A simple process to obtain onion oil by direct solvent extraction was proposed. Several solvents commonly utilized in the food industry were tested for their selectivity in the extraction of the oil of onion. Diethyl ether and methylene chloride appeared to be the most suitable solvents for the extraction operation. The direct solvent extraction method produced a yield of onion oil approximately seven times higher than the yield obtained by the steam distillation method.

A process of fermentation of the ground raw onions was used prior to the solvent extraction operation. This produced an improvement in the onion oil yield of 60% over the normal solvent extraction method.

In order to determine the quality of the onion oil obtained, refractive index, specific gravity, melting point, and sulfur content were determined. Sulfur content in the onion oil obtained by the method proposed here had one-third (weight basis) of the sulfur content of commercial onion oil.
Two organoleptic evaluations were conducted for commercial onion oil and for the onion oil obtained by direct solvent extraction: odor threshold determination and comparative flavor evaluation. The commercial onion oil showed a lower threshold concentration (1.6 ppb) than the onion oil obtained in the laboratory (8.4 ppb). With respect to the comparative flavor tests, the test panels did not detect a statistically significant difference between the flavor of commercial onion oil and the oil obtained by the method proposed here.
An Improved Solvent Extraction of Onion Oil

by

Ernesto Hernandez-Molinar

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Typed by Donna Lee Norvell-Race for Ernesto Hernandez-Molinar
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# TABLE OF CONTENTS

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>INTRODUCTION</strong></td>
<td>1</td>
</tr>
<tr>
<td><strong>LITERATURE REVIEW</strong></td>
<td>4</td>
</tr>
<tr>
<td>Flavor Compounds in Onions</td>
<td>4</td>
</tr>
<tr>
<td>Methods of Evaluation of Aroma Extracts</td>
<td>7</td>
</tr>
<tr>
<td>Methods of Extraction of Flavor Concentrates</td>
<td>12</td>
</tr>
<tr>
<td>Extraction with Liquid Carbon Dioxide</td>
<td>14</td>
</tr>
<tr>
<td>Extraction with Supercritical Gases</td>
<td>16</td>
</tr>
<tr>
<td>Onion Oil Properties</td>
<td>17</td>
</tr>
<tr>
<td><strong>EXPERIMENTAL</strong></td>
<td>21</td>
</tr>
<tr>
<td>Liquid-Liquid, Solid-Liquid Extraction</td>
<td>21</td>
</tr>
<tr>
<td>Steam Distillation</td>
<td>23</td>
</tr>
<tr>
<td>Fermentation</td>
<td>25</td>
</tr>
<tr>
<td>Analysis of the Onion Oil</td>
<td>25</td>
</tr>
<tr>
<td>Refractive Index, Melting Point, and Specific Gravity</td>
<td>26</td>
</tr>
<tr>
<td>Sulfur Content of Onion Oil</td>
<td>26</td>
</tr>
<tr>
<td>Infrared Analysis</td>
<td>28</td>
</tr>
<tr>
<td>Odor Threshold Determination</td>
<td>28</td>
</tr>
<tr>
<td>Comparative Flavor Test</td>
<td>29</td>
</tr>
<tr>
<td><strong>RESULTS AND DISCUSSION</strong></td>
<td>31</td>
</tr>
<tr>
<td>Effect of Type of Solvent on Onion Oil Yield</td>
<td>31</td>
</tr>
<tr>
<td>Effect of Time of Extraction on Onion Oil Yield</td>
<td>33</td>
</tr>
<tr>
<td>Onion Oil Yield in Different Varieties of Onion</td>
<td>37</td>
</tr>
<tr>
<td>Effect of Fermentation on Onion Oil Yield</td>
<td>38</td>
</tr>
<tr>
<td>Some Chemical and Physical Properties of Onion Oil</td>
<td>40</td>
</tr>
<tr>
<td>Odor Threshold</td>
<td>45</td>
</tr>
<tr>
<td>Flavor Evaluation</td>
<td>49</td>
</tr>
<tr>
<td><strong>CONCLUSIONS</strong></td>
<td>50</td>
</tr>
<tr>
<td>Suggested Future Research</td>
<td>51</td>
</tr>
<tr>
<td><strong>BIBLIOGRAPHY</strong></td>
<td>53</td>
</tr>
</tbody>
</table>
## LIST OF FIGURES

<table>
<thead>
<tr>
<th>Figures</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Flow chart of the solvent extraction process of onion oil</td>
<td>22</td>
</tr>
<tr>
<td>2</td>
<td>Steam distillation process diagram</td>
<td>24</td>
</tr>
<tr>
<td>3</td>
<td>Effect of extraction time on onion oil yield</td>
<td>34</td>
</tr>
<tr>
<td>4</td>
<td>Effect of fermentation of raw onions on onion oil yield and pH</td>
<td>39</td>
</tr>
<tr>
<td>5A</td>
<td>Infrared spectra of dipropyl disulfide</td>
<td>43</td>
</tr>
<tr>
<td>5B</td>
<td>Infrared spectra of solvent extracted onion oil</td>
<td>44</td>
</tr>
<tr>
<td>5C</td>
<td>Infrared spectra of commercial onion oil</td>
<td>44a</td>
</tr>
<tr>
<td>6</td>
<td>Odor stimulus response to different concentrations of commercial onion oil</td>
<td>46</td>
</tr>
<tr>
<td>7</td>
<td>Odor stimulus response to different concentrations of onion oil obtained by direct solvent extraction</td>
<td>47</td>
</tr>
</tbody>
</table>
LIST OF TABLES

<table>
<thead>
<tr>
<th>Table</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Effect of Type of Solvent on Onion Oil Yield</td>
<td>31</td>
</tr>
<tr>
<td>2</td>
<td>Onion Oil Yield in Different Varieties of Onions</td>
<td>37</td>
</tr>
<tr>
<td>3</td>
<td>Some Chemical and Physical Properties of Commercial Onion Oil and Onion Oil Obtained by Direct Solvent Extraction</td>
<td>41</td>
</tr>
<tr>
<td>4</td>
<td>Statistical Data of the Threshold Analysis of Onion Oil</td>
<td>48</td>
</tr>
<tr>
<td>5</td>
<td>Scores for the Flavor Evaluation of Onion Oil</td>
<td>49</td>
</tr>
</tbody>
</table>
AN IMPROVED SOLVENT EXTRACTION OF ONION OIL

INTRODUCTION

Aromas in food are usually extracted for reasons such as better microbial stability; less volume for storage and handling can be readily added to a food product after a thermal process, therefore giving better flavor characteristics to the food; also extracted aromas present the advantage of being available all year-round. The use of aromas and essential oils has increased in recent years, mainly with respect to seasoning products such as onions, garlic, leeks, cloves, etc., because of the advantages mentioned above and also because of the development of new packing techniques, such as microencapsulation which greatly improves the shelf life of essential oils.

For years, the principal method of extraction of essential oils and aroma concentrates has been steam distillation. In 1892, Semmler first prepared an essential oil of onion by this procedure, and even identified some of the aroma compounds present in the oil. The method of extraction by steam distillation presents the advantage of extracting mainly volatile compounds from the food during the injection of the steam. However, this procedure does not separate many aroma components that have relatively high volatilities.

Alternative methods of extraction of food aromas have been tried by aroma manufacturers such as distillation by gas entrainment and
direct solvent extraction. This last method is being utilized on products like hops, coffee and vegetable oils at an industrial scale, but apparently it has not been utilized for seasoning products such as onions.

The principal factor in the method of extraction of food aromas by direct solvent extraction is the use of the right solvent. First of all, the solvent used in this type of operation must meet the requirements of food stuff legislation. Even though these requirements can vary from country to country, some of them are high degree of purity (food grade), inertness (the solvent must not react with any food chemical); also must be non-toxic and easily separable from the food. In addition to these factors, the solvent must be chosen in such a way that it selectively extracts the aroma components of the food. Availability and cost of the solvent must be taken into account as well.

Even though the extraction of food aroma components has been conducted for a long time, standardized methods are not available to evaluate some essential oils, onion oil in particular. The literature suggests a variety of methods to evaluate onion oil, from as sophisticated as combined mass spectroscopy-gas liquid chromatography to the determination of the total sulfur content in the oil or aroma concentrate. Probably the reason why there is not a generally accepted procedure to evaluate these types of oils is because most of the research done on the extraction of essential oils is carried out by
private industry and not much information is released for public knowledge. Adding to this is the fact that the composition of these essential oils is very complex.

The purpose of this work is to develop a method of extraction of onion oil by direct use of a solvent. The solvents utilized in the extraction were chosen from several food-approved solvents, taking into account the specifications for solvents used in food. In an attempt to improve the yield of onion oil and facilitate the extraction operations, a process of fermentation was carried out. To evaluate the product obtained three approaches were taken: organoleptic evaluation of the onion oil, determination of the total sulfur content in the oil, and a comparative determination of dipropyl disulfide, the main flavor component of onions, by infrared spectroscopy. Other properties of the oil were also determined such as refractive index, specific gravity, and melting point.
LITERATURE REVIEW

Flavor Compounds in Onions

So far there is not absolute agreement about the composition of the flavor constituents of Allium species, onion in particular. However, it is now generally recognized that the flavor compounds in the fresh onion are not present as such (Freeman and Whenham, 1976). Actually, these flavor compounds develop only after an enzyme known as alliinase acts upon the flavor precursors such as alk(en)yl derivatives of L-Cysteine. In onions, this precursor is S-(1-propenyl)-L-cysteine sulfoxide. The enzyme alliinase will act on the precursor only after the onions are crushed or bruised, which means that this enzyme is confined within the plant cell and is separated from the flavor precursor. The general enzymatic reaction is as follows (Whitaker, 1976):

\[
\begin{align*}
\text{NH}_2 & \quad \text{Aliinase} \\
\text{CH}_3-\text{CH}=\text{CH-S}-\text{CH}_2-\text{CH-COOH} & \rightarrow \text{CH}_3-\text{CH}=\text{CH-S} + \text{CH}_3-\text{C-COOH} + \text{NH}_3
\end{align*}
\]

The main products of the action of alliinase on the sulfur aminoacid derivative are 1-propenyl sulfenic acid, pyruvic acid and ammonia. 1-propenyl sulfenic acid has been suggested to be the main precursor for the development of the flavor compounds in the onion. This compound is very unstable and quickly is transformed to thiopropanal-
S-oxide (Whitaker, 1976), the lacrimary factor in onions, and which, upon further reactions, is transformed into thiosulfinates of the type R-S-S-R'.

Early works on the study of flavor components in onions were carried out by Semmler in 1892 who studied the composition of an essential oil of onion and found that the main flavor volatile component was allyl-n-propyl disulfide. Kohman in 1947 reported propanal to also be an important flavor compound in onions. A more extensive analysis on onion flavor was carried out by Carson and Wong in 1961. Using activated carbon as an adsorbing agent for the extraction of the onion oil, these workers reported compounds present in onion oil such as methyl- and methyl-n-propyl disulfides and trisulfides. A later work by Brodnitz et al. (1969) showed a mass spectroscopy-gas liquid chromatography analysis of onion flavor. These researchers reported, for the first time, the presence of compounds such as alkyl thiophenes, propenyl di- and trisulfides.

Boelens et al. (1971) carried out an extensive MS-GLC analysis of the volatile flavor components of onions. They identified 45 flavor constituents in steam distilled onion oil, most of which were oxygen compounds, thiols, thiophenes, monosulfides, disulfides, and trisulfides. The oxygen compounds such as propanal, 2-methyl pentanal, and 2-methyl pent-2-enal together with the thiosulfinates were found to be the main constituents of fresh-cut onions. The main compounds found in steam distilled onion oil were propyl and propenyl
mono-, di-, and trisulfides which imparted a characteristic boiled onion flavor to the oil. Other compounds such as the thiophenes were found to give a fried onion flavor to the oil. Albrand et al. (1980) isolated and identified for the first time the compound 3,4-dimethyl-2,5-dioxo-2,5-dihydrothiophene in onions and leeks by infrared spectroscopy and nuclear magnetic resonance. The odor of this compound is described as hydrogen sulfide-like.

Schwimmer and Friedman (1972) present a thorough analysis on the origin of volatile sulfur-containing food flavors in general. In this review, the authors include the enzymology of the genesis of disulfides and related flavor compounds in alliaceous such as onions; the enzymology of the isothiocyanates of the family of the Cruciferae; and flavor production by thermal, photochemical and other non-enzymatic transformations of amino acids. The authors also include a discussion on the role of divalent sulfur compounds in flavor acuity.

The relative contribution of each of the identified onion oil components was investigated by Galetto and Bednarczyk (1975). These workers correlated quantitative gas chromatographic data with organoleptic evaluation by multiple regression analysis. They found that the flavor effect of each component was interdependent on each other, which is a common occurrence with natural products. However, surprisingly, they also found that dipropyl disulfide, believed for a long time to be one of the main components of cooked onion flavor, did not contribute significantly to the overall onion flavor. On the other
hand, these researchers did not identify compounds such as dimethyl thiophene or alkyl thiosulfinates, which are the compounds responsible for the cooked and fresh onion flavor, respectively (Boelens et al., 1971).

Matikkala and Virtanen (1967) found that onions have a potential flavor precursor, the compound L-\{\text{-glutamyl}-S-(1-propenyl) cysteine sulphydoxide. The amount of this dipeptide is similar to that of S-(1-propenyl) cysteine sulphydoxide (approximately 2mg/g). However, the enzymes capable of breaking down the flavor precursor dipeptide are not present in dormant onions (Austin and Schwimmer, 1970).

Schwimmer (1971) produced an enhancement of flavor in onion powders through a coupled reaction using non-endogenous glutamyl transpeptidase to break down the dipeptide derivative, and L-Cysteine C-S lyase to produce the release of sulfur flavor derivatives from the onion powder.

**Methods of Evaluation of Onion Aroma Extracts**

Onions and seasoning products in general can be processed to obtain either seasoning extracts or essential oils. Onion and garlic extracts, in contrast to all other types of extracts, are made commercially by extraction with water instead of an organic solvent. Salzer (1975) reported a series of procedures for the analytical evaluation of these types of products, including the criteria to
assess the quality of the seasoning extracts and essential oils of some products. With respect to onions, Salzer (1975) suggests the content of sugars, water, minerals, nitrogenous compounds, and aroma components as a possible criteria to assess the quality of onion extracts. The suggested method to determine water content is the azeotropic distillation method with xylol. Sugars can be determined qualitatively by GLC. The method suggested to determine the aroma quality of the seasoning extracts is by analyzing the key compounds present in the typical flavor of the product, i.e., dipropyl disulfide in the case of onions.

Early works on the evaluation of the aroma quality of onions were carried out by Schwimmer and Guadagni (1962), who found that pyruvic acid content of onions could be used to determine their pungency. This finding is based on the fact that pyruvic acid is one of the first products from the action of the enzyme alliinase on the amino acid derivative responsible for the flavor development in onions (Whitaker, 1976). However, Saghir et al. (1964) could not find any correlation between the aliphatic mono- and disulfides, which are the main components of the typical onion flavor, and the pyruvic acid content in onions. This could be partially explained by the fact that not all the propanal-S-oxide, the lacrymatory factor in onions and one of the first products of the alliinase action on the aminoacid flavor precursor, is converted into flavor compounds.

Saguy et al. (1970) suggest that Chemical Oxygen Demand (COD)
could be used as a reliable method to evaluate the aroma components of dried and raw onions. They found that COD of onion juice correlated well with odor threshold values for raw onions and with taste scores for dehydrated onion products.

It appears that several methods have been suggested to evaluate aroma content in raw onions and onion extracts, but only a few for the evaluation of onion oil. Salzer (1975) proposed some methods for the quality evaluation of onion oil, such as the determination of the total sulfur content in the oil as sulfate, the determination of volatile sulfur by the method proposed by Currier (1944), the argentometric determination of the disulfide components of the product after distillation by reducing them to mercaptans with the method suggested by Siggia and Stahl (1957). Salzer (1975) suggests also the determination of disulfide compounds, by means of infrared spectroscopy. Finally, he also proposes gas chromatographic analysis of the main flavor components of the oil of onion. However, most of the methods of analysis mentioned above are not sufficiently accurate (Salzer, 1975). They do not correlate well with organoleptic evaluations except for the infrared determination of the disulfide compounds and the gas liquid chromatography analysis of the flavor compounds of the onion oil. The determination of the total sulfur content in the oil is useful in that it gives an idea of the amount of sulfur aroma compounds present in the onion oil, but does not tell what type of sulfur compounds these are, whether mono-,
di-, or trisulfides. As was mentioned before, the disulfide compounds are the main components of the onion aroma, therefore the methods of onion oil analysis by infrared spectroscopy and gas liquid chromatography seem to be the most suitable. It has been determined that in the region of 1050-1200 cm\(^{-1}\), alkyl disulfides show a strong absorption band caused by the C-S-S-C linkage. In the case of dialkyl disulfides, dipropyl disulfide in particular, a strong band can be detected at 1050-1075 cm\(^{-1}\) (Salzer, 1975). This fact makes the infrared spectroscopy procedure very useful for routine analysis, considering that gas chromatography and organoleptic evaluations are more lengthy and costly.

Even though gas liquid chromatography is not very suitable for routine analysis, this procedure can be a useful tool for an extensive analysis of onion oil; Selzer (1975) describes a procedure where he adds to the ground onions, prior to steam distillation, a known amount of a compound not naturally present in the onion extract (the authors suggest diallyl disulfide) to act as an internal standard. Then, he extracts the distillate with carbon disulfide and develops the chromatogram of the CS\(_2\) solution. Most of the specialized works on the analysis of onion extracts or essential oil of onion are carried out by combined mass spectroscopy-gas liquid chromatography (Brodnitz et al., 1969; Boelens et al., 1971). However, this is not always the best analytical technique since, as it will be discussed later, some of the aroma compounds in onions are very heat-sensitive.
Bandyopdhyay et al. (1970) carried out the separation of some flavor components of onion oil by thin layer chromatography and suggested that it can be used as a new approach for the evaluation of the flavoring constituents of onion oil. These researchers separated on a silica gel plate seven major aroma components and determined their odor quality by sensory tests. However, the authors do not provide the chemical identification of the compounds separated, for which there are already methods available in the literature (Schwimmer and Friedman, 1972). The use of thin layer chromatography as a procedure for the separation of onion oil components offers some advantages over GLC, i.e., low temperature separation, inexpensive, quick, and, best of all, not sample-destructive.

As was mentioned before, gas liquid chromatography is the most widely used method to separate and analyze sulfur aroma components in allium species. However, this method presents the disadvantage of changing the structure of heat labile compounds such as thiopropanal-S-oxide, the lacrymatory factor in onions. Probably the alternative method of analysis of heat labile aroma compounds that presents the greatest potential is high performance liquid chromatography (HPLC). By this method the aroma components of a food do not have to be subjected to destructive high temperatures. Also, it is possible to separate compounds with low volatility which have important flavor properties (Macrae, 1980). Unfortunately, not much research has been done on the analysis of flavor components of allium species by HPLC.
Methods of Extraction of Flavor Concentrates

The methods of separation of flavor components from a food stuff will depend on the type of food and on the type of flavor components. Teranishi et al. (1971) provide a comprehensive review on the methods for the isolation and concentration of volatile food constituents. The method of distillation is by far the most widely used. In their review, Teranishi et al. (1971) describe two of the most utilized variations of this method: flash distillation and high vacuum (steam) distillation. These methods of extraction of aroma components are most commonly used commercially. Flash distillation is used mainly in the recovery of essences in the fruit juice industry (Milleville and Eskew, 1946) and steam distillation is widely used in the extraction of concentrates and essential oils of seasoning and aromatic herbs (Heath, 1973).

Flash distillation consists basically of two steps: first, heating the juice or liquid to be distilled to a temperature slightly above that of the boiling point of the liquid, then allowing the hot liquid to pass to a separation chamber (which can be under vacuum) where volatile components of the mixture are separated into either a packed column or a simple condenser. Steam distillation is quite similar to flash distillation, the difference being that live steam is injected into the liquid or solid mixture which contains the flavor volatiles. When the steam separates from the mixture, it
carries the flavor volatiles with it, the steam is then condensed and subjected to a liquid-liquid extraction with a solvent or simply is further concentrated (Teranishi et al., 1971). There are other methods of extraction of flavor components which are practiced mainly in the laboratory such as gas entrainment, liophylization, freeze concentration, derivative formation, and solvent extraction. These methods, excepting solvent extraction, are not commonly practiced commercially because they are either costly or inefficient (Teranishi et al., 1971).

Actually, in commercial applications more than one method of aroma extraction is practiced. For instance in steam distillation the distillate is subjected to a liquid-liquid extraction in order to separate the flavor components from the aqueous solution or emulsion. An alternative for this procedure is to separate the water by freeze concentration after distillation (Thijssen, 1970). This method presents the advantage of handling the flavor concentrate at low temperatures which permits better retention of the original aroma.

Merrit et al. (1959) developed an interesting technique for the isolation, separation, and identification of volatile components of various foodstuffs. By this method, isolation and separation of the aroma components are carried out at low temperatures and high vacuum, utilizing gas chromatography to identify the separated volatile components. Basically this procedure consists of cooling the sample to approximately -196°C with liquid nitrogen while air is pumped out of
the system. Then, after a predetermined vacuum reading is reached, the vacuum pump is closed off and the sample allowed to warm up at room temperature, or higher if desired. The volatile compounds so generated are condensed in a receiver flask cooled with liquid nitrogen. The temperature of the receiver can be varied according to the differences in the vapor pressure-temperature relationships of the aroma compounds present, in such a way that the flavor components can be selectively separated.

Extraction with Liquid Carbon Dioxide

One of the methods of aroma extraction that has received some attention lately is solvent extraction with liquid CO$_2$. Liquid carbon dioxide has been found to be a very selective solvent for the extraction of aroma compounds such as terpenes, aldehydes, and ketones, while other components of foods such as sugars, fruit acids, salts, amino acids, fats, and water are practically insoluble (Schultz and Randall, 1970). Early works on liquid CO$_2$ extraction were carried out by Francis (1955), who devised a process to use liquid carbon dioxide to increase the dissolving power of conventional solvents and also carried out an extensive study on the mutual solubilities of liquid carbon dioxide with 261 different substances (Francis, 1954). One of the first uses of liquid carbon dioxide was on the extraction of coffee aroma (Sivetz, 1963). Schultz and
Randall (1970) carried out a liquid CO$_2$ extraction of aroma components from apple, pear and orange juices, orange pieces, and roasted-ground coffee. They also list data about the distribution of alcohols and esters between liquid carbon dioxide and water. They found that liquid CO$_2$ is highly selective to compounds such as esters, aldehydes, ketones, and alcohols and since salts, amino acids, and fruit acids as well as water are practically insoluble in liquid CO$_2$ this method of aroma extraction appears to have a great deal of potential. The authors claimed that they obtained highly concentrated essence extracts, i.e., up to 100,000 fold in the case of apple juice.

The greatest use of liquid CO$_2$ extraction method is probably in the preparation of hop extracts for the brewing industry. Currently hop extracts are prepared mainly by direct solvent extraction. The solvents utilized are generally methylene chloride, trichloroethylene, hexane or methanol. Laws et al. (1977) carried out an extensive study on the extraction of a solvent-free isomerized concentrate from hops, and claimed a recovery of extractables from hops of up to 90%. However, even though the product showed excellent organoleptic properties, its shelf life was rather limited. The Russians seem to be the most advanced in this field, for after twelve years of extensive research they are now industrially producing hop extracts obtained with liquid carbon dioxide (Prokopeuk, 1974).
Extraction with Supercritical Gases

A relatively new technique of flavor extraction, and probably one of the most promising, is extraction with supercritical gases (Zosel, 1978). Extraction with supercritical gases, in contrast to the liquid ones such as liquid CO$_2$, offers advantages such as a wider range of possible operating temperatures, the fact that density and dielectric constant of the gas can be changed by varying the total pressure in the system, and dissolving power of supercritical gases is superior to that of the liquid ones. Sthal et al. (1978) suggested five gases suitable for the extraction of food aromas: carbon dioxide, nitrous oxide, ethylene, trifluoro-chloromethane, and trifluoromethane. The authors concluded that substances that can be satisfactorily extracted with supercritical gases are preferably lipophylic.

A characteristic that makes this new method of extraction important is that relatively involatile materials can be dissolved by supercritical gases. Haney and Hogart first observed in 1879 that supercritical ethanol could easily dissolve potassium iodide. However this important property of supercritical gases has been emphasized only lately. Another important feature of the method of extraction of aroma concentrates with supercritical gases is that both the enhancement of vapor pressure and phase separation play a role in the process. In other words, two unit operations are being carried out simultaneously, namely, distillation and solid-liquid or
liquid-liquid extractions. As mentioned above, the properties of the extracting agent such as density and dielectric constant can be modified by changing temperature and pressure, according to the properties of the substances to be extracted. Supercritical gases also present the advantage that they can be easily separated from the extracted concentrate. However, this new method of extraction presents two basic drawbacks: the physicochemical principles involved in the theory of this process are highly sophisticated and the technology to develop the high pressure system necessary to carry out the extraction operation requires some degree of complexity.

Hubert and Vitzthum (1978) carried out the extraction of aroma concentrates of hops, pepper, chilies, and tobacco with supercritical carbon dioxide with a percent recovery of 99% α-acids for hops, between 99-97% of extractable substances for the spices and 94.7% nicotine for tobacco, all these figures appearing to be higher than those obtained commercially. Eggers (1978) suggested a general criteria for the design of a large-scale industrial plant for the extraction of food aroma components with supercritical gases, i.e., the process data needed such as output capacity, mode of operation, bulk density of the material to be extracted, and process extraction time.

Onion Oil Properties

Onion oil is described by Haensel (1903) as a brown oily liquid product of a distillation of common kitchen onions with a specific
gravity at 35°C of 0.996, and optical rotation of -3° 40'. Chris (1937) obtained onion oil by distilling dried onion plants (with a yield of 0.05%, weight basis). Fenaroli (1971) describes the onion oil as a yellowish liquid with a characteristic onion odor whose main constituents are di-n-propyl and methyl-n-propyl disulfide with the following properties:

- Specific gravity: 1.047-1.098
- Optical rotation: +1° 31' - 3° 53'
- Refractive index (20°C): 1.5373-1.5588
- Solubility: 1:10 (in 90% ethanol)
- Acid value: 12 - 19.8

Onion oil has been granted the status "GRAS" (generally recognized as safe) by the Food and Drug Administration (Fenaroli, 1971). Onion oil forms part of the "White list" of the FDA which means that in order for a product to be recognized as safe, the conditions of intended use must be known and reasonable assurance given that the actual use conforms to the intended conditions. Hall and Oser (1965) provide a list of flavoring ingredients which are "GRAS" and the average maximum use levels at which each ingredient has been reported to be used in different categories of food. These authors also present and discuss the guidelines of "good" manufacturing practices of flavoring ingredients.

The average maximum level of onion oil reported by FEMA
(Flavoring Extract Manufacturers' Association) in different products is (Fenaroli, 1971):

<table>
<thead>
<tr>
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<tbody>
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<tr>
<td>Condiments</td>
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<tr>
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<tr>
<td>Ice cream, ices, etc.</td>
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</tbody>
</table>

Besides being commonly used as a food condiment, onion oil shows some other potential uses. Wit et al. (1979) found that onion oil (or garlic oil), when used in the proportion of 1.5 mg/g in meat slurry, inhibited toxin production by *Clostridium botulinum* type A (strain 73A). However, the inhibition of toxin production was not complete since the oil solution did not inhibit toxin production by *Clostridium botulinum* type B (strain R1V1) and type E (strain R1V2). This implies that the onion oil would not have any antimicrobial properties with respect to toxin-producing *Clostridia* in fish products.

Also some studies have been conducted on the inhibition of aflotoxin-producing fungi by onion extracts by Sharma et al. (1979), who report the effect of an onion extract (2% v/v), onion oil solution (10% v/v), lacrymatory factor solution (1% v/v), and dipropyl
disulfide on the growth rate of cultures of Aspergillus flavus and Aspergillus parasiticus. They found that the onion extract, the onion oil solution, and the lacrymatory factor solutions possess similar fungi-growth inhibitory properties and that the dipropyl disulfide solution hardly inhibited the culture growth. Apparently the lacrymatory factor was the main component responsible for the inhibition of the aflotoxin-producing fungi growth.
EXPERIMENTAL

Liquid-Liquid, Solid-Liquid Extraction

Two methods of extraction of onion aroma were utilized, a combination of solid-liquid and liquid-liquid extraction, and steam distillation. The first step for the solid-liquid extraction consisted in taking off the outer layers and grinding the onions in a Waring blender, together with an equal weight of water (see Fig. 1). Then the mixture was allowed to extract for various periods of time with slow agitation and was filtered through a cheese cloth. The filtrate was subjected to a liquid-liquid extraction with the experimental solvent with a filtrate-solvent ratio of 1:1/3 (volume basis). The cake resulting from the filtration step was subjected to a solid-liquid extraction with the experimental solvent with the same volume ratio of cake-solvent of 1:1/3. It was determined that the time of extraction at this stage should be two hours since after this time no significant additional extraction of onion oil was noticed. After the liquid-liquid extraction step, the solvent was separated from the aqueous phase and filtered. With respect to the solid-liquid extraction step, the mixture was filtered through a cheese cloth and the solvent phase was separated and combined with the solvent phase of the liquid-liquid extraction.

In the case of solvents partially soluble in water, the solvent
Figure 1. Flow chart for the solvent extraction process of onion oil.
phase was passed through a bed of sodium sulfate to absorb the water solubilized in the solvent and then the solvent separated in a rotatory evaporator using a vacuum 20 inches of Hg to allow the separation of the solvent at low temperature. The oil remaining in the round bottom flask of the evaporator was then transferred to a weighed vial and the amount of onion oil calculated by difference in weights.

Steam Distillation

The second method of extraction utilized was steam distillation, which was carried out as follows: a weighed amount of ground onions (approximately 1000 g) was placed in a four-liter round bottom flask with two outlets. This container was heated with a heating mantle to 100°C in order to maintain a homogeneous temperature in the flask during the distillation operation (see Fig. 2). One of the outlets of the container was connected to a steam generator which was simply a container with boiling water; the other outlet of the first container was connected to a condenser, and the condenser was connected to a condensate receiver. The ground onion in the distillation flask was heated to 100°C and the steam was injected into the mixture until 500 ml of condensate was collected. It was determined that no further aroma was extracted after 500 ml of condensate was collected. The condensate was then subjected to a liquid-liquid extraction with the
1. Steam source.
2. Heating mantle.
3. Ground onions.
4. Distillation flask.
5. Thermometer.
6. Condenser.
7. Condensate receiver.

Figure 2. Steam distillation process diagram.
experimental solvent. Again, for solvents partially soluble in water, sodium sulfate was used to separate this contaminant from the aroma solution. After the liquid-liquid extraction step, the solvent was separated in the rotatory evaporator (at a vacuum of 20 in Hg), the residue in the evaporator was transferred into a weighed vial and the amount of oil calculated by weight difference.

**Fermentation**

The procedure followed to develop a microbial growth in the ground onions was the conventional method normally used for natural lactic acid fermentation of cabbage, described by Prescott and Dunn (1949). A weighed amount of ground onions was mixed with an equal weight of water, and 2.5% of the total mixture (weight basis) of sodium chloride (reagent grade). Then, the mixture was allowed to stand at 65°F for different periods of time. After fermentation, the mixture was analyzed for pH and subjected to the combined liquid-liquid and solid-liquid extraction procedures described previously.

**Analysis of the Onion Oil**

The oil obtained by the method of direct solvent extraction outlined above was analyzed for refractive index, melting point, specific gravity, sulfur content, and absorption pattern with the infrared spectrophotometer.
Refractive Index, Melting Point, and Specific Gravity

The refractive index measurement was carried out in a Bausch and Lomb refractometer at 21°C. The melting point was measured by the capillary tube method described by Mehlebencher (1960); briefly, it consists of placing a certain amount of solidified oil in a capillary tube (1 mm i.d., 2 mm o.d.), the capillary tube is attached to a thermometer with a rubber band and placed in a water bath with a slowly increasing temperature, and the melting point is recorded when the turbidity of the oil disappears. The specific gravity was measured with a conventional 5 ml pycnometer.

Sulfur Content of Onion Oil

The sulfur content measurement of the onion oil was carried out according to the method described by Butters and Chinery (1959), as follows:

Reagents:

1. Magnesium nitrate solution (25 g of Mg metal chunks was dissolved in 400 ml of fuming HNO₃).
2. Nitric acid (25% v/v solution).
3. Orthophosphoric acid (analytical reagent grade).
4. Acetic acid (50% v/v).
5. Gum acacia solution (5 g/lt).
7. Barium chloride powder, passed through a 1 mm mesh screen.

Procedure for standard curve:
Measure 0, 2, 4, 6, 8, 10, 12, 16, and 20 ml of standard sulfur solution in a 50-ml calibrated flask. Add 5 ml of 50% acetic acid solution, 5 ml of 25% nitric acid solution, and 1 ml of orthophosphoric. Add 1 g of barium chloride to each flask without disturbing the contents. Let set for 10 minutes then invert twice; let set again for 5 minutes and invert twice. Let set 5 minutes once more and invert ten times. Then add 1 ml of gum acacia solution, dilute to volume and invert twice. After one-and-a-half hours invert flask ten times and measure optical density.

Procedure for sulfur determination in sample:
Weigh 0.01 g of onion oil into a 30-ml beaker. Add 2 ml of fuming nitric acid, cover with a watch glass and let it stand overnight. Add 2 ml of magnesium nitrate solution, evaporate excess moisture and heat overnight at 450°C. Then place 5 ml of 25% nitric acid in the cold beaker and dissolve contents. Transfer solution into a 50-ml calibrated flask and dilute to volume. Filter solution and place 1 ml of filtrate in a 50-ml calibrated flask and add 5 ml of 50% acetic acid, 3 ml of 25% nitric acid, 1 ml of orthophosphoric acid, dilute to about 48 ml, mix, and develop turbidity as mentioned before. Then,
calculate the sulfur content from the standard curve previously obtained.

**Infrared Analysis**

The infrared analysis was conducted on a Beckman IR-18 spectrophotometer, wavenumber scan 4000-800 cm⁻¹, using sodium chloride cells; spectra for pure dipropyl disulfide, onion oil extracted in the laboratory, and of onion oil obtained from commercial sources (Stange Company) were recorded.

**Odor Threshold Determination**

The triangular test was selected to determine the odor threshold of onion oil. The procedure for the calculations followed in this experiment was based on a method described by Salo (1970). First 0.5 g of the onion oil was blanded with 0.5 g of Tween 80, and the mixture was diluted to a total volume of 100 ml. From this solution a series of dilutions was carried out in order to have concentrations of oil solutions at different levels of intensity. Forty judges were asked to select the odd samples from a set of three containers by sniffing them. One of the containers had the oil solution and that was the odd sample, or two of the containers had the oil solution, and the container without onion oil was the odd sample.
Since the triangular test was utilized for this experiment, the equation (1) was used to determine the percentage of correct judgments over and above chance (Salo, 1970).

\[ P_c = \frac{3}{2}(P_o - 33.33) \]  

where

- \( P_o \): percentage of correct judgments observed in the test.
- \( P_c \): percentage of correct judgments over and above chance.

The threshold concentration is the one determined 50% of the time.

**Comparative Flavor Test**

In order to determine the flavor desirability of the onion oil obtained in the laboratory the following procedure was used: 0.06 g of onion oil were blended with 0.06 g of Tween 80 and mixed with 300 g of tomato sauce, 6.0 g of commercial iodized salt and 700 ml of distilled water. Both samples were heated to 190°F for 10 minutes and served into paper cups (30 g approximately). Forty judges were asked to score on a 9-point hedonic scale their degree of like and dislike for the freshness, typical/natural, intensity, and overall desirability of the onion flavor in each sample. For the commercial onion oil 0.02 g of the oil were utilized instead of 0.06 g based on the fact that commercial onion oil has three times more sulfur compounds than the one obtained in the laboratory.

All the calculations for the odor threshold and flavor comparison
analyses were done using computer package programs of two-way analysis of variance for the flavor comparative test and linear regression for the odor threshold calculations.
RESULTS AND DISCUSSION

Effect of Type of Solvent on Onion Oil Yield

The first step of this work consisted of determining what solvent would be the most suitable for a direct solvent extraction of the essential oil of onion, considering the factors mentioned in the Introduction of this paper, namely, toxicity, purity, availability, separability from the food, and selectivity for the oil to be extracted. Table I shows the results obtained using four solvents commonly used in the food industry. It includes average yield of extraction from samples in triplicate, and characteristics of the oil obtained.

<table>
<thead>
<tr>
<th>Solvent used</th>
<th>Yield x 10^-h (gr oil/gr onion)</th>
<th>Characteristics of the oil</th>
</tr>
</thead>
<tbody>
<tr>
<td>Diethyl ether</td>
<td>5.201 ± 0.07</td>
<td>Brown liquid, very onion-like odor</td>
</tr>
<tr>
<td>Methylene chloride</td>
<td>2.760 ± 0.06</td>
<td>Yellowish liquid, very onion-like odor</td>
</tr>
<tr>
<td>Ethyl acetate</td>
<td>4.040 ± 0.08</td>
<td>Brownish liquid, not so much onion-like odor</td>
</tr>
<tr>
<td>Hexane</td>
<td>0.850 ± 0.03</td>
<td>Brownish liquid, not so soluble in solvent</td>
</tr>
</tbody>
</table>

^a Mean of samples in triplicate ± S.D.
The procedure of extraction of the onion oil with each solvent was the procedure described in Figure 1. For these preliminary experiments, the extraction time after the onions were ground was 10 hours which, as it will be discussed later, is not the optimum extraction time. Diethyl ether appears to be the most appropriate solvent for the extraction operation. It gave the highest yield of onion oil and has a relatively low boiling point (36°C), which permits an easy separation without losing too many flavor volatiles.

The fact that diethyl ether is partially soluble in water presents the problem of water contamination in the onion oil. To solve this problem, the ether solution of onion oil was passed through a bed of sodium sulfate, a commonly used water adsorbant.

One advantage the use of methylene chloride in the solvent extraction presents is that it is not soluble in water. However, this solvent does not seem to be as selective as diethyl ether for the extraction of onion aroma components since it extracts only half as much onion oil as diethyl ether (see Table I).

Ethyl acetate appeared to be as selective as diethyl ether for the extraction of onion oil. However, ethyl acetate has a relatively high boiling point (76°C) which causes the loss of many volatile aroma components during the evaporation step. Hexane, a definitely non-polar solvent, did not appear to have much selectivity for the onion aroma components, with respect to the onion oil yield (0.00085 gr oil/gr onion).
Effect of Time of Extraction on Onion Oil Yield

One important step in the method of extraction of onion oil developed here is the time of extraction after the onions are ground. As was mentioned before, the components of the onion aroma are not present in the intact onion as such, but are actually derived from the action of the enzyme alliinase on the amino acid derivative S-(1-propenyl)-L-Cysteine sulphoxide (Freeman, 1976). Figure 3 shows a graph of the time of extraction against yield of onion oil. A time of extraction of 20 hours was observed to be the time at which the maximum yield of onion oil was obtained. This time is critical for the process since enough time should be allowed for the enzyme to come in contact with the amino acid precursor. Also, this extraction time permits the onion aroma components to be solubilized or mixed with the carrier agent, which in this case is water.

The yield of onion oil obtained with the process developed here was 0.073% (weight basis), whereas by steam distillation it was 0.0085%. The literature reports 0.01% of onion oil normally obtained by the steam distillation procedure (Fenaroli, 1971). The process of direct solvent extraction developed here yields approximately seven times more onion oil than the steam distillation method. This could be attributed to the fact that by direct solvent extraction, onion aroma components with higher volatilities than water can be extracted. The efficiency of extraction in this case will depend on factors such as particle size of the solids to be extracted, the solvent utilized,
Figure 3. Effect of extraction time on onion oil yield.
the temperature at which the operation is carried out, and the agita-
tion of the fluids (Heldman, 1975). It is generally accepted that
smaller particles have larger interfacial area between solid and
liquid, thus improving the rate of extraction of solutes. As ex-
pressed in the general mass-transfer equation, \( \frac{dN_s}{dt} = AK(C_s) \), the
rate of transfer of the solute \( \frac{dN_s}{dt} \) is directly proportional to the
transfer area \( A \), the mass transfer coefficient \( K \), and the concen-
tration of the solute \( C_s \). However, particularly in our case, it was
noticed that an excessive reduction of the particle size of the
ground onion will produce the release of excessive pectic substances
from the onion tissue which will cause the solvent, the water, and the
solid material to emulsify and make the extraction and filtration op-
erations more difficult. It was determined in the laboratory that
grinding the onions in the Waring blender for a period of 40 seconds
was the optimum grinding time to avoid the problem of an excessive
release of pectins.

The temperature selected for the extraction operation was room tem-
perature. It would be expected for the diffusion coefficients for the
solvent within the solid particles to increase at higher temperatures
resulting in a more rapid extraction rate. However, for our parti-
cular case it is desirable to avoid higher temperatures since some
of the aroma components of onions are heat labile.

The rate of agitation selected during the extraction operation
was 50 rpm. Even though it is generally accepted that a fast
agitation promotes a better contact between the solute and the solvent, it was noticed in our case that an agitation rate higher than 50 rpm will cause an excessive "emulsification" of the pectic substances in the ground onions and the solvent, making the filtration operation difficult.

An advantage of the method of direct solvent extraction of onion oil proposed in this work is that it does not utilize extreme temperatures during the process, but the highest temperature in the process would be the boiling temperature of the solvent in the step of evaporation. This allows the extraction of an onion oil with a raw onion aroma, whereas onion oil from steam distillation has a flavor designated as "cooked" onion flavor (Boelens et al., 1971).

It was also noticed that after a period of extraction of approximately 20 hours, the filtration step was much easier. Alexander and Sulebele (1973) found that onion skin contains from 11 to 12% pectin which causes problems in filtrating the onions immediately after grinding. After allowing the ground mixture to set for a certain time (20 hours), the filtration time was reduced to almost half. Even though we could not find any data in the literature on endogenous pectinase activity in onions, it is likely that during the holding time some of the pectin present in the ground onion is hydrolyzed or solubilized by pectinase enzymes, allowing a more rapid and clean filtration.
Onion Oil Yield in Different Varieties of Onion

Three varieties of onion, the most commonly consumed in the region, were studied for onion oil content using the method of direct solvent extraction. Table 2 shows a list of the yield of onion oil obtained. The variety Spanish Yellow (Early Shipper) gave the largest yield of onion oil (0.0703%, weight basis); the variety Granex Y33 yielded similar amounts of onion oil (0.070%). Even though the variety Denver Yellow is famous for its pungency, it yielded the lowest amount of onion oil.

<table>
<thead>
<tr>
<th>Onion variety</th>
<th>% Oil yield&lt;sup&gt;a&lt;/sup&gt; (weight basis)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spanish Yellow Early Shipper</td>
<td>0.0703 ± 0.002</td>
</tr>
<tr>
<td>Danver's Yellow Globe</td>
<td>0.0490 ± 0.008</td>
</tr>
<tr>
<td>Granex Y33</td>
<td>0.0700 ± 0.0045</td>
</tr>
</tbody>
</table>

<sup>a</sup>Mean of triplicate samples ± S.D.

The Spanish Yellow (Early Shipper) onion variety appears to be the most suitable for onion oil extraction due to its higher oil content, low price, and availability. This variety of onion is grown mainly in the eastern part of the State of Oregon where the land seems to be more suitable to grow onions.
**Effect of Fermentation on Onion Oil Yield**

Based on the fact that onions possess an appreciable amount of a potential precursor of onion aroma, the compound L-γ-Glutamyl-S-(1-propenyl) Cysteine sulfoxide, it was thought that the yield of onion oil could be significantly improved by somehow hydrolyzing this dipeptide into the monopeptide derivative S-(1-propenyl) Cysteine sulfoxides. However, the enzyme capable of breaking down the precursor dipeptide is not present in dormant onions (Austin and Schwimmer, 1970). Therefore, it was thought that if some kind of microorganism development is allowed in the onions, such as a mild fermentation, some γ-L-Glutamyl peptidase could be formed from microbial growth and the breakdown of the dipeptide flavor precursor could take place.

The type of fermentation was natural lactic acid fermentation such as the one utilized with cabbage in the production of sauerkraut to selectively allow the growth of lactic acid bacteria and to exclude growth of other types of undesirable bacteria that could be either pathogenic or produce bad odor or flavor. Figure 4 shows a plot of oil yield against time of fermentation. It was observed that after a week of microbial growth in the ground mixture, there was an increase of onion oil yield of almost 60% of that obtained by the normal solvent extraction procedure (approximately 0.11%, weight basis) indicating that it is probable that the lactic acid microbial growth released some enzymes capable of breaking down the dipeptide L-γ-Glutamyl-
Mean of samples in triplicate.

Figure 4. Effect of fermentation of raw onions on onion oil yield and pH.
S-(1-propenyl) Cysteine sulfoxide.

Even though an appreciable increase in the yield of onion oil was observed using a fermentation step after the onions are ground, it was noticed that after the fifth day of fermentation, there was a development of a bitter acid-like off-flavor in the oil after the extraction was completed which could be due to an excessive lactic acid microbial activity on the carbohydrates present in the onions. Pant et al. (1962) found that the composition of carbohydrates in onions is 11% of the total weight. Figure 4 shows the change in pH during the fermentation process, which went from 6.0 (normal pH of the onion juice) to 4.6, indicating the probable development of lactic acid bacteria. It is interesting to notice that even up to the fifth day of fermentation there was still an appreciable increase of approximately 50% (see Fig. 4) in the onion oil yield over the yield obtained by the normal solvent extraction process.

In addition to increasing the onion oil yield, the fermentation process also facilitated greatly the filtration operation. This was probably due to the increased acidity and the breakdown of the pectins in the onion mixture during the process.

Some Chemical and Physical Properties of the Onion Oil

The onion oil obtained by the process of direct solvent extraction is a brownish thick oil similar in color to the onion oil sold
Table 3 shows some characteristics of the onion oil obtained such as refractive index, density, melting point, and sulfur content. With respect to refractive index and density, the values obtained were very similar to those reported in the literature.

| TABLE 3. Some Chemical and Physical Properties of the Onion Oil Obtained by Direct Solvent Extraction. |
|-------------------------------------------------|-------------------------------------------------|
| **Solvent extraction** | **Commercial** |
| Refractive index = 1.5215 | 1.5373<sup>a</sup> |
| Sp. gravity = 0.9915 gr/ml | 0.996<sup>b</sup> |
| Melting point = 61°F | - |
| Sulfur content = 7.9% | 21.0% |

<sup>a</sup>Fenaroli (1971).

<sup>b</sup>Haensel (1903).

Values for sulfur content were not found reported, so this parameter was also determined in commercial onion oil in order to compare it with the value for the oil obtained by the process described in this paper. As was mentioned before, the values for the total amount of sulfur in the onion oil can be used as a means to evaluate it (Salzer, 1975), since most of the onion aroma components are sulfur compounds such as mono-, di-, and trisulfides, thiophenes, thiosulfonates, thiols, etc.
Table 3 shows that commercial onion oil has three times more sulfur content than the onion oil obtained in the laboratory, suggesting that the commercial onion oil may possess three times more flavor. This fact could be regarded as a disadvantage for the process developed here. However, even if it was accepted that the commercial onion oil has three times as much flavor components as the oil obtained in our work, the oil yield obtained by direct solvent extraction is still approximately seven times higher than the yield obtained by steam distillation, which makes the amount of flavor compounds more than two times higher than the commercial onion oil.

Even though the sulfur content in the onion oil tells us how much sulfur components are present, it does not indicate what kinds of compound these are. Dipropyl disulfide has generally been recognized as one of the main compounds in onion aroma (Boelens, 1971), therefore, its determination in the onion oil would give a better idea of the quality of the oil. Salzer (1975) suggested a procedure by infrared spectroscopy for the determination of dipropyl disulfide either pure or in solution. Figure 5 shows the IR spectra of pure dipropyl disulfide, pure commercial onion oil, and purified onion oil obtained by the method of extraction here. It can be noticed that both the commercial onion oil and the oil obtained by direct solvent extraction have similar absorption pattern and also show similar absorption peaks in the same wavelengths as dipropyl disulfide spectrum, especially in the 2800 - 3000 cm\(^{-1}\) range. This indicates that even
Figure 5A. Infrared spectra of dipropyl disulfide.
Figure 5B. Infrared spectra of solvent extracted onion oil.
Figure 5C. Infrared spectra of commercial onion oil.
though the onion oil obtained by our method has one-third as much sulfur compounds per unit weight as the commercial onion oil, they have a similar amount of dipropyl disulfide.

**Odor Threshold**

For the odor threshold determination of the onion oil an amateur taste panel was selected composed of graduate students and several faculty members. For this experiment, the triangular test was selected since this type of test has proved to be advantageous from the point of view of statistics (Peryam and Swartz, 1950).

The concentrations of onion oil detected 50% of the time for commercial onion oil and solvent extracted onion oil were 1.8 and 8.4 p.p.b. respectively (see Figs. 6 and 7; Table 4). The graph of concentration of onion oil against probability (percentage of correct judgments over and above chance) resulted in a fairly straight line; the value for goodness of fit was 0.97, which conforms to the law suggested by Fechner (Harrison and Elder, 1950) which states that the smell perception varies with the logarithm of the stimulus value.

The low concentration value determined for the odor threshold of the onion oil gives an idea of the amount of the volatile components present in the oil and also of the nature of these components. Comparing the data of our onion oil with the data for the odor threshold of commercial onion oil, we notice that the concentration for the odor threshold of the commercial onion oil is significantly
Figure 6. Odor stimulus response to different concentrations of commercial onion oil.
Figure 7. Odor stimulus response to different concentrations of onion oil obtained by direct solvent extraction.
lower than that of the oil obtained in the laboratory (see Table 4), approximately in a proportion of 1:5.

Not many references are reported in the literature about the odor threshold evaluation of the essential oil of onion, particularly on the relationship of the sulfur compound concentration in the onion oil and odor threshold values. Schwimmer and Guadagni (1962) carried out a comparison analysis between olfactory threshold concentration and pyruvic acid content of onion juice. These workers found a highly significant correlation ($r = -0.97$) between the enzymatically developed pyruvic acid present in the juice of the comminuted onions and the olfactory threshold concentration of the juice. They reported odor threshold concentration of juices of different varieties of onion, from 3 ppm to 23 ppm. However, this procedure for the evaluation of onion odor threshold cannot be applied to the onion oil since, as was mentioned before, most of the pyruvic acid from the onion is likely to remain in the water of extraction.

<table>
<thead>
<tr>
<th>Onion oil</th>
<th>Covariance</th>
<th>Regression coefficient</th>
<th>Goodness of fit</th>
<th>ppb (at 50% prob.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Commercial Obtained in lab.</td>
<td>6.1203</td>
<td>0.940</td>
<td>0.884</td>
<td>1.6</td>
</tr>
<tr>
<td></td>
<td>4.1925</td>
<td>0.970</td>
<td>0.947</td>
<td>8.4</td>
</tr>
</tbody>
</table>
Flavor Evaluation

In order to get a better idea of the quality of the oil obtained, a flavor comparison test with a commercial onion oil was carried out, and the results of this experiment are expressed in Table 5.

<table>
<thead>
<tr>
<th></th>
<th>Freshness</th>
<th>Typical/natural flavor</th>
<th>Intensity</th>
<th>Overall desirability</th>
</tr>
</thead>
<tbody>
<tr>
<td>Commercial onion oil</td>
<td>5.75</td>
<td>5.25</td>
<td>5.45</td>
<td>5.32</td>
</tr>
<tr>
<td>Solv. extr. oil</td>
<td>5.25</td>
<td>5.07</td>
<td>5.02</td>
<td>5.20</td>
</tr>
<tr>
<td>LSD at 5%</td>
<td>0.64</td>
<td>0.66</td>
<td>0.63</td>
<td>0.65</td>
</tr>
</tbody>
</table>

The onion oil obtained by the procedure developed here and the commercial onion oil did not show any apparent difference in any of the four parameters tested (freshness of flavor, typical/natural onion flavor, intensity, and overall desirability). The scores obtained for the commercial onion oil show slightly higher values than those for the onion oil obtained in the laboratory but none of the scores were statistically different at the 5% level. The concentration of the onion oil in the formula utilized was determined by asking the opinion of some of the students present at the time in the laboratory.
CONCLUSIONS

This report outlines the research conducted to develop a process for the direct solvent extraction of the essential oil of onion, using diethyl ether as the extracting agent. This process offers advantages over the steam distillation procedure such as better yield, more economical from the energy utilization point of view, and relatively low operation temperatures, which have favorable effects on the quality of the oil. With respect to yield, direct solvent extraction of the onion aroma shows a definite advantage over the steam distillation method since a yield of about seven times higher was estimated for the method developed in this research.

The use of a fermentation step after the grinding of the onions proved to be advantageous with respect to yield of oil. This indicated that the microbial development in the mixture probably released the enzymes for the breakdown of some of the potential flavor precursors present in the onion.

Even though generally recognized standard specifications for onion oil were not available, the chemical and physical characteristics of the product obtained by the method developed here, such as refractive index and density, conform to the data reported in the literature.

The organoleptic evaluation showed that our onion oil has comparable flavor characteristics to commercial onion oil. The resulting scores for both oils did not show a statistically significant difference. From the odor threshold analysis results, it can be concluded
that the commercial onion oil has more volatile aroma components than the oil obtained by our procedure; this appears to be obvious since the steam distillation procedure, as was mentioned before, separates compounds of low volatility. However, it has to be mentioned that even though the steam distillation process separates volatile compounds mainly, it also produces the formation of heat-deteriorated compounds, due to the higher temperatures utilized.

The analysis of both oils—the one obtained by the procedure developed here and the commercial oil—showed that the solvent extraction procedure with fermentation extracts approximately three times more sulfur compounds (per raw onion weight) than the steam distillation method.

Suggested Future Research

1. Onions possess a potential flavor precursor, the dipeptide L-γ-glutamyl-S-(1-propenyl) cysteine sulphoxide which is not attacked by the enzyme alliinase. Thus, studies should be done on the use of non-endogenous L-γ-glutamyl transpeptidase and cysteine-sulphoxide lyase to breakdown the potential flavor precursor and to improve the yield of aroma compounds extracted.

2. More studies on the process of fermentation of the onions should be done regarding the control and optimization of the fermentation operation.
3. Studies need to be done on the stability and shelf life of the onion oil obtained by direct solvent extraction.

4. Raw onion flavor components are heat-sensitive, therefore studies should be done using high pressure liquid chromatography.

5. Studies should be done on extraction of flavor aroma concentrates using supercritical gases. This method of extraction has great application on the extraction of heat-sensitive aroma compounds.
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