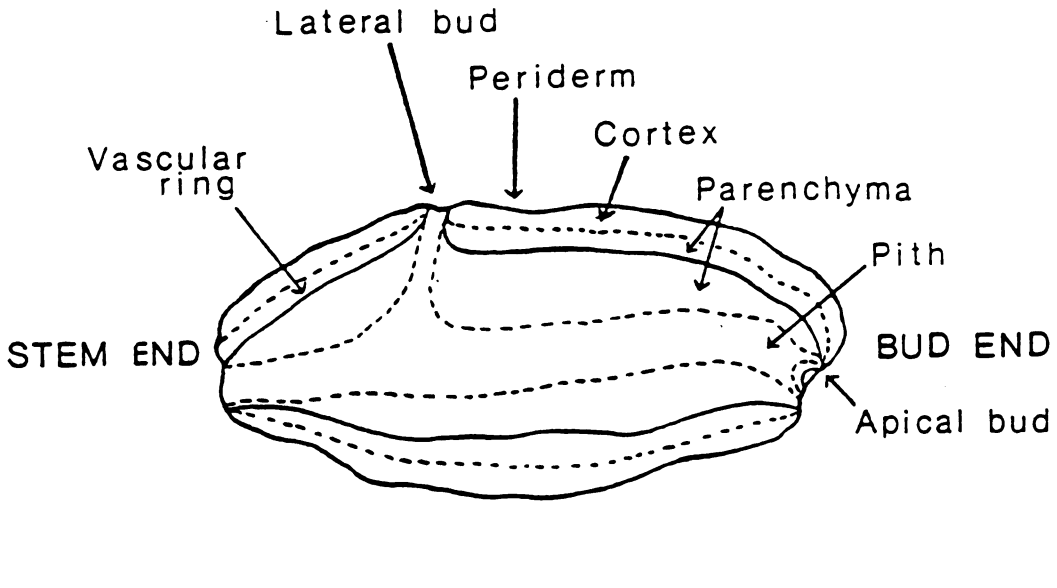


Figure 2. Structural features of potato tuber section.

Table 1. Proximate analysis of potatoes (wet basis) (Kroner et al., 1950; Watt et al., 1963).

	Average %	Range %
Water	77.5	63.2-86.9
Total solids	22.5	13.1-36.8
Protein	2.0	0.7-4.6
Fat	0.1	0.02-0.96
Carbohydrate		
Total	19.4	13.3-30.53
Crude fiber	0.6	0.17-3.48
Ash	1.0	0.44-1.9

Table 2. Nitrogen containing compounds (crude protein) of the potato (Schreiber, 1961).

N Fraction	% of Total N
True protein N	50
Non-protein N	50
Inorganic N	
Nitrate N	1
Nitrite N	trace
Ammonia N	3
Amide N	
Asparagine N	13
Glutamine N	10
Remaining N	
Free amino acid N	15
Basic N	8[a]

[a]Alkaloids, certain vitamins, purines, pyrimidines, quaternary ammonium compounds, etc.

of the total nitrogen (Schreiber, 1961) but may vary from 37% to 74% (Schuphan, 1960; Li and Sayre, 1975). In relation to Table 2, Markakis (1975) stated that it is doubtful that there is so much free ammonia (3%) in potatoes; ammonia is formed from glutamine during acid hydrolysis.

Kapoor et al. (1975) measured the protein fractions present in potatoes, as percentages of total protein nitrogen expressed on a freeze-dry basis, and found that globulin I (tuberin) accounted for 71.3%; globulin II, 3%; albumin (tuberinin), 6.6%; prolamine, 1.7%; glutelin, 7.6%; and insoluble residue, 9.8%.

It is known that heavy nitrogen fertilization results in a total protein increase, mainly by increasing the contents of aspartic and glutamic acids and amides asparagine and glutamine. Lysine content increases proportionally with fertilization, but methionine content drops significantly (Hoff et al., 1971). However, Leuscher (1972) found that a high free methionine content (2.07 g/16 g NPN) was obtained with 185 kgN/ha.

Quantitative differences for total protein, free and total amino acids, ratio of free to total nitrogen and methionine are attributed to differences in variety, year, location, fertilization and very highly to genotype x environmental conditions (Augustin, 1975; Davies, 1977).

Essential amino acids in the NPN fraction are present at a much lower level than in the protein fraction and no free

tryptophan or free cysteine could be detected in the NPN fraction. The methionine content of potato families varies and free methionine is responsible for 93% of the variation in available methionine. Free methionine ranges from 0.34 to 2.2 g/16 g non-protein N. Free methionine contributes from 12 to 62% of all methionine present in the total protein (Leuscher, 1972; Kaldy and Markakis, 1972; Herrera, 1979).

The free amino acids occurring in the NPN fraction are subject to variations affected by storage, nutrition of the plant, year, location and treatment with chemicals such as ethylene chlorohydrin (Talley et al., 1970). In general, the most abundant free amino acids are valine, arginine, aspartic acid, glutamic acid, and the amides asparagine and glutamine. However, in addition to the above Kaldy (1971) reported a very high serine content in six cultivars. He reported that 11% of the total N of potatoes was present in the form of free amino acids, 69% in the form of bound amino acids, and 20% was unaccounted for.

Nitrogen changes also have been studied in cooked potatoes, chips, canned, drum dried and french fried potato samples. The nitrogen losses occurring during processing are attributed to leaching of non-protein nitrogen. Free amino acid losses occur as a result of both leaching and the Maillard reaction.

Retention values of nitrogen and other constituents like minerals, water soluble vitamins and crude fiber are affected

by the cooking methods involved and specifically by the individual unit operations, e.g. blanching, deep-fat frying, mashing, dehydration etc. Water blanching is the chief contributor toward the reduction of nutrients. (Retention values of nitrogen and other constituents are significantly greater with hot air blanching).

The leaching losses in peeled potatoes or potatoes cut into small pieces are higher than in whole potatoes or potatoes cut into large pieces (Augustin et al., 1979; Herrera, 1979; Kozempel et al., 1982). Kozempel et al. (1982) reported that hot water blanching at 77^{o}C for 16 min resulted in significant losses of several amino acids, specifically glutamic acid, aspartic acid, valine, phenylalanine, arginine, methionine, tryptophan, as well as gamma-aminobutyric acid.

Potato protein is being recognized for its nutritional quality. The evaluation of the potato protein has been tested chemically by amino acid analysis and biologically by animal feeding experiments, human feeding experiments, and microbial growth. According to several investigators the potato protein has a good amino acid composition and balance for maintenance and growth promotion in humans. A protein score of 70 was reported by Markakis (1975) for the "pure" potato protein; this value compares favorably with other foods which have the following protein scores: beef 80, fish 75, soyflour 70, milk 60, wheat flour 50,

maize 54, rice 65 (FAO/WHO, 1965; Payne, 1976).

Potatoes have a high content in the amides, asparagine and glutamine, 13% and 10% of the total nitrogen content, respectively (Schreiber, 1961). It has been suggested that some compounds of the potato, such as amides, have a substantial influence upon the efficiency of the utilization of the amino nitrogen, by preventing the antagonism between certain amino acids; their role in human nutrition could be important subject for further investigations (McCay, 1959).

Ascorbic Acid

Potatoes have been reported to be a good source of several water soluble vitamins (Augustin et al., 1975). One hundred and fifty grams of raw potatoes can supply as much as 90% of the Recommended Dietary Allowances (RDA) for ascorbic acid, 12% for thiamin, 8% for riboflavin and folic acid each, as well as up to 20 and 30% for niacin and vitamin B6, respectively (Augustin et al., 1978).

The American Medical Association (1974) claims that potatoes continue to be an important vitamin C source, particularly for individuals who do not regularly consume other fresh or frozen vegetables and fruits.

The initial level of ascorbic acid in raw potatoes vary, as it is dependent on several factors, such as potato cultivar, production, harvest and storage conditions,

as well as length of storage. Long storage decreases ascorbic acid significantly. Potato products contain from 3-21 mg of vitamin C per 100 g (wet basis) depending upon initial concentrations of vitamin C in the raw potatoes and the method of processing (Augustin et al., 1978, 1979; Shekar et al., 1978).

Thermal processes such as blanching, soaking, and frying have been reported to result in losses of ascorbic acid in potato products (Augustin et al., 1978). Leaching and thermal degradation have been found to be the two main process parameters involved in ascorbic acid losses of potatoes and other vegetables. Some investigators (Lathrop and Leung, 1980) attribute ascorbic acid loss during hot water blanching of vegetables, almost entirely to leaching. Swartz and Carroad (1979) showed that, in the absence of leaching, thermal degradation accounts for ascorbic acid loss. However, Rognerud (1972) reported significant losses in ascorbic acid, during blanching of vegetables due to leaching. The leaching losses in some cases were two to three times greater than losses due to thermal degradation. Kozempel et al. (1982) reported a leaching model, with diffusion as the rate controlling step, which successfully predicted losses of the water soluble vitamins of hot water blanched potatoes, as a function of process parameters.

Retention values of ascorbic acid during potato processing are dependent on several factors including peeling, temperature and duration of blanching, circulation of blanching water, as well as time and temperature of processing steps following blanching. Pelletier et al. (1977) reported ascorbic acid retentions of 66 to 80% for fried potatoes while Artz et al. (1983) reported retention values ranged from 83.2 to 54.1% for water blanched French fries.

C. Frying Fats

In the recent decades there is a worldwide trend to consumption of oils at the expense of solid fats. The increased consumption of fluid fats is related to the wider use of frying techniques. In the culinary process known as "saute" only a small quantity of animal or vegetable fat is used in the vessel, while in "deep frying" food is submerged in a bath of oil.

In the U.S. oil consumption has increased by a factor of 14, during 1910-1976, the last ten years showing a much higher rate (Friend et al., 1979). This is related to the rapid growth of the pre-cooked food industry, primarily the pre-fried foods (potatoes, chicken, fish, etc).

In general, the significance of the frying process is the same as of all thermal processes:

a) notable increment of palatability

b) decrease of the preparation time

c) small oxygen influence

Nutritionally, frying affects the palatability, digestibility and metabolic utilization of both food and frying fat (Varela, 1980).

The frying fats commonly used in commercial production line of French fries are hydrogenated vegetable oils such as cottonseed, soybean, palm, sunflower, coconut, peanut corn oil, either alone or in combinations, depending upon price and availability.

The vegetable oil is hydrogenated, a process of adding hydrogen to the unsaturated fatty acid component of the fat, to increase its stability against rancidification. Hydrogenated shortenings usually have a high smoke point, and are also resistant to foaming and gum formation during frying.

Olive oil is particularly palatable due to its organoleptic properties, which are mainly attributed to a number of pleasant flavoring compounds, such as aliphatic and aromatic hydrocarbons, aliphatic and terpenoic alcohols, aldehydes, ketones, ethers, esters, furan and thiopene derivatives (Fedeli, 1977). In the frying of potatoes olive oil forms a thin crust of high fat concentration, while other fats form a thicker and less dense crust (Varela, 1980).

Phenols, sterols and primarily tocopherols are natural antioxidants responsible for the stability of vegetable oils. Olive oil is relatively high in natural antioxidants, particularly in tocopherols (Sherwin, 1976). The basic criteria for evaluation of olive oil quality are the free fatty acid (FFA) content, the peroxide value, the ultraviolet absorption values, and the organoleptic characteristics (taste and odor). The reason olive oil is not used commercially in frying industry is its high price. Nevertheless it is very popular in home prepared fried stuff, particularly for the finish-frying of commercially frozen "par-fried" foods, all over the world.

Kernel olive oil is oil extracted from olive fruit kernels after the extraction of olive oil from pressed fresh olives. Commercially, it is subjected to refining by decolorization (clarification), neutralization of FFA excess (acidity reduction), and deodorization. It can be used in the par-frying step of French fries production, since it bears some of the olive oil organoleptic properties, which keep it in very competitive position, as compared to other vegetable oils; on the other hand, it is inexpensive, fact that supports its position, particularly in countries where it is available.

Fat may break down or deteriorate in several ways during frying, including:

Hydrolysis

Reaction with water or steam which breaks the fat into its component fatty acids and glycerol. Free surface water should be removed from French-fry slices to reduce fat hydrolysis. The FFA content of the commercial shortening should be kept below 1%.

Oxidation

Atmospheric oxygen reacts with fat and causes darkening, foaming, and development of off-odors and off-flavors during frying. An oxidized fat reduces the storage stability of the fried product. Fat oxidation ends up as rancidity, although fats do not reach this stage in the frying operation. Excessive oxidation may be avoided by preventing aeration during filtering and circulating of the frying fat.

Polymerization

Formation of gum or gummy deposits in frying fats is attributed to polymerization. Oxidation may or may not be involved.

MATERIALS AND METHODS

A. Potato Processing

Two potato cultivars were chosen for this study: cv. Jaerla (spherical, medium solids content) and cv. Spunta (oblong, medium solids content).

These cultivars are of Dutch origin, but they have been cultivated for more than two decades in Greece. Potatoes were grown on the NE region of Greece, called Xanthi. They were fertilized with 115 kg/ha N, 50 kg/ha P_2O_5 and 120 kg/ha K_2O.

After harvest, tubers were stored at 14°C for 10 days and then they were transferred to 4.5°C with 92% RH. Chloro-isopropyl-phenylcarbamate (CPC) was used for sprouting inhibition.

A potato hydrometer was used for the specific gravity determination of the tubers. After 2 months storage, the tubers were conditioned at 14°C for 15 days, before processing.

Approximately 50 kg of tubers, from each cultivar, were washed, peeled by a 10% NaOH solution at 88°C for 90 sec, cut to pieces of 1 cm x1 cm x 6 cm and hot water blanched at 80°C for 8 min. A portion of unblanched raw pieces

were stored at 4.5°C.

The water-blanched pieces were par-fried in kernel olive oil at 175°C for 60 sec, immediately defatted by a vibration system, air-cooled and frozen at -30°C by the I.Q.F. (Individual Quick Freezing) system. A portion of the frozen par-fried slices were stored at -18°C. The rest frozen par-fried slices were finish-fried with olive oil of 182°C for 2 min and stored at 4°C.

The above processing was employed in a commercial operation in Greece. A quantity of the same raw potatoes were brought by air to M.S.U., where they were processed in a fashion similar to that in Greece.

B. Analytical Methods

Moisture, ash, fat, total Kjeldahl N, non-protein N, free amino acids and ascorbic acid were determined in raw, par-fried and finish-fried potatoes. Individual sugars were assayed in raw potatoes. Total and free fatty acids were determined in olive oil and kernel olive oil. Some of the above mentioned nutrients were analyzed in Greece, some in M.S.U. and some in both places as shown below:

Greece	M.S.U.
moisture	Kjeldahl N
ash	non-protein N
fat	FAA's
Kjeldahl N	ascorbic acid
non-protein N	sugars
	total FA's
	FFA's

Duplicate or triplicate samples at each processing step, from each cultivar were used.

Moisture Content Determination

The moisture content was determined by the AOAC method 14.002 (1980). The vacuum oven (Precision Thelco, model 29, Chicago, IL) was adjusted at 60°C until constant wt (5 days).

Ash Content Determination

Basically the AOAC method 7.009 (1980) was used with minor changes.

Fat Content Determination

The AOAC method 44.174(a) (1980) was employed to determine the crude fat content by an intermittent extraction with the Soxhlet apparatus.

Sugar Analysis by High Percormance Liquid Chromatography (HPLC)

Liquid Chromatography

A Waters Associates HPLC (Milford, MA) equipped with an M-45 Solvent Delivery System, a 600 A pump, a Rheodyne 701 injector (load-inject 20 µl), two combined Differential Refractometers (one R401 and one Electronic Unit), was used. The detector signal was recorded on a Kontes 100 Recorder.

The column system consisted of a 3.2 mm i.d.x4.0 cm precolumn packed with C18 Porasil B (Waters Associates) and

a 3.9 mm i.d.x30 cm column packed with μBondapak/Carbohydrate packing.

The mobile phase was acetonitrile (CH_3CH, 99+% spectrophotometric, Grade Gold Label) - water in a ratio 80:20 (both products of Aldrich Chemical Co., Inc., Milwaukee, WI)

Operating conditions:

Injection amount: 20 μl

Flow rate: 3.5 ml/min

Detector Sensitivity (Attenuation): 4x

Chart Speed: 1 cm/min

Recorder's Amplifier 88-0083:10 mV

Standard Solution Preparations

Fourteen standards of four sugars (fructose, glucose, sucrose, and maltose were prepared in 25 ml volumetric flasks containing equal concentrations of each sugar as follows: 0.025, 0.05, 0.1, 0.2, 0.3, 0.4, 0.5, 0.6, 0.7, 0.8, 0.9, 1.0, 1.1, and 1.2 mg/ml. A 10 ml aliquot was removed from each 25 ml volumetric flask and mixed separately with 10 ml of Ethanol 80% followed by centrifugation at 2000 rpm for 15 min (Sorvall, type SS-1, Gx6000).

After passing the supernatant through a C_{18} Sep Pak filter (Waters Associates), the first milliliter of each standard was discarded and the next 2.5 ml was collected. A reference curve for each sugar was prepared by injecting 20 μl of the standard solutions, as shown in Figure 5.

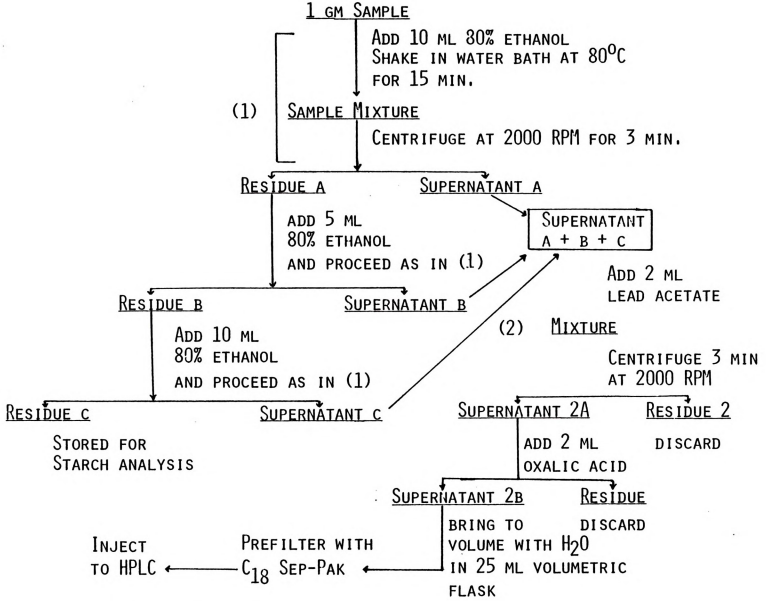


FIGURE 3. FLOW DIAGRAM OF SUGAR ANALYSIS.

Quantification of each of the sugars was accomplished by comparing peak area of the samples to peak area of the standard.

Sample Preparation

Samples were macerated in a Blender 700, Model 1120 (Dynamics Corp., N. Hartford, CT), and 1 g of each sample was processed as in Figure 3 (Agbo, 1982).

The water bath used was a Gyrator (New Brunswick Scientific Co., N. Brunswick, NJ).

The centrifuge was the same used for the standard solution.

The lead acetate ($Pb(C_2H_3O_2)_2 \cdot 3H_2O$ (Mallinckrodt Chemical Works, NY) was used to clarify the sample solution.

In order to precipitate the lead, oxalic acid (Mallinckrodt Co.) was added.

All samples passed through a filter system connected to a syringe in the following order: C_{18} Sep Pak-Millipore filter, type AP-Millipore filter, type HA (pore size: 0.45 μm, Millipore Corp., Bedford, MA). The sample was injected through the syringe to the Rheodyne injector which loaded-injected to HPLC 20 μl per time.

Recovery Studies

The recovery of added fructose, glucose, sucrose and maltose at two levels (2 mg/g and 8 mg/g) was determined by dividing the extract of 2 g slices into two equal portions, with one portion having no sugar added, while

the other was spiked with sugar at the appropriate level. The recoveries were calculated based on the difference between the total amount determined in the spiked samples and the amount found in the non-spiked samples.

Total Nitrogen Determination

The conventional "total protein" content (Nx6.25) was determined by the AOAC 7.015 (1980) Kjeldahl method.

Non-protein Nitrogen Determination

3.5 g of each sample were mixed with 10 ml of 10% trichloroacetic acid (TCA), left to stand for one hour, and then centrifuged. The supernatant was decanted and saved, and the precipitate was washed twice with 5 ml 5% TCA and centrifuged. The collected supernatants were concentrated in a rotary evaporator under vacuum to about 5 ml, then diluted to 10 ml with 5% TCA.

Later 2 ml out of 10 ml of this solution were used to determine the non-protein N content by the A.O.A.C. 47.021 (1980) Micro-Kjeldahl method. Percentage of non-protein N was calculated by the following formula:

$$\% N = \frac{(\text{ml HCl} - \text{ml Blank}) \times \text{HCl Normality} \times 14.007 \times 100}{3500 \text{ mg sample}}$$

Free Amino Acid Determination

The free amino acid content of 12 samples (duplicates x 3 processing stages x 2 varieties) was determined by a

121 Automatic Amino Acid Analyzer (Beckman, Palo Alto, CA).

Samples were prepared as described by Toepher (1965) for tissue extracts.

A 3.5 g FW of each sample was triturated with 35 ml 1% picric acid (Eastman, Rochester, NY) and the mixture was promptly centrifuged to remove the precipitate. The supernatant liquid was then passed through a 2 cm high Dowex 2-x10 resin column in a 2x20 chromatograph tube. The walls of tube and the resin bed were washed with five 3 ml samples of 0.02 N HCl. The effluent and washings were concentrated under vacuum on a rotary evaporator at 55°C to about 3 ml. The concentrate was quantitatively transferred to a small glass tube and adjusted to pH 7.2 with 1 N NaOH. To this solution 0.2 ml of freshly prepared 0.5 M Sodium Sulfite was added, and the sample was allowed to stand, open to the air, for four hours. The pH of the solution was adjusted to 2.2 with 1 N HCl, and diluted to 10 ml final volume.

Fifty microliters of each sample were analyzed on the Amino Acid Analyzer. The Amino Acid Analyzer was operated at 44°C and 65°C for 5 hours.

A Sodium Citrate (Pierce, Rockford, IL) buffer system of pH 2.2±0.01 was used.

Each sample (50 µl) was mixed with 1950 µl of the buffer system.

The resulting chromatograms were compared to those obtained from the analysis of a standard amino acid

calibration mixture. Ten nanomoles of norleucine and 10 nanomoles of taurine were used as standard amino acid mixture. The integration by height-width method (Beckman Instruction Manual AIM, 1962) was used to calculate the amino acid peak area, which compared to the standards and converted accordingly gave the free amino acid content.

Total Ascorbic Acid Determination

The ascorbic acid was determined as total ascorbic acid = reduced ascorbic + dehydroascorbic acid. The fresh weight of each sample was in the range 40-60 g. The AOAC 43.061 (1980) microfluorometric method was employed for this purpose. Naturally occurring reduced ascorbic acid was oxidized to dehydroascorbic acid in presence of norit. The total dehydroascorbic acid is reacted with o-phenylene-diamine to produce a fluorophor which has an activation max. at approximately 350 nm and a fluorescence max. at approximately 430 nm. Fluorescence intensity is proportional to concentration.

Ascorbic acid plus dehydroascorbic acid is calculated by comparing the corrected fluorescence reading for the sample, with that of a standard solution similarly oxidized and treated.

A Fluorometer G.K. Turner, model B111 (G.K. Turner Associates, Palo Alto, CA) was used for the fluorescence measurement.

C. Fatty Acid Analysis of Frying Oils

Total Fatty Acid (FA) Composition

The fatty acid composition of both olive oil and kernel olive oil was determined by Gas-Liquid Chromatography, followed exactly the same procedure. Both oils were Greek commercial oils.

Fatty acid methyl esters were prepared according to the method of Morrisson and Smith (1964).

Boron trifluoride-methanol was used for the esterification, as shown below:

$$RCOOH + CH_3OH \xrightarrow{BF_3} RCOOCH_3 + H_2O$$

Fatty acid — Methanol — Methyl ester

Preparation of Methyl Esters

The oil was placed in centrifuge tubes and the reagent was added under nitrogen in a proportion of 1 ml reagent per 4-16 g of oil. Tubes were closed with screw caps and heated, at 100°C for 30 minutes, cooled and opened.

The esters were extracted by adding 2 volumes of pentane, then 1 volume of water, shaking briefly and centrifuging until two clear layers were formed. The top layer which contained the esters was removed using a micro-pipette and placed in a clean vial.

Gas Liquid Chromatography

With a GC syringe, 1 µl sample was injected into a Hewlett Packard Gas Chromatograph 5840A, equipped with a hydrogen flame detector. A coiled stainless steel column, model 1-1904 (Supelco Inc., Bellefonte, PA), 180 cm long and 3 mm i.d. packed with 15% (w/w) DEGS on 80/100 mesh Chromosorb-w was used for the separation of the methyl esters.

Operation Conditions:

Column oven temperature: 100°C

Injector temperature: 210°C

Detector temperature: 350°C

Flow rate of nitrogen carrier gas: 31.3 ml/min

Flow rate of hydrogen: 24.6 ml/min

Attentuation: 7

The emerging components were identified by comparison with standard mixtures of known fatty acid methyl esters.

Peak areas were calculated by an electronic integrator (5840 GC Terminal Hewlett Packard).

Free Fatty Acid (FFA) Determination

The FFA were isolated by Blakely's column chromatography procedure (1970).

Removal of FFA from Fat

Reagents: a) Silicic acid (Mallinckrodt 2847, 100 mesh). Coarser particles of silicic acid were selected by suspending 100 g in 400 ml methanol and decanting and

discarding the silicic acid that did not settle within 5 min. This procedure was repeated once with methanol and once with 400 ml of acetone. The remaining silicic acid was rinsed with ethyl ether and air dried.

Fifty grams of the coarse particle preparation were washed 3 times with 150 ml ether containing 2.5 percent phosphoric acid and then washed 2 times with 150 ml ether. The silicic acid was air dried, washed with distilled water, redried, and activated in a vacuum oven at 175°C for 18 hrs and stored in a desiccator; b) Isopropanol-KOH: Twenty-five grams of KOH pellets (85%) was dissolved in 400 ml of isopropanol by warming on a steam bath and swirling. The supernatant isopropanol-KOH solution was decanted from aqueous KOH clinging to the bottom of the flask. Solution was cooled and stored at 4°C.

Procedure (Column Chromatography): Four grams of prepared silicic acid were weighed into a 50 ml beaker. Eight ml of isopropanol-KOH and 24 ml of ethyl ether were added to the silicic acid with mixing. After standing 5 min, the silicic acid was slurried into a 18x180 mm chromatographic column, equipped with a fritted glass filter, 2 mm Teflon stopcock and a detachable 250 ml liquid reservoir.

The column was washed with 100 ml of ether and air bubbles removed with a glass rod.

Five ml oil was passed over the silicic acid-KOH column within one minute. The column was washed with 75 ml

of ether to remove the lipids.

The FFA were eluted with 60 ml of ether containing concentrated phosphoric acid (2.5 percent, v/v) at a flow rate of 10 ml/min. The eluate was collected in a round bottom flask and the solvents were removed with a rotary evaporator.

FFA Composition

The esterification and GLC procedures were similar to those for the total FA's with the only modification, that esterification was accomplished in 2 min at 100°C rather than 30 min at 100°C.

Total FFA Content

Total FFA's were determined by the official AOAC 28.029(b) (1980) method.

To 50 ml 95% alcohol, a few drops of oil and 2 ml 1% phenolphthalein indicator were added and placed at 60-65°C water bath. Alcohol was neutralized with enough 0.1 N NaOH to produce faint permanent pink. An oil sample of 56.4 g was added to the neutralized alcohol and titrated with 0.1 N NaOH until the appearance of pink color persisted for 30 sec.

The FFA percentage was calculated by multiplying the ml of 0.1 N NaOH by 0.05 and expressed as % oleic acid.

D. Frying Quality of Oils

The quality evaluation of the finish-fried product of both varieties was based on the USDA (1967) grade system with some modification. The relative importance of each scored factor is expressed numerically on a scale 0 to 100. The maximum number of points that may be given each factor is:

Factors	Score Points
Color	30
Texture	30
Taste-Flavor	40

Six Greek commercial oils were used and seven frying oil combinations were employed to par-fry and finish-fry potatoes of both varieties as follows:

Oil Combinations

a. 100% kernel olive oil (par-frying), 100% olive oil (finish-frying)

b. 100% kernel olive oil (par-frying), 50% olive oil + 50% kernel olive oil (finish-frying)

c. 100% kernel olive oil (both fryings)

d. 100% corn oil (both fryings)

e. 100% sunflower oil (both fryings)

f. 100% cottonseed oil (both fryings)

g. 100% palm oil (both fryings)

Six Greek panelists were employed and evaluated the French fries of both varieties processed with the above mentioned seven frying oil combinations in Greece. They also evaluated the frying quality of the seven oil groups according to Kramer's method (1963) of Rank Sums.

Seven samples of French fries, one from each oil combination, were ranked for sensory evaluation by six panelists. Samples were ranked from 1 (most accepted) to 7 (least accepted).

Kramer's rank totals table (Table 23) was used for determining the significance of differences between the seven oil groups. Samples which did not show any significance of differences were re-ranked.

RESULTS AND DISCUSSION

A. Nutrient Analysis

Specific Gravity-Dry Matter-Moisture

The specific gravity and dry matter (DM) results are shown in Table 3. They are slightly different than those reported by Vakis (1978) in Cyprus, as a mean for each variety, but they fall within the reported range. The differentiation of the specific gravity of the same variety is affected by factors such as soil type, soil moisture and temperature, location, type and amount of fertilizers, date of planting, plant emergence and harvesting, pesticides, vine killing etc. (Findlen and Glaves, 1964).

The results were positively correlated to the dry matter (DM) content of the tuber and fit the formulae and tables given by Simmonds (1974, 1977), Vakis (1978), and Orphanos (1980).

D% = 211 G - 207.7 (Simmonds)

D% = -269.59 + 268.24 G (Orphanos)

where D = Dry matter

G = Specific gravity

Table 4 gives the moisture content and retention in raw, par-fried and finish-fried potatoes, on a fat and

Table 3. Relationship between specific gravity (G) and dry matter (DM) in cv. Jaerla, and cv. Spunta[1].

Cultivar	G	DM from analysis	DM from Simmonds (1974) formula
Jaerla	1.080	20.2	20.2
Spunta	1.076	19.5	19.3

[1]Means of triplicates.

Table 4. Moisture content in raw, par-fried and finish-fried potatoes (% with fat, % fat-free, and % retention)[1]

	cv. Jaerla			cv. Spunta		
	with fat	fat-free	retention	with fat	fat-free	retention
Raw	79.8	79.8	100	80.5	80.5	100
Par-fried	72.9	76.5	96	71.6	75.7	94
Finish-fried	47.3	58.0	73	47.1	58.2	72

[1]Means of duplicates.

fat-free basis. Because of differences in the moisture and fat content between the product of the three processing steps, changes in the nutrient retention values could not be properly assessed, unless they had been computed on an equal moisture of dry weight and fat-free basis. It should be clarified that initial fat content is not excluded on the fat-free basis. Consequently, the data listed in all following tables were computed on such a basis.

Ash Content

Table 5 shows the ash content of the potatoes during processing as well as the ash retention values in the par-frying and finish-frying step. The results are in good agreement with those reported in the literature (Augustin et al., 1979).

Ash losses in the par-frying step are attributed to leaching of minerals during blanching, and par-frying. Leaching losses are greater in the finish-frying step, because they occur as a result of, either the disruption of cellular membranes, caused by freezing, or by the increased cell separation of the cooked tissue at the higher and longer temperature of the finish-frying (Fedec et al., 1977; Mondy et al., 1983).

Fat Content

Table 6 shows the fat (%) content of raw, par-fried and finish-fried potatoes. The results fall within the

Table 5. Ash content in raw, par-fried and finish-fried potatoes (% wet and fat-free dry basis, and as % retention)[1]

	cv. Jaerla			cv. Spunta		
	wet	fat-free dry	retention	wet	fat-free dry	retention
Raw	0.80	3.97	100	0.85	4.38	100
Par-fried	0.73	3.10	78	0.85	3.48	79
Finish-fried	0.91	2.16	55	1.02	2.43	56

[1]Means of duplicates.

Table 6. Fat content in raw, par-fried and finish-fried potatoes (% wet and fat-free dry basis)[1]

	cv. Jaerla		cv. Spunta	
	wet	fat-free dry	wet	fat-free dry
Raw	0.1	0.5	0.1	0.5
Par-fried	3.7	15.8	4.1	17.1
Finish-fried	10.8	25.7	11.1	26.7

[1]Means of duplicates.

range reported by several workers (Sayre et al., 1978; Lee et al., 1979).

Fat content increased gradually going from raw to finish-fried product. An exchange of water for oil during frying occurs. According to Tables 4 and 6 there is a negative relationship between moisture losses and fat increases. In the case of par-frying, oil absorption exceeded moisture loss, whereas in the case of finish-frying moisture loss exceeded fat absorption. These observations are in accordance with those of Higo (1981).

The cv. Spunta absorbed more oil than the cv. Jaerla, probably because cv. Jaerla contains more solids than cv. Spunta. Generally, the higher the specific gravity the lower the oil absorption in the crisps (Marlowe, 1966).

Sugar Content

Figure 4 shows a typical separation of fructose, glucose and sucrose. For these three sugars, two recovery tests resulted in the 100% recovery for fructose, 98% for glucose, and 94% for sucrose.

Figure 5 shows the reference curves used for the quantitative estimation of fructose, glucose and sucrose. The characteristics of the reference curves are shown below:

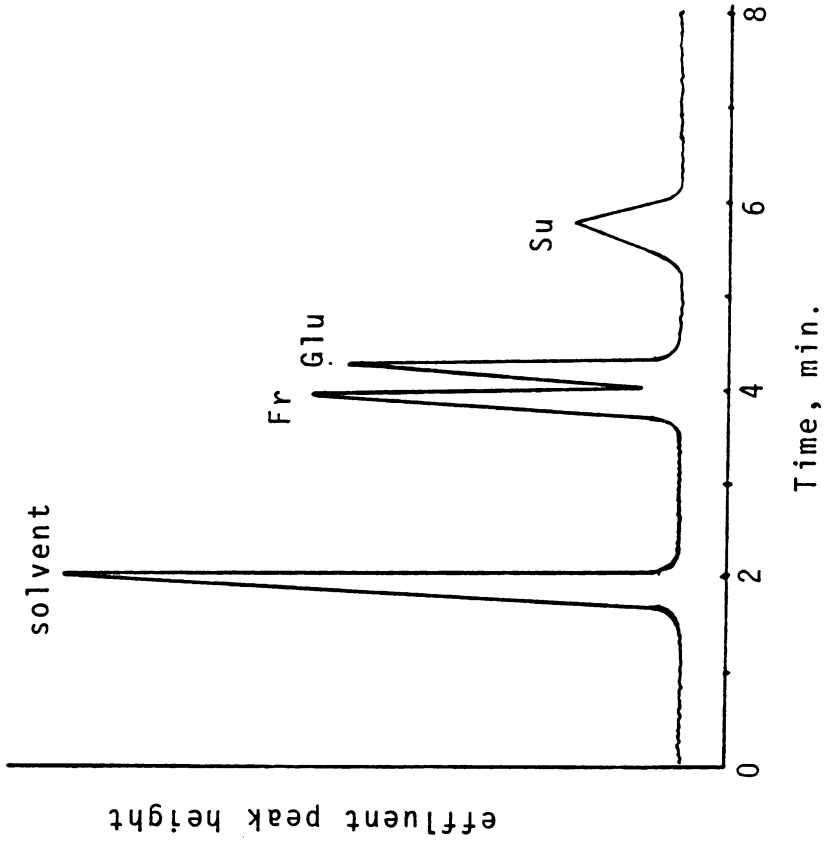


Figure 4. Elution of fructose, glucose and sucrose from a potato extract (Figure 3) through an HPLC column (Waters C-18), with acetonitrile-water, 80:20 v/v.

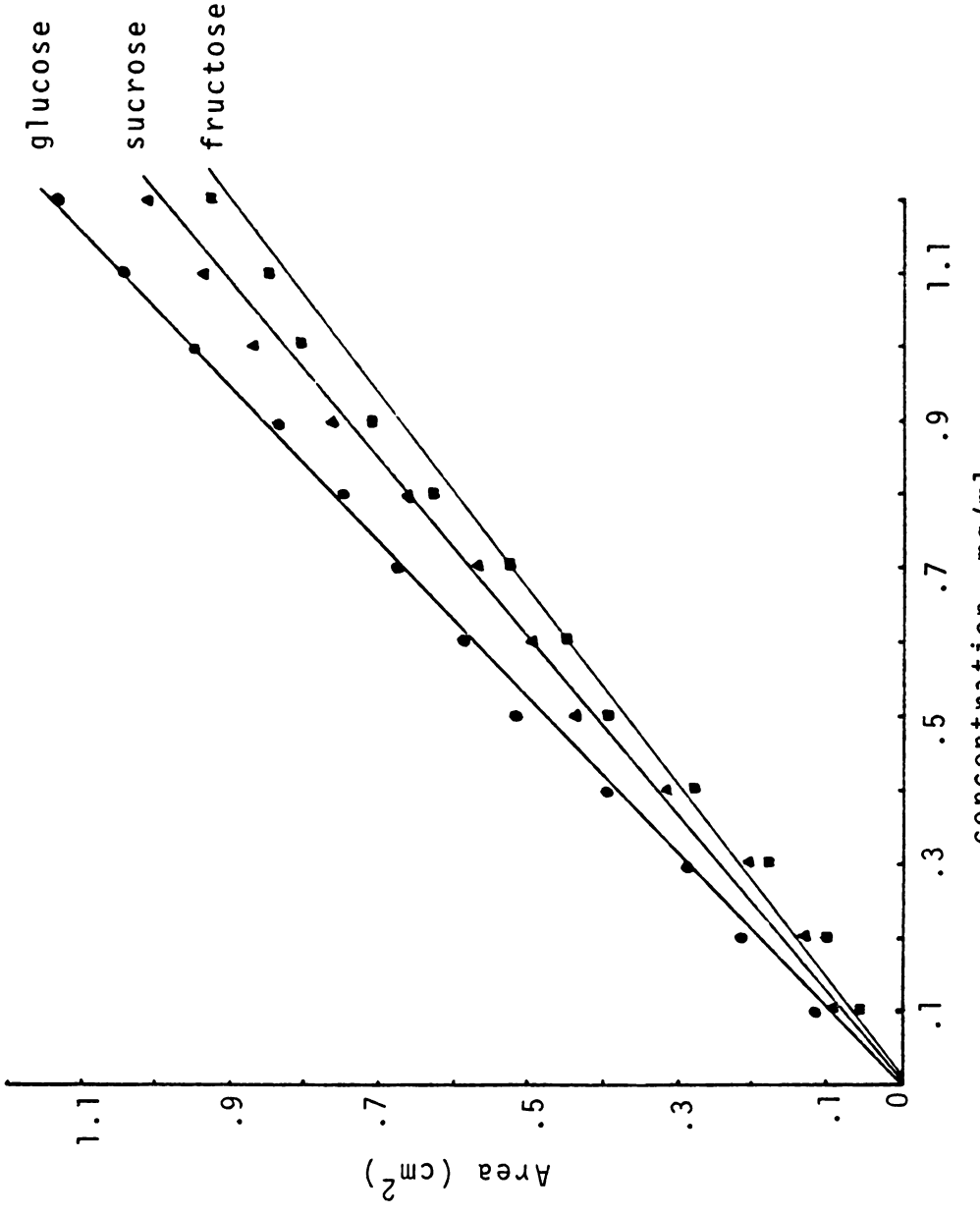


Figure 5. Reference curves for the quantitative estimation of fructose, glucose and sucrose in raw potatoes by HPLC (Figure 4).

	Slope	Intercept	Correlation
Glucose	0.91185	0.03428	0.99902
Fructose	0.84130	-0.03317	0.99614
Sucrose	0.85038	-0.00365	0.99654

Table 7 shows the percent content of fructose, glucose and sucrose in cv. Jaerla and cv. Spunta tubers, stored at 4.5°C for 2 months and conditioned at 14°C for 15 days. Results show that cv. Jaerla forms a little higher sugar content than cv. Spunta. Both cultivars can be considered as low sugar formers, since they did not contain more than 1% dry basis, reducing sugars (2% reducing sugar content, dry basis, is the upper limit acceptable for processing). In fact, they showed a low browning tendency, even when they were fried immediately after storage at 4.5°C for 2 months, without any conditioning at higher temperature.

The results are in accordance with those reported by Wilson et al. (1981) for Kennebec, Katahdin and Russet Burbank tubers stored at two storage temperatures (3.3°C and 7.2°C) and analyzed by similar HPLC method. The sensitivity of the method of this study was up to 0.01 percent level.

Nitrogen Content

The analyzed cultivars showed a closed N composition as well as similar N retention values during the processing.

Table 7. Sugar content in cv. Jaerla and cv. Spunta potatoes stored at 4.5°C for 2 months and conditioned for 15 days at 14°C (% wet and dry basis)[1].

	cv. Jaerla		cv. Spunta	
	wet	dry	wet	dry
Fructose	0.08	0.396	0.06	0.308
Glucose	0.11	0.545	0.09	0.462
Sucrose	0.05	0.250	0.04	0.205

[1]Means of triplicates.

Crude protein content (Kjeldahl N% x 6.25) and percent retention values of raw, par-fried and finish-fried potatoes are shown in Table 8. Augustin et al. (1979) measured the retention values of crude protein in the finished product as compared to the corresponding raw material, as well as the retention during water blanching. The data in Table 8 are in good agreement with those reported by those investigators. It is important to mention, that N retention values in large sized French fries, after par-frying, are a little lower than those after water blanching. Differences between total N retention in the finish-fried product and retention in the par-fried one were not significant. The data clearly show leaching to be the main reason of crude protein losses, occurring primarily during water blanching, and to some extent during par-frying and finish-frying of the commercial frozen potato product operation.

Tables 9 and 10 show total and non-protein nitrogen (NPN) content, their retention values, and ratio (NPNx100): total N changes during processing of the two potato varieties. The retention values of total N (crude protein) and NPN in par-frying and finish-frying are 80, 71% and 60, 39% for cv. Jaerla and 79, 69% and 58, 38% for cv. Spunta, respectively. It is noteworthy that the retention values for NPN after finish-frying are much lower than those for total N.

Table 8. Crude protein content in raw, par-fried and finish-fried potatoes (Kjeldahl N% x 6.25, % wet and fat-free dry basis, and % retention)[1]

	cv. Jaerla			cv. Spunta		
	wet	fat-free dry	retention	wet	fat-free dry	retention
Raw	2.1	10.3	100	2.0	10.3	100
Par-fried	1.9	8.2	80	2.0	8.1	79
Finish-fried	3.0	7.2	70	2.9	7.0	69

[1]Means of duplicates.

Table 9. Total nitrogen (Kjeldahl) and non-protein nitrogen (NPN) contents in Jaerla potatoes (in mg N/100 g potatoes, wet, and fat-free dry basis and as % retention.

	Total N			NPN			NPN / total N x 100
	wet	fat-free dry	retention	wet	fat-free dry	retention	
Raw	333	1646	100	168	830	100	50
Par-fried	309	1317	80	117	498	60	38
Finish-fried	491	1153	70	136	324	39	28

[1] Means of duplicates.

Table 10. Total nitrogen (Kjeldahl) and non-protein nitrogen (NPN) contents in Spunta potatoes (in mg N/100 g potatoes, wet, and fat-free dry basis and as % retention)[1].

	Total N			NPN			NPN / total N x 100
	wet	fat-free dry	retention	wet	fat-free dry	retention	
Raw	320	1642	100	167	856	100	52
Par-fried	313	1290	79	121	496	58	38
Finish-fried	470	1125	69	136	326	38	29

[1]Means of duplicates.

The ratio (NPNx100):total N in raw, par-fried and finish-fried product is 50, 38 and 28% for cv. Jaerla and 52, 38 and 29% for cv. Spunta, respectively. These figures also show that NPN losses are much higher than those for crude protein.

Both retention values and ratio changes following processing indicate that water soluble NPN fraction contributes mostly to the nitrogen losses, by leaching through the potato cell membranes.

Tables 11 and 12 show free amino acid (FAA) content, retention value, and free amino acid N as % of total Kjeldahl N of raw and processed potatoes. Sixteen FAA's were determined by the Beckman 121 automatic amino acid analyzer. Free cystine and tryptophan did not appear in the chromatograms. Kaldy (1971) and Herrera (1979) also did not find these amino acids free in the American potatoes, that they analyzed.

The dominant FAA's in raw and processed potatoes of both cultivars were aspartic acid, serine, glutamic acid and arginine. The FAA composition of potatoes, given in Table 13, is affected by the mineral nutrition of the plant, the environmental conditions, the variety and other factors (Davies, 1977). The two cultivars analyzed here differed slightly from each other in their FAA composition. Their serine content is higher than that reported by other workers (Davies, 1977; Herrera, 1979), but similar to that

Table 11. Free amino acid (FAA) content in raw, par-fried and finish-fried Jaerla potatoes (in mg FAA/100 g potatoes, fat-free dry basis, and as % retention)[1].

	Raw		Par-fried		Finish-fried	
	mg/100 g	retention	mg/100 g	retention	mg/100 g	retention
Aspartic	150.0	100	84.0	56	39.0	26
Threonine	62.0	100	38.4	62	19.8	32
Serine	225.0	100	128.3	57	65.3	29
Glutamic	202.5	100	111.4	55	50.6	25
Proline	56.0	100	35.3	63	16.8	30
Glycine	18.5	100	12.4	67	6.1	33
Alanine	30.0	100	19.5	65	9.0	30
Valine	99.0	100	57.4	58	27.7	28
Methionine	31.0	100	20.2	65	9.9	32
Isoleucine	28.3	100	18.5	65	8.2	29
Leucine	32.6	100	21.2	65	9.8	30
Tyrosine	60.0	100	40.8	68	15.0	25
Phenylalanine	76.0	100	45.6	60	19.0	25
Histidine	40.0	100	27.6	69	11.2	28
Lysine	97.0	100	56.3	58	25.2	26
Arginine	140.4	100	78.6	56	35.1	25
Total	1348.3	100	795.5	59	367.7	27
FAA N as % of total Kjeldahl N	13.1%		9.7%		5.1%	

[1]Means of duplicates.

Table 12. Free amino acid (FAA) content in raw, par-fried and finish-fried Spunta potatoes (in mg FAA/100 g potatoes, fat-free dry basis, and as % retention.

	Raw		Par-fried		Finish-fried	
	mg/100 g	Retention	mg/100 g	Retention	mg/100 g	Retention
Aspartic	129.5	100	71.2	55	30.6	24
Threonine	31.6	100	19.3	61	9.5	30
Serine	211.5	100	123.5	58	57.7	27
Glutamic	190.7	100	106.8	56	45.8	24
Proline	50.1	100	30.1	60	14.5	29
Glycine	13.5	100	8.9	66	4.5	33
Alanine	22.6	100	14.0	62	6.5	29
Valine	99.8	100	54.9	55	26.9	27
Methionine	26.6	100	17.3	65	8.5	32
Isoleucine	33.5	100	21.1	63	9.4	28
Leucine	17.8	100	11.2	63	5.2	29
Tyrosine	70.3	100	46.4	66	17.6	25
Phenylalanine	79.8	100	47.1	59	19.2	24
Histidine	42.0	100	28.1	67	11.3	27
Lysine	87.6	100	50.6	58	22.8	26
Arginine	156.6	100	86.1	55	38.5	25
Total	1263.5	100	736.6	58	328.5	26
FAA N as % of total Kjeldahl N	12.3%		9.1%		4.7%	

[1]Means of duplicates.

Table 13. Percentage free amino acid distribution in raw and processed potatoes (cv. Jaerla and cv. Spunta.

	Raw		Par-fried		Finish-fried	
	Jaerla	Spunta	Jaerla	Spunta	Jaerla	Spunta
Aspartic	11.0	10.3	10.6	9.7	10.6	9.3
Threonine	4.6	2.5	4.8	2.6	5.4	2.9
Serine	16.7	16.7	16.1	16.8	17.8	17.6
Glutamic	15.0	15.1	14.0	14.5	13.8	13.9
Proline	4.2	4.0	4.4	4.1	4.6	4.4
Glycine	1.4	1.1	1.6	1.2	1.6	1.4
Alanine	2.2	1.8	2.5	1.9	2.4	2.0
Valine	7.4	7.9	7.2	7.4	7.5	8.2
Methionine	2.3	2.1	2.5	2.3	2.7	2.6
Isoleucine	2.1	2.6	2.3	2.9	2.2	2.9
Leucine	2.4	1.4	2.7	1.5	2.7	1.6
Tyrosine	4.5	5.6	5.1	6.3	4.1	5.4
Phenylalanine	5.6	6.3	5.7	6.4	5.2	5.8
Histidine	3.0	3.3	3.5	3.8	3.0	3.4
Lysine	7.2	6.9	7.1	6.9	6.9	6.9
Arginine	10.4	12.4	9.9	11.7	9.5	11.7
	100.0	100.0	100.0	100.0	100.0	100.0

found by Kaldy (1971) and Schaller and Wunsch (1973). Collectively, the FAA losses resulting from par-frying were about half as large as those following finish-frying. According to Kozempel et al. (1982), hot water blanching results in considerable losses of the water soluble constituents of potatoes. It is likely that the FAA losses observed after par-frying in this study are mainly due to the water blanching that preceded par-frying. Regarding the large losses related to finish-frying, they are probably due to both release of water from the tissue and the Maillard reaction occurring during finish-frying (Fitzpatrick and Porter, 1966).

The retention values of total FAA's in par-frying and finish-frying were 59, 27% for cv. Jaerla and 58, 26% for cv. Spunta, respectively. Aspartic acid, serine, glutamic acid, valine, lysine, and arginine disappeared to a larger extent during par-frying than the other amino acids.

The FAA N as % of total Kjeldahl N in raw, par-fried and finish-fried product was 13.1, 9.7, and 5.1 for cv. Jaerla and 12.3, 9.1 and 4.7 for cv. Spunta. These findings pertaining to raw potatoes (13.1% and 12.3%) are in good agreement with those reported by Schreiber (1961) and Kaldy (1971).

Ascorbic Acid Content

Table 14 shows the ascorbic acid content of raw, par-fried and finish-fried potatoes, as well as the corresponding

Table 14. Total ascorbic acid (AA) content in raw, par-fried and finish-fried potatoes (in mg AA/100 g potatoes, wet, and fat-free dry basis, and as % retention)[1]

cv. Jaerla			cv. Spunta		
wet	fat-free dry	retention	wet	fat-free dry	retention
15.2	75.3	100	14.1	72.4	100
11.0	47.0	62	10.8	44.5	61
16.4	39.1	52	15.3	36.6	51

[1]Means of triplicates.

retention values in the processed products. The content values of raw potatoes are within the range reported in the literature (Augustin et al., 1979).

Because of differences in the moisture and fat contents between the raw, the par-fried and the finish-fried potatoes, changes in the ascorbic acid content were computed on a moisture free, fat-free dry basis, listed in Table 4.

Par-frying decreased the ascorbic acid retention value in both cultivars, due to leaching and some heat degradation. It should be noted here, that par-frying losses are mostly due to the preceding water blanching than to the par-frying itself, as it has been demonstrated previously (Augustin et al., 1979; Kozempel et al., 1982; Artz et al., 1983).

Finish-frying decreased somehow the ascorbic acid retention value, due to some extra leaching and heat degradation. However, ascorbic acid losses, due to finish-frying, are lower than those resulting from par-frying. It is possible for freezing to result in extra leaching during the finish-frying, due to tissue disruption.

Total Carbohydrate Content

Table 15 summarizes the percentage composition of the analyzed raw potatoes, as well as the ascorbic acid content on a wet and dry basis. Total carbohydrate content was determined by difference from the total solids.

Table 15. Percentage composition of raw potatoes (peeled), stored at 4.5°C for 2 months and conditioned at 14°C for 15 days (wet and dry basis).

	cv. Jaerla		cv. Spunta	
	wet	dry	wet	dry
Water	79.8	0.0	80.5	0.0
Total solids	20.2	100.0	19.5	100.0
Crude protein	2.1	10.3	2.0	10.3
Fat	0.1	0.5	0.1	0.5
Ash	0.8	4.0	0.9	4.4
Total-CH=0 by difference	17.2	85.2	16.5	84.8
Ascorbic acid in mg/100 g raw potato	15.2	75.3	14.1	72.4

The percentage composition of the commercially prepared French fries is given in Table 16, on a wet, dry with fat and fat-free dry basis. Naturally, the percentage values on a moisture free, fat-free basis were higher than those on a moisture free basis alone. The contribution of the frying fat to this increase was approximately 13.5% and 21.0% for the par-fried and finish-fried product, for both cultivars.

Total carbohydrate content of French fries was again determined by difference from the total solids.

Results on the wet basis simply show the important contribution of 100 g French fries to the diet.

Frying Fats

A comparative analysis by GLC was performed on the total and free fatty acid composition of kernel olive oil, used in par-frying, and olive oil in finish-frying. The percentage distribution of total fatty acids in kernel olive oil and olive oil are given in Tables 17 and 18, respectively. The results of olive oil are close to those reported in the literature (Kiritsakis, 1982). Arachidic acid (C20:0) values detected in this study are within the range reported by Wolff (1968). As expected both oils contained a small amount of linolenic acid ($C_{18:3}$) and a proportion of oleic acid ($C_{18:1}$). The two oils have a very close fatty acid composition, with the olive oil containing a little more oleic acid.

Table 16. Percentage composition of French fries commercially prepared from tubers, stored at 4.5°C for 2 months, and conditioned at 14°C for 15 days (wet, dry-with-fat and dry-without-fat basis).

	cv. Jaerla			cv. Spunta		
	wet	dry with fat	dry w/o fat	wet	dry with fat	dry w/o fat
Water	47.3	0.0	0.0	47.1	0.0	0.0
Total solids	52.7	100.0	100.0	52.9	100.0	100.0
Crude protein	3.0	5.7	7.2	2.9	5.5	7.0
Fat	10.8	20.5	0.5	11.2	21.2	0.5
Ash	0.9	1.7	2.2	1.0	1.9	2.4
Total -CH=O by difference	38.0	72.1	90.1	37.8	71.4	90.1
Ascorbic acid: in mg/100 g French fries	16.4	31.1	39.1	15.3	28.9	36.6

Table 17. Percentage distribution of fatty acids in Greek kernel olive oil[1].

Fatty acid		Percentage
Trivial Name	Symbol	
Palmitic	$C_{16:0}$	12.0
Palmitoleic	$C_{16:1}$	0.9
Stearic	$C_{18:0}$	2.6
Oleic	$C_{18:1}$	72.0
Linoleic	$C_{18:2}$	11.2
Arachidic	$C_{20:0}$	0.3
Linolenic	$C_{18:3}$	1.0
		100.0

[1]Means of triplicates.

Table 18. Percentage distribution of fatty acids in Greek olive oil[1].

Fatty Acid		Percentage
Trivial name	Symbol	
Palmitic	$C_{16:0}$	11.0
Palmitoleic	$C_{16:1}$	0.9
Stearic	$C_{18:0}$	2.5
Oleic	$C_{18:1}$	78.8
Linoleic	$C_{18:2}$	5.4
Arachidic	$C_{20:0}$	0.4
Linolenic	$C_{18:3}$	1.0
		100.0

[1] Means of triplicates.

The free fatty acid (FFA) percentage distribution in kernel olive oil and olive oil are given in Tables 19 and 20, respectively. Seven FFA's were detected in kernel olive oil and eight in olive oil. Lauric acid ($C_{12:0}$) was the limiting FFA in olive oil, while in kernel olive oil myristic ($C_{14:0}$) was the limiting one (no lauric acid was detected). Oleic acid was the dominant FFA in both oils. Two FFA's were tentatively identified in both oils as $C_{15:0}$ and $C_{19:0}$, on the basis of retention times. It seems certain that these two FFA's are the same in both oils, as the respective retention times are almost the same.

Titration of kernel olive oil and olive oil revealed a total FFA content of 0.4% and 0.7% as oleic acid, respectively. The FFA composition of the two oils appears to be very close.

The finish-fried products prepared by seven combinations of frying oils were subjected to sensory evaluation by six panelists. The results of this evaluation are summarized in Table 21 and 22. Table 21 shows the total score of each French fry sample, prepared with different oil combination and evaluated for color, texture, taste and flavor. Oil combination a = 100% kernel olive oil (par-frying), 100% olive oil (finish-frying) obtained the highest total score and g = 100% palm oil (both fryings) obtained the lowest score for both varieties.

Table 19. Percentage distribution of free fatty acids (FFA) in Greek kernel olive oil (Total FFA content as oleic is 0.4%)[1].

Free fatty acid		Percentage
Trivial name	Symbol	
Myristic	$C_{14:0}$	2.8
	$C_{15:0}$*	4.7
Palmitic	$C_{16:0}$	11.6
Palmitoleic	$C_{16:1}$	3.0
Stearic	$C_{18:0}$	10.1
Oleic	$C_{18:1}$	51.6
	$C_{19:0}$*	3.9
Linoleic	$C_{18:2}$	8.9
Arachidic	$C_{20:0}$	3.4
		100.0

*Tentative identification.

[1]Means of triplicates.

Table 20. Percentage distribution of free fatty acids (FFA) in Greek olive oil (total FFA content as oleic is 0.7%)[1].

Free fatty acid		Percentage
Trivial name	Symbol	
Lauric	$C_{12:0}$	1.1
Myristic	$C_{14:0}$	2.9
	$C_{15:0}$*	4.5
Palmitic	$C_{16:0}$	10.9
Palmitoleic	$C_{16:1}$	3.4
Stearic	$C_{18:0}$	8.3
Oleic	$C_{18:1}$	56.5
	$C_{19:0}$*	3.7
Linoleic	$C_{18:2}$	4.3
Arachidic	$C_{20:0}$	4.4
		100.0

*Tentative identification.

[1]Means of triplicates.

Table 21. Sensory evaluation of French fries prepared with different frying oils (averages of six scores by six panelists).

Oil combination	Color (max. 30)	Texture (max. 30)	Taste-Flavor (max. 40)	Total Score (max. 100)
cv. Jaerla				
a*	25	24	40	89
b	27	26	34	87
c	26	26	27	79
d	28	28	27	84
e	27	28	28	84
f	26	27	24	77
g	25	24	24	73
cv. Spunta				
a	25	23	40	88
b	27	25	34	86
c	26	25	27	78
d	28	27	27	83
e	27	27	28	83
f	26	26	24	76
g	25	23	24	72

*a = 100% kernel olive oil (par-frying), 100% olive oil (finish-frying)
b = 100% kernel olive oil (par-frying), 50% olive oil + 50% kernel olive oil (finish-frying)
c = 100% kernel olive oil (both fryings)
d = 100% corn oil (both fryings)
e = 100% sunflower oil (both fryings)
f = 100% cottonseed oil (both fryings)
g = 100% palm oil (both fryings)

Table 22. Kramer's method for determining significance of differences in frying oils, from rank sums.

Tally of Rank Data (12-36 at 5%, 10-38 at 1%)

Panelists	Samples (oil combinations)*						
	a	b	c	d	e	f	g
1	1	2	3	5	4	6	7
2	1	2	4	5	3	7	6
3	2	1	5	3	4	6	7
4	1	2	3	5	4	6	7
5	1	2	4	5	3	7	6
6	1	2	3	4	5	6	7
Rank Sum	7	11	22	32	23	38	40

Tally of Re-Ranked Samples (9-21 at 5%, 8-22 at 1%)

Panelists	c	d	e	f
1	1	2	4	3
2	4	2	1	3
3	3	4	2	1
4	2	1	4	3
5	2	3	1	4
6	1	4	3	2
Rank Sum	13	16	15	16

*a through g same as in Table 19.

a = superior at 1% level of significance.
b = superior at 5% level of significance.
g = inferior at 1% level of significance.
c, d, e, f = no significance of differences, even after they were re-ranked.

Table 22 shows the results obtained by Kramer's rank sum method (1960; 1963). The rank totals for 5% and 1% levels of significance were obtained from Table 23.

Kramer's method classified the seven oil combinations a through g as follows:

a = superior at 1% level of significance

b = superior at 5% level of significance

g = inferior at 1% level of significance

c, d, e, f = no significance of differences

even after they were re-ranked.

The results of Table 21 and 22 are in good agreement and indicate that panelists prefer French fries prepared with an oil combination based on olive products (the combination olive oil for both par-frying and finish-frying was not used as uneconomical).

Table 23. Kramer's Rank Sum Method. Rank totals for significance - any treatment. Top row = 5%; Bottom row = 1%; Smallest number = lowest insignificant rank sum; Largest number = highest insignificant rank sum.

Panelists	2	3	4	5	6	7	8
3	--	--	--	4-14	4-17	4-20	4-23
	--	--	--	--	--	--	--
4	--	5-11	5-15	6-18	6-22	7-25	7-29
	--	--	--	5-19	5-23	5-27	6-30
5	--	6-14	7-18	8-22	9-26	9-31	10-35
	--	--	6-19	7-23	7-28	8-32	8-37
6	7-11	8-16	9-21	10-26	11-31	12-36	13-41
	--	7-17	8-22	9-27	9-33	10-38	11-43
7	8-13	10-18	11-24	12-30	14-35	15-41	17-46
	--	8-20	10-25	11-31	12-37	13-43	14-49
8	9-15	11-21	13-27	15-33	17-39	18-46	20-52
	9-15	10-22	11-29	13-35	14-42	16-48	17-55
9	11-16	13-23	15-30	17-37	19-44	22-50	24-57
	10-17	12-24	13-32	15-39	17-46	19-53	21-60
10	12-18	15-25	17-33	20-40	22-48	25-55	27-63
	11-19	13-27	15-35	18-42	20-50	22-58	24-66
11	13-20	16-28	19-36	22-44	25-52	28-60	31-68
	12-21	15-29	17-38	20-46	22-55	25-63	27-72
12	15-21	18-30	21-39	25-39	25-47	28-56	31-65
	14-11	17-31	19-41	22-50	25-59	28-68	31-77
13	16-13	20-32	24-41	27-51	31-60	35-69	38-79
	15-24	18-34	21-44	25-53	28-63	31-73	34-83
14	17-25	22-34	36-44	30-54	34-64	38-74	42-84
	16-26	20-36	24-46	27-57	31-67	34-78	38-88
15	19-26	23-37	28-47	32-58	37-68	41-79	46-89
	18-27	22-38	26-49	30-60	34-71	37-83	41-94
16	20-28	25-39	30-50	35-61	40-72	45-83	49-95
	19-29	23-41	28-52	32-64	36-76	41-87	45-99
17	22-29	27-41	32-53	38-64	43-76	48-88	53-100
	12-21	15-29	17-38	20-46	22-55	25-63	27-72
18	23-31	29-43	34-56	40-68	46-80	52-92	57-105
	22-32	27-45	32-58	37-71	42-84	47-97	52-110
19	24-33	30-46	37-58	43-71	49-84	55-97	61-110
	23-34	30-46	34-61	40-74	45-88	50-102	56-115
20	26-34	32-48	39-61	45-95	52-88	58-102	65-115
	24-36	32-48	36-64	42-98	48-92	54-106	60-120

SUMMARY

Two Dutch potato varieties, cv. Jaerla and cv. Spunta, cultivated for more than two decades in Greece, were used for preparing French fries under commercial conditions.

A comparative analysis for moisture, ash, fat, Kjeldahl N, non-protein N (NPN), free amino acids (FAA), and ascorbic acid was performed on raw, par-fried and finish-fried products. Individual sugars were assayed in raw potatoes. Total and free fatty acids were determined in olive oil and kernel olive oil. These oils, along with cottonseed oil, corn oil, sunflower oil, and palm oil were used in the trials.

The dry matter results of the raw products were positively correlated to their specific gravity and fit Simmonds formula. Moisture results were computed on a fat-free basis, which was employed to calculate the nutrient retentions, during processing.

Moisture losses in the par-fried and finish-fried potatoes were 4% and 27% for Jaerla and 6% and 28% for Spunta.

Ash losses in the processed potatoes are attributed to leaching of minerals during blanching and frying. Losses in par-fried and finish-fried products were 22% and 45%

for Jaerla, and 21% and 44% for Spunta.

Fat increased during par-frying and three more times after finish-frying, due to the frying fat accumulation. Raw, par-fried and finish-fried potatoes contained 0.1%, 3.7% and 10.8% in Jaerla and 0.1%, 4.1% and 11.1% in Spunta, respectively.

Individual sugars, fructose, glucose and sucrose were determined by HPLC, in tubers stored at 4.5°C for 2 months and conditioned for 15 days at 14°C. Both cultivars did not contain more than 1% dry basis reducing sugars (2% reducing sugar content, dry basis, is the upper limit acceptable for processing).

Kjeldahl N (crude protein) losses in par-fried and finish-fried products were 20% and 30% for Jaerla, and 21% and 31% for Spunta.

NPN losses were greater than Kjeldahl N losses. Par-frying and finish-frying decreased by 40% and by 61% the NPN in Jaerla and 42% and 62% in Spunta.

FAA losses in par-fried and finish-fried potatoes were 41% and 73% in Jaerla and 42% and 74% in Spunta. Serine, glutamic, aspartic and arginine were the dominant FAA's in raw and processed potatoes. FAA's accounted for 13.1% and 12.3% of the total Kjeldahl N in Jaerla and Spunta potatoes, respectively.

The ascorbic acid losses in the two cultivars were 38% and 39% after par-frying, and 48% and 49% after

finish-frying.

Total carbohydrate content was determined in raw and finish-fried product, by difference from the total solids. The average percentage composition of French fries was: moisture 47.2%; crude protein 3.0%; fat 11%; ash 0.9%; and total carbohydrate 37.8%; their ascorbic acid content was 15.8 mg/100 g French fries.

The total and free fatty acid composition of Greek olive oil and kernel olive oil were very close, in type and quantity of fatty acids. The free fatty acid content (acidity) of the two oils were 0.7% for olive oil, and 0.4% for kernel olive oil.

Six Greek panelists evaluated seven frying oil combinations, by scoring the finish-fried potatoes, in terms of color, texture, taste and flavor. These oils were: olive oil, kernel olive oil, cottonseed oil, corn oil, sunflower oil, and palm oil.

The sensory evaluation by Kramer's method showed that the preferred frying oil combination was: 100% kernel olive oil for par-frying and 100% olive oil for finish-frying.

The conclusions drawn from this study are summarized as follows:

1. The contents in moisture, ash, Kjeldahl N, non-protein N, free amino acids, and ascorbic acid

decreased, as a result of par-frying and more so following finish-frying.

2. Non-protein N losses were greater than those in total Kjeldahl N.
3. A sensory panel evaluation of the finish-fried potatoes indicated that par-frying with kernel olive oil and finish-frying with olive oil results in the best product.

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