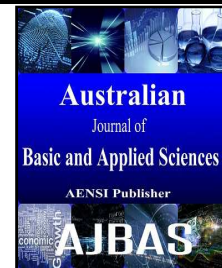




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A Comparative Review Of Conventional And Microwave Assisted Extraction In Capsaicin Isolation From Chili Pepper

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ABSTRACT

In recent times, major concern had been placed on the economic importance of major constituents of chili pepper to our society; research work had therefore been extensively carried out on the conventional way of extracting this active component called capsaicin obtainable in different cultivars of locally grown peppers. However several drawbacks abound when isolating capsaicin using the conventional approach and these include high solvent consumption, low extraction yield, solvent contamination, higher cost of extraction and longer extraction time, among other factors. These set-backs therefore necessitated the introduction of an improved method called microwave assisted extraction. This review therefore provided a simple theoretical background to capsaicin leaching processing using different traditional methods with a careful comparative description of microwave potential for optimum extraction.

INTRODUCTION

Chili pepper is grown in many parts of tropical and subtropical parts of the world including Vietnam, India, Brazil, Indonesia, and Malaysia among others. Vietnam being the largest producer of the world pepper market, accounted for over 44% of the world production followed by India being second world largest pepper grower (Mokshapathy, 2013; Pandey, 2012). Pepper is therefore an important agricultural crop with economical, nutritional and health benefits, used as spices in food industry, traditional medicine as anti-rheumatic, agricultural industry, pharmaceuticals as an analgesic, essential balm production as an adiabatic substance, and also as tear gas components in policing (defense) (Koleva *et al.*, 2013; Nwokem *et al.*, 2010., Adkins, L. D. 2003). This benefit is due to the presence of significant quantities of different varieties of carotenoids, vitamins, minerals, and phenolic compounds with antioxidant characteristics (Howard *et al.* 2000). Its nutritional quality, pungency, aroma and colour make them good food additives. Also, besides its use as food additives, capsaicin has also gotten clinical use in pharmaceutical industry and is often regarded as an analgesic substance (in surgery). Due to its ability to suppress pain without necessarily inhibiting brain responses it is considered as a potential replacement for traditional anesthesia which has the disadvantages of different health risks, such as blockage in the nerve impulses, sore throat, vomiting after surgery, teeth damage, shivering and other side effects (Giordano *et al.* 2012; Derry & Moore, 2012; Kulkantrakorn *et al.*, 2013).

Length *et al.* (2015) in his investigation elucidated the therapeutic remedies when used in small quantities for various ailments such as sore throats, asthma, coughs, toothaches reliever, balm production to assuage pain, shingles, rheumatism and arthritis. Its anti-bacterial can also not be overemphasized (Kaye *et al.*, 2002). Ivonne *et al.* (2014), also reported the use of capsaicin in the treatment of arthritis, rheumatism, stomach aches, skin rashes, and snake bites. This was supported by Chemat *et al.* (2012) who recorded the use of some notable capsicum species as anti-mutagenic, diabetic neuropathy, post-herpetic neuralgia and anti-tumor agent. Robbins (2000) in

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investigated the clinical application of capsaicinoids in the extensive management of a number of sensory nerve fiber disorders, such as cystitis and human immunodeficiency virus (HIV).

Capsaicin(trans-8-methyl-N-vanillyl-6-nonenamide) is a stable, powerful and major component of the pepper accounting for about 69% of the total content. It belongs to a distinct group of genus *capsicum*, exemplifying up to twenty seven species with five domesticated and twenty two un-domesticated (Bosland, *et al.*,2012).It has a molecular formula $C_{18}H_{27}NO_3$ and can be industrially produced either from the reaction between vanillamine and 7-methyloct-5-ene-1-carboxylic acid chloride or through from extraction from grounded chilli pepper(Reilly *et al.*, 2003 ; Sharma *et al.*, 2013; L.Asnin& S.Park,2015).

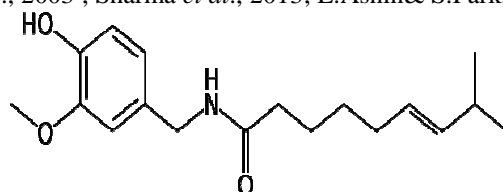


Fig. 1: Chemical structure of capsaicin (trans-8-methyl-n-vanillyl-6-nonenamide)

It is a pungent, colourless, odourless, and volatile crystalline alkaloids regarded as an active agent (due to its high concentration in chilli pepper) as compared to other capsaicinoids which are present only in trace quantity (Bosland 1996). There are six major naturally occurring capsaicinoids in chili pepper and these include capsaicin, dihydrocapsaicin, nordihydrocapsaicin, homodihydrocapsaicin, homocapsaicin and nonivamide with capsaicin taking up higher proportion from the total capsaicinoids as shown in figure 2 below. Its content therefore varies with variety, climate, geographical location, maturity, and methods of processing (Rodriguez-Amaya, 1997). The combine effect of these therefore shows that, no one particular pepper is rich in all nutrients, hence the need to consume the pepper as combinations for nutritional benefits(Bosland1994;Emmanuel, 2014).

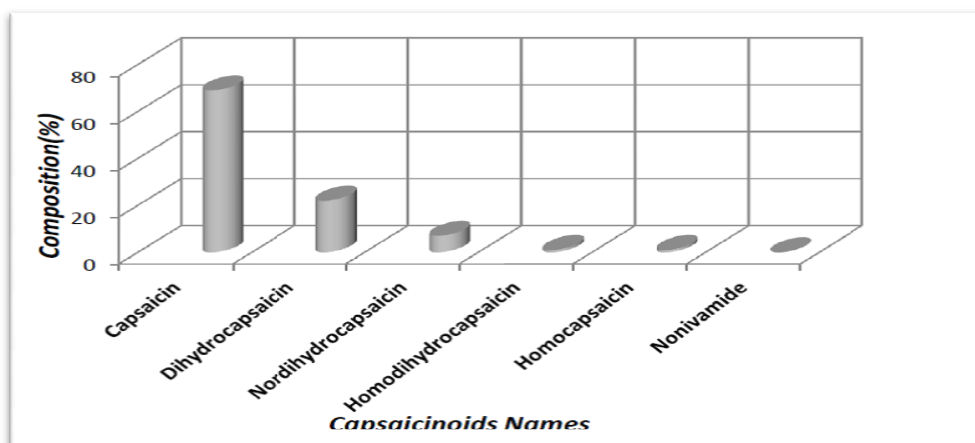


Fig. 2: General composition of major natural occurring capsaicinoids in chilli pepper

1.2 Overview Ofconventional Methods OfCapsaicinextraction:

There are several approaches used in the extraction of useful soluble components from several natural products;thesolid-liquid extraction is such method usedin purifying and extracting soluble constituents from chilli pepper. Different methods employed in the purification and extraction of capsaicinoids from pepper matrix can therefore be broadly categorized into conventional and modern extraction techniques (Viktorijaet *al.*, 2013; Silva *et al.*2005; Vesnaet *al.* 2011; Veggiet *al.* 2014). The conventional method of extraction includes the maceration, hydro-distillationand soxhlet extraction, techniques (Satyajitet *al.* 2005; Fernández-Roncoet *al.* 2013; Chen *et al.* 2015; Silver *et al.* 2013).

Table 1 shows the summary of some of the conventional methods employed in the isolation of several capsaicinoids components of different species of chilli pepper.

Table 1: Recent Application of Different Conventional Method in Capsaicin Isolation

Author	Method of Extraction	Extracting Agent	Pepper Sample	Global Yield
Jiang <i>et al.</i> ,2013	Hydro-distillation	Water	Black Pepper(piper nigrum L.)	3.1%
Mageedet <i>al.</i> ,2010	Hydro-distillation	Water	White and black pepper	White=75.2 % ± 1.9 Black =76.2% ±1.9

Mohd-Said <i>et al.</i> ,2013	Hydro-distillation	Steam	<i>P.nigrum</i> L. (black pepper seed),	-
Rouatbiet <i>al.</i> ,2007	Steam distillation	Steam	Black pepper	2.1-3.5%
Boonkirdet <i>al.</i> , 2008	Maceration Soxhlet Extraction	Ethanol	Dreid Thailand Capsicum frutescens(fruit)	Maceration= 79.4% Soxhlet=92.0%
Caporaso <i>et al.</i> , 2013	Maceration	Hexane	Dried chili pepper (<i>Capsicum annum</i>)	10%-20%
Sivakumaret <i>al.</i> ,2014	Maceration	n-Hexane Methanol	Red and Yellow pepper(sweat pepper)	-
Santos <i>et al.</i> ,2015	Soxhlet Extraction	Ethylacetate Dichlomethane Ethyl ether Hexane	Malaguetapepper(capsicum frutescens L.)	Ethylacetate=88.8% Dichlomethane=92.1% Ethyl ether=72.1% Hexane=77.4%
Martinez <i>et al.</i> ,2014	Soxhlet and Extraction	Petroleum Ether	Jalapeno peppers(capsicum annum)	-
Vesnaet <i>al.</i> ,2011	Maceration Method	Ethanol, methanol n-hexane	Capsicum <i>annum</i> L.,ssp(microcarpumLongumconoides)	-
Viktorijaet <i>al.</i> ,2014	Maceration	Ethanol and acetone	Macedonia Capsicum(Vezena,Feferona,Bombinal,Sivrija)	-
Paduanoet <i>al.</i> ,2014	Maceration SoxhletExtraction	Ethanol	Red chili (Capsicum frutescens)	-
Sciet <i>al.</i> ,2014	Three-Phase-Extraction	n-hexane,Acetone and K ₂ HPO ₄	Red Chili	88%
Hadaret <i>al.</i> ,2014	SoxhletExtraction	Acetone	Turmeric(<i>Curcumelonga.L</i>)	6.49%

1.2.1 Maceration Extraction:

This process is widely used in the formulation of concentrated infusion, tinctures and plant extracts, involving dampening and softening of plant analytes with suitable solvents (men strum) at room temperature. This is performed in a closed reactor to prevent the solvent evaporation and batch-wise variations (Jain & Sharma, 2003). Samuelson (2004), suggested that the reactor used should be subjected to a constant agitation to attain spontaneity and a rapid equilibrium. This brings the clean men strum to the surface of the plant matrix with the extraction process usually staying for up to 5-15 days, after which the upper liquid layer is then strained or decanted off the solid residue(marc). And placed under pressure to remove the solution using a cloth or special press and the mixture is thereafter clarified using the filtration method(Singh, 2008).

Viktorijaet *al.* (2014), investigated the extraction of capsaicin from four species of grown Macedonia Capsicum cultivars (namely vezena, bombona, feferona and sivrija) using the traditional maceration method and vacuum filtration methods. This study indicated that maceration method extraction was effective for extracting the higher percentage of capsaicin from the Bombona species as compared to the other three species of capsicum grown in Macedonia. The result shows that acetone as an extracting agent is inappropriate solvent for spectrophotometer wavelength above 280nm when compared to ethanol. He concluded that the major drawback for this study is the longer time involved in the maceration extraction which took about 6 hours to complete at a temperature of 50°C. Vesnaet *al.* (2011), used the traditional maceration extraction approach to obtain biological active component in two dried red paprika fruits (capsicum annum L., ssp. and microcarpumlongumconoides). Three different organic solvents (ethanol, methanol and n-hexane) were employed and a comparison made on the extraction efficiencies of each of them at different condition of temperature, dynamic time and the solvent time. The three solvent were later compared and concluded that methanol and ethanol permit a shorter extraction time and a reduced solvent consumption. Also, the extraction yields of the analytes were higher in maceration method of extraction but the major drawback in maceration method is the high solvent consumption, and a lower extraction yield and longer extraction time (Bucaret.a.2013).

However main advantage of this method is the attainment of a complete extraction of the constituents of interest and prevention modification in the chemical constituents of the extract (Jankovicet *al.* 2015). Another merit of maceration method is the reduction in the cost of evaporation, thereby minimizing the rupture in the cellular arrangement of thermo-labile constituents in the extract. This method is highly regarded and extensively used in the production of phyto-chemicals resulting in the isolation of single pure molecules and standardized extracts for therapeutic purposes (Sham *et al.*,2015)

1.2.2 Hydro-Distillation Extraction Approach:

Hydro-distillation is a conventional method used for the isolation of constituents of chilli pepper either through the use of a Clevenger apparatus or by steam distillation (Manzanet *al.*,2003; Tandon.,2007). The former involves a mixture of distilled water and the pepper matrix in adequate proportions with the addition of heat the latter involves passing steam through a bed of pepper matrix. In both methods the hydrated plant sample is

distilled and the component pepper extract turned into a vapour phase.(Ferhat *et al.*, 2006;Gloria *et al.*2005).The condensation of this vapour formed a water-extract phase layer which can later be separated out to obtain pure capsaicinoids extracts.



Fig. 3: Schematic Diagram of Hydro-distillation Extraction

(Stahl *et al.*, 1988) reported black pepper as containing fatty oil and a mixture of carotenoids which is difficult to extract and can only be isolated under a high pressures and moderate to high temperatures The extract is viscous, pasty, and semisolid and thus difficult to recover from separation vessels (Yao, 1994).However some thermo-labile (heat sensitive) constituents may be lost during extraction and this can be minimized through the use of a vacuum which helps in reducing the extraction temperature.

One of the major advantages of hydro-distillation extraction is the use of a low cost inorganic (water) solvent which can be mixed before the dehydration of the pepper matrix which is most suitable when the pepper sample is in dried basis (Tepe *et al.* 2005). The simplicity and availability of their equipments makes it a better option when compared to novel methods of extraction like microwave-assisted, supercritical fluid, and ultrasound assisted extraction (Gavahian *et al.*, 2012). The major drawback in hydro-distillation process is the difficulties in heat control which may lead to variability in the extraction rate with the scaling up to commercial capacity practically difficult. It is therefore desirable to explicate a new extraction technique that is fast, sensitive, safe, and energy conserving (Khajeh *et al.*, 2004).

Assam *et al.*(2012) pointed that the demerit experienced in hydro-distillation extraction has attracted the recent research focus and provoked the intensification, optimization and improvement of this technique. There is an increased demand for alternative extraction techniques, tractable to automation, with lesser extraction times and low organic solvent consumption, reduced pollution and lower sample preparation costs (Moradalizadeh *et al.* 2013). Jiang *et al.*,(2013) isolated essential oils from black pepper (*Piper nigrum* L.) using hydro-distillation (HD) and microwave-assisted hydro-distillation (MHD) method.The result of the study shows that the hydro-distillation and microwave assisted extraction having an extraction yield of 3.1 % and 3.8%, respectively. This further confirms the need for a more efficient extraction process which will fully optimize our plant sample.Majeed *et al.*, (2013) made a comparison between the antioxidant activity of the spice oil extracted from white and black pepper. The changes that took noticeable in the antioxidant activity of the spice oil extracted were estimated when hydro-distillation extraction and microwave assisted extraction. It was therefore concluded that the use of hydro-distillation techniques reduces the antioxidant nature of the spice oil extracted as compared to that obtained during the microwave assisted extraction process.

1.2.3 Soxhlet Extraction Method:

The conventional soxhlet extraction is one of the oldest method of solid-liquid extraction (otherwise known as leaching or lixiviation) invented as far back as 1879 by Franz Von Soxhlet (Chauhan *et al.*, 2015). The soxhlet apparatus is employed when the solubility of the capsaicinoids constituents is very low and when the impurities inside the extraction medium remain insoluble inside the solvent. The powdered pepper sample is loaded into the main chamber of the soxhlet extractor along with a condenser and later incorporated into a round bottom flask

containing the extracting solvent. Heat is applied refluxing to the boiling point of the extracting solvent and the solvent vapour travels through the distillation path to the thimble where the pepper sample is housed. The pepper matrix will soon be submerged inside the warm solvent and the constituents of interest are selectively isolated from the pepper matrix according to their boiling points. This cycle can be repeated a number of times given rise to a lower solvent consumption.

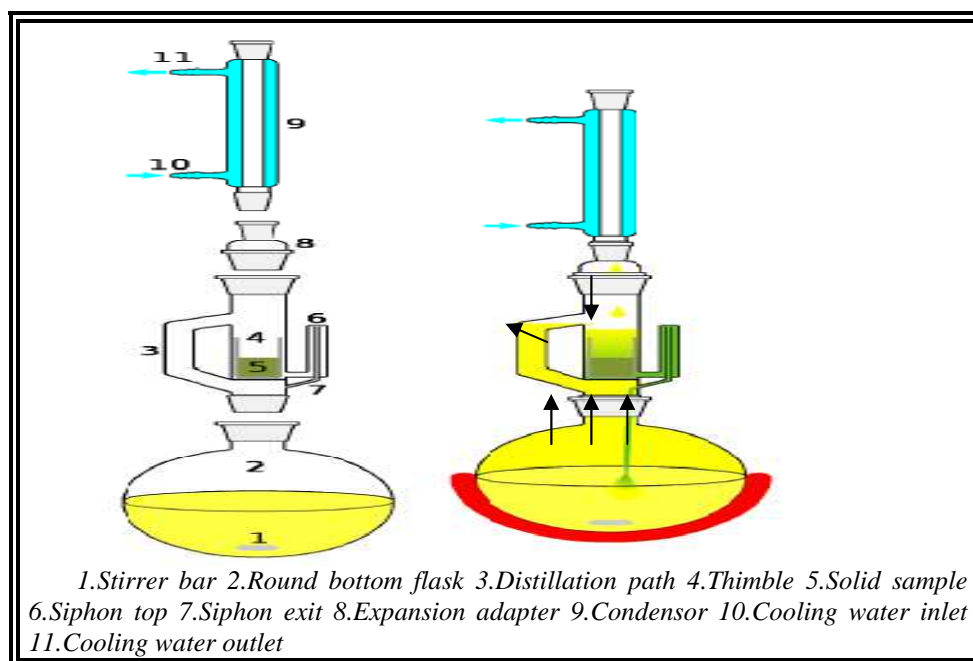


Fig. 4: Schematic Diagram of Soxhlet Extraction Set-up

(Source: *Origin of the Soxhlet Extractor*. William B., 2007)

The advantage of this method is the ease of recycling and optimization of the extracting solvent which is later removed through the use of rotary evaporator. However, the need for auxiliary equipment's like filter and rotary evaporator makes the commercial set-up expensive; this is the major drawback of soxhlet extraction method. Soxhlet extractor was used by Viktorija *et al.*, (2013) to extract capsaicin from different species of red hot pepper grown in Macedonia using ethanol as the extracting agent. The result obtained from soxhlet extraction were compared with vacuum filtration method which shows a remarkable difference in the quantity of the capsaicin extracted. Santos *et al.*, (2015) selected four different organic solvents (Ethyl acetate, dichloromethane, ethyl ether and hexane) to determine capsaicinoids content of malagueta pepper (*Capsicum frutescens* L.). The result shows a percentage of ethyl acetate, dichloromethane, ethyl ether and hexane as 88.8%, 92.1%, 72.1% and 77.4% respectively.

1.2.4 The Merits And Demerits Of Conventional Method Of Capsaicin Extraction:

The uniqueness of different extraction methods such as maceration, hydro-distillation and soxhlet are in their advantages, each of them portends. There are however several drawbacks in the use of the aforementioned conventional approach and these include, high solvent consumption, low extraction yield, contamination of the solvent, high cost of extraction and a large period of time required to carry out the extraction process, among other factors (Shams *et al.*, 2015). The high consumption of organic solvents involves an extra cost and a lower extraction yield means the plant extract is not being well optimized, leading to a waste of material and also being damaging to the environment (Luque and Garcia, 1998). The modern method of extracting capsaicinoids in different species of pepper was therefore introduced as an alternative technique for optimizing the yield, reducing unwanted contaminants, improving solvent consumption and reducing the time of extraction.

The merits and demerits of these methods are carefully highlighted in Table 2.

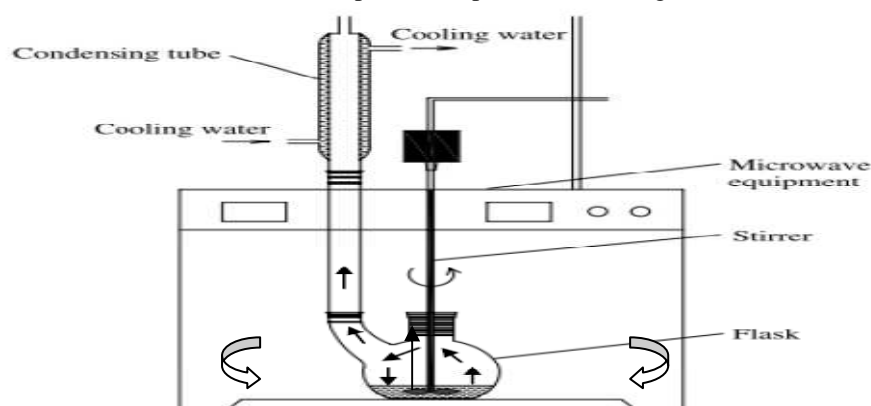
Table 2: Merit and Drawbacks of Convectional Extraction Approaches

Extraction Approaches	Merits	Drawbacks
Maceration	<ul style="list-style-type: none"> *Achievement of complete extraction of compounds with higher molecular weight *Lower chemical modification of the extracts. * Reduction in the cost of evaporation *Better homogeneity 	<ul style="list-style-type: none"> * It consumes lots of solvent. * A lower extraction yield that is not commensurate with time spent on extraction. *Higher extraction time which can take days.
Hydro-distillation	<ul style="list-style-type: none"> *Reduction in organic solvent contamination. *Simplicity of set-up 	<ul style="list-style-type: none"> *High cost of energy *Loss of heat to the environment *Degradation and loss of thermo labile compounds.
Soxhlet Extraction	<ul style="list-style-type: none"> *Ease of solvent recycling *Preservation of thermo-labile constituents 	<ul style="list-style-type: none"> *Expensive due to auxiliary equipment requirements (evaporators, filters etc)

1.3the Principle Of Isolating Capsaicin Using Microwave Assisted Extraction:

In the microwave assisted extraction the rate of heat and mass transfer is uniform throughout the heating fluid (homogeneity). This is because heat is volumetrically dispersed within the irradiate medium unlike the conventional method of extraction in which heat is transfer from the region of higher temperature to a lower region. Tameshiaet. al., (2010) opined that the conventional solid-liquid extraction can generate unwanted residuals with plant matrix and the extract experiencing oxidative quantitative change during the solvent removal stage. However, various scientific studies revealed the microwave assisted extraction's relevance to obtaining pure extracts from natural products, without undesirable residues. Microwave-assisted extraction is therefore a new approach which united the microwave and traditional solvent extraction with the merit of shorter extraction time, low solvent consumption and higher extraction rate (Milan *et al.*, 2004) Strauss & Trainor (1995) corroborated this by shedding more light on two fundamental phenomenons governing the microwave heating as ionic conduction and dipole rotation. In many instances, these two phenomena takes place at the same time with the ionic conduction offering a stiff resistance to the movement of ion which in turn generate a resistance leading to an heating effect on the medium. However the dipole rotation involves the re-adjustment of the molecular dipole moment to the ever changing electric field (Desai *et al.*, 2010) The electric field generated inside the microwave induces an ionic current in the solution which triggers off the extraction process. Due to their electromagnetic nature, microwaves possess electric and magnetic fields which are perpendicular to each other and the mechanisms of this field are the dipolar rotation and ionic conduction. There is therefore an ionic migration as the dipole rotates about its axis. The solvent in-turn offers impedance to the flow of its ion under the influence of the rapidly altering electric field. Frost *et al.*, (1997), concluded that the level of chaos in the solvent-ions migration inside the plant matrix reduces as the dipole rotation reduces and a subsequent reduction in the heat energy generated from the microwave. A pressure gradient is then built up and leading to a mass transfer inside the enter volume of the reactor. This is in contrast with the hydro-distillation extraction in which there is unequal pressure gradient in the enter volume of the container. Hence the extraction time is significantly reduced during since it takes only little time for mass transfer within the enter volume of the reactor.

This indicates that the migration of solvent ions from one region to another causes a resistance in the medium which causes an induction in the isolation of components in plant matrix (Srogiet *al.* 2006).

**Fig.5:** Schematic Diagram of a Microwave –Assisted Extraction

1.3.1 Effects of Dielectric Properties of a Mono and Binary Solvents Mixtures:

In microwave extraction process, the dielectric property, dissipation factor and solubility are the major parameters that determine the selection of suitable solvents in capsaicin isolation from chilli pepper (Kormin,2010 ;Medaet *al.*,2005). This property decides to a larger extent the rate of energy absorption of a biological medium (solvent-powdered pepper) from the microwave electric and magnetic fields. This is because energy is absorbed and usually converted into heat energy whenever there is a passage of the micro-wave into plant-solvent medium (Gwendolyn 2009 ; Hong *et al.*2001,Lou *et al.*,1997) and this wave is located between the infrared radiation and the radio waves in the electromagnetic spectrum. Microwave extraction therefore works on the principle of interaction between the extracting agent (solvents) and the electromagnetic/ electric field rotation (Singh *et al.*, 2014,Baoet *al.*, 1996). This triggers off the thermal activation and frictional effect which causes the migration of solvents ions. The dipole moment of the extracting agents influence the affinity and ability of the solvent to absorb the energy generated from the microwave electric and magnetic field rotation (Suratet *al.* 2012). The ability of solvent to absorb this energy from the microwave is therefore refer to as the dissipation energy and is denoted by a constant of proportionality called the dissipation factor (Ω) as shown in equation(1).

$$\text{Dissipation Factor } (\Omega) = \tan^{-1} \frac{\epsilon_1}{\epsilon_0} \quad (1)$$

Where ϵ_0 and ϵ_1 are the dielectric constant and dielectric loss respectively with the former being the capacity of the molecules of the extractants to become polarized by the rotating electric field and the latter determines the efficiency of the absorbed microwave energy with electromagnetic field to be converted to heat energy (Surat *et al.* 2012). A higher dissipation constant of solvent therefore indicates a higher efficiency of the extracting solvent. The choice of a solvent therefore plays an important role in the amount of the yield that will be obtained from an extraction process. Hence the dielectric properties of the extracting agent determines to a larger extent the ability of the solvents in converting the electromagnetic and electric field into a kinetic energy of the solvent molecules at given temperature and frequency of the microwave.

In conventional extraction method, water as a polar solvent is used in exploiting the solubility of natural products of different species. However some organic solvents of different degree of polarities have been introduced in recent times. Goguset *al.*(2015), used hexane and water separately as the extracting agent for capsaicinoids flavor from red pepper fruit. A total seventy-nine compounds were determined using the two-dimensional gas chromatography with the time of flight. The microwave assisted extraction gave the highest number of volatiles as compared to when water was used and this is due to the difference in dielectric properties of the solvents. Different solvents used generally used cover a wide degree of polarities. Polar compounds are therefore associated with high dielectric constant and can rapidly absorb heat faster than aromatic and aliphatic compounds with no net dipole moment (Gupta *et al.*,2009).The dielectric constants and dissipation factors of some solvents are shown in Table 1:

Table 3: Dielectric Constants of some commonly used solvents used in Capsaicin Extraction from Chilli Pepper

Solvents	Dielectric Constants	Molecular Weight(g/mol)
Water(H ₂ O)	78.3	18.01520
Ethanol (C ₂ H ₅ OH)	24.3	46.06844
Methanol (CH ₄ O)	32.6	32.04000
Acetone (C ₃ H ₆ O)	20.7	58.07140
Acetonitrile(C ₂ H ₃ N)	37.5	41.05192
Hexane (C ₆ H ₁₄)	1.89	86.17560
Isopropanol(C ₃ H ₈ O)	19.9	60.09502
DiethylEther(C ₄ H ₉ OH)	4.33	74.1216
Xylene	2.57	106.17
Toluene	2.38	92.14

In contrast, Renoe, 1994 suggested that the extracting ability of the medium to interact with microwaves can be modulated by using mixtures of solvents. The mixture of solvent could either be a binary or tertiary mixture and this have been utilized in both analytical and pharmaceutical sciences. A proper understanding of the underlying principle of dielectric constant is therefore required in the use of a multi-solvent in the process of isolating different constituents from natural products. Brachet *et al.* (2002) opined that the ability of solvents to interact with microwave energy can be further improved by the use of mixtures of solvents. Solvents such as ethanol, water and methanol possess a polar ends which absorbs a sufficient amount of energy from the microwave electric field.However,non-polar solvents such as hexane,toluene and xylene with lower dielectric constant can have their energy extracting ability improved by the introduction of polar solvents such as water and ethanol.The concepts of mixed solvents system had been employed in acid dissolution of drugs (Craiget *al.*, 1982), stability of pharmaceuticals (Sanyudeet *al.*, 1991) and in photoisomerisation reaction (Ikeda *et al.*, 2002). It is worthy of note that this method had not been fully harnessed in the extraction process, most especially in capsaicin isolation from chilli pepper.

The dielectric constant of ideal multi-solvents can be estimated using the method of weighted averages otherwise called additive function as proved in equation (2) - (6) (Dumanovicet *al.*, 1992; Jouybanet *al.*, 2004).

The mole fraction is calculated as shown in equation (2) and (3) below: Given that

NOTATION

$\tilde{\eta}_1$ = Mole fraction of solvent 1 $\tilde{\eta}_2$ = Mole fraction of solvent 2

W_1 = Molecular weight of solvent 1

W_2 = Molecular weight of solvent 2

W_t = Molecular weight of both solvent 1 & 2

$\mathcal{E}_{\text{Mixtures}}$ = Dielectric constant of the binary mixture

\mathcal{E}_1 = Dielectric constant of solvent 1

\mathcal{E}_2 = Dielectric constant of solvent 2

$$\tilde{\eta}_1(\text{solvents1}) = \frac{W_1}{\sum_{i=0}^n W_t} \quad (2)$$

$$\tilde{\eta}_2(\text{solvents2}) = \frac{W_2}{\sum_{i=0}^n W_t} \quad (3)$$

$$\mathcal{E}_{\text{Mixtures}} = \tilde{\eta}_1 \mathcal{E}_1 + \tilde{\eta}_2 \mathcal{E}_2 \quad (4)$$

$$\mathcal{E}_{\text{Mixtures}} = \tilde{\eta}_1 \mathcal{E}_1 + (1 - \tilde{\eta}_1) \mathcal{E}_2 \quad (5)$$

$$\mathcal{E}_{\text{Mixtures}} = \tilde{\eta}_1 (\mathcal{E}_1 - \mathcal{E}_2) + \mathcal{E}_2 \quad (6)$$

In microwave-assisted extraction (MAE), the microwave energy generates heat through the interaction between the oscillating electric field and the ionic component inside the solvent. The effect of microwave energy on the extraction yield is determined by the nature of the solvents and the solid matrix (sample) under consideration. The chosen solvent must therefore possess a high dielectric constant with high affinity for the absorption of the microwave energy. To increase the energy absorbing capacity of non-polar solvents such as hexane, toluene and xylene, a 10% amount of water is sufficient to trigger off the extraction rate and hence optimize the yield as shown in Table 4. Study has revealed that a combination of water with other non-polar extractants increases to a larger extent the rate of energy absorption of the mixture. (Brachetet *al.*, 2002). However polarity of the mixture increases as more water is added hence small volume of water is needed when using a binary mixture of water with other solvents (Talebiet *al.*, 2004).

Table 4: The static dielectric constant for ideal binary solvent mixtures

Solvents Mixtures	Dielectric Constant of Mixtures
Water- Ethanol	63.18
Water-Methanol	49.01
Water-isopropanol	33.30
Ethanol-Methanol	27.70
Ethanol-Diethyl ether	11.98
Xylene-Water	93.39
Toluene-Water	79.98
Hexane-Water	72.20

This effect could therefore be increased through the use of mixtures of ideal solvents; this will increase efficiency of extraction and help in cost reduction for a very expensive solvent as the combining effect will reduce the quantity of solvent used. Binary mixture of ideal solvents is therefore a way of optimizing the amount of scarce and expensive solvents in the extraction of natural products. In some cases, the matrix itself interacts with microwaves while the surrounding solvent possesses a low dielectric constant and thus remains cold (Jassieet *al.*, 1997).

1.3.2 The Dependency of Capsaicin Yield on Extraction Time:

The Figure 4 below shows the schematic diagram depicting the influence of extraction time on the extraction yield. When heat is applied at an initial stage (induction) of the extraction process, the weak hydrogen bond is disrupted as a result of the dipole rotation of the molecules. The molecular rotation of the molecule can be slowed down when the extracting medium is of a high viscosity and which in turn hamper the ionic conduction (Beatrice and Philippe, 2002). According to Veggiat *al.*, (2012), in a solid-liquid medium mass transfer occurs in three different stages in relation to the extraction time, these include the induction phase, intermediary transition phase and diffusion phase as shown in Figure 4 below.

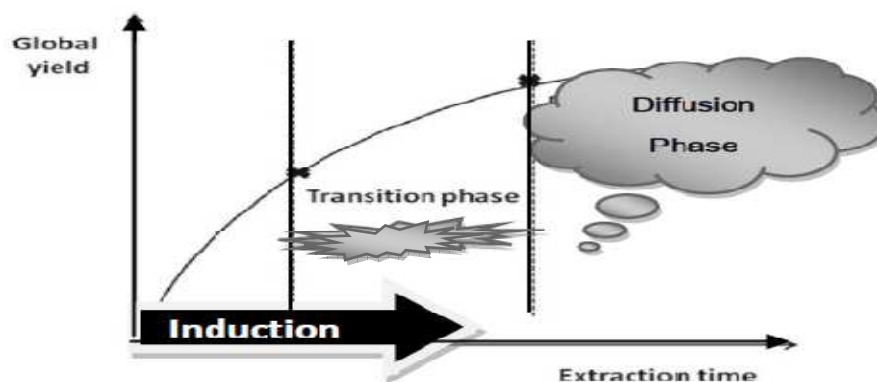


Fig. 6: The Schematic Diagram of Extraction Stages in Microwave assisted distillation

The induction phase is the region between the start of heating process the point and the point where the first drop of the extract appears. At this region the pepper matrix becomes soluble and is removed from its outer layer. This pave way for the intermediary transition phase in which the mass transfer is restricted at the solid-liquid interface and the mass transfer thereafter is met with a resistance at the solid-liquid interface and the transfer of mass by convection and diffusion pre-dominates. However at the last stage (diffusion phase), the solute must overcome the interactions that bind it to the matrix and diffuse into the extracting solvent. The extraction rate at this stage is reasonably low and the removal of the extract through the diffusion mechanism is noticeable. This point is an irreversible step of the extraction process; it is often regarded as the limiting step of the extraction process at which the extraction time remains steady (Veggi, *et al.*, 2012).

To avoid rupture or degradation of the plant matrix it's important to note the time requirement in the microwave assisted extraction as low when compared to the traditional hydro distillation method (Aguilera *et al.*, 2003). A longer extraction time is therefore required for substance of higher dielectric constant such as ethanol, methanol and water when the constituent of interest is stable to heat (non-thermos liable compound). Chan *et al.*, (2011), therefore proposed a step-wise extraction cycles for a thermos liable plant matrix through the addition to the residue a fresh solvent in order to optimize all the extractable constituents of the plant matrix.

1.3.3 Pepper Matrix Characteristics, Surface Area and Matrix to Solvent Ratio:

The surface area of the plant matrix has a substantial effect on the extraction efficiency on microwave extraction. Chilli pepper in powdery form therefore provides a spread and larger area for the ionic conduction within the biological medium. The size distribution of the powder allow for proper penetration of the extracting agent into the pepper matrix giving rise to a lower power requirement, smaller solvent consumption and lower time of extraction (Camel, 2001).

1.3.4 Microwave Power and Temperature Factor in Capsaicin Extraction:

Gao *et al.*, (2006) reported an accelerated effect on the ionic conduction and dipole rotation which in turn leads to an increase in the extraction yield. This is due to the release of more microwave energy to the biological medium as the microwave power increases. Polar solvents rates of absorption improve with an increasing power and a pen ultimately resulting in higher heating and extraction rate (Desai and Parikh, 2012). Clark *et al.*, (2000) described the energy density of microwave heating the power per unit quantity of sample under extraction as shown in Equation (7) below:

$$\text{Energy Density (E) in kW/g} = \frac{\text{Microwave Power (W)}}{\text{Quantity of sample (grams)}} \quad (7)$$

In the same vein, increasing microwave temperature above the boiling point of the extracting agent has the same effect on the microwave extraction by weakening the intermolecular force of attraction and this leads to a free flow of the molecule within the plant matrix. This in turn reduces the viscosity of the extracting solvents thereby increasing the solubility in the plant matrix (Henwimonet *al.* 2007). However due to an increasing microwave power and temperature there is possibility of adecreased extract purity as a result of extraction of other contaminants which makes the extract impure at higher power (Desai and Parikh, 2012). The power in a microwave is therefore directly proportional to the temperature of extraction. The relationship between the microwave power and the temperature of extraction is as shown in Equation (8) below:

$$P(\text{kW}) = \frac{\Delta T}{\Delta t} * \rho C_p \quad (8)$$

Where P is the microwave power, ΔT is the rise in temperature, Δt is the extraction time, ρ and C_p are density and specific heat capacity respectively.

Conclusion:

The general overview of this study clearly shows there is a significant difference in number of components obtained using the microwave assisted extraction (MAE) which is more than that obtained using the traditional approach. The microwave assisted extraction is therefore notable for its lower operating temperature, stability of thermolabile compounds to heat degradation, shorter extraction time; high selectivity in the extraction of compounds; and higher capsaicinoids quality. The microwave assisted extraction is therefore adjudged to be a cost-effective method on a pilot scale. There is therefore a need for further research into an accurate evaluation of an economic feasibility for a possible scale-up of each unit operations in the extraction process.

REFERENCES

- Adkins, L.D., 2003. Oleoresin Capsicum: an Analysis of the Implementation of Pepper Spray into the Law Enforcement Use of Force Continuum in a Selected Police Department. Electronic Theses and Dissertations, 86. Retrieved from <http://dc.etsu.edu/etd/779>
- Aguilera, J.M., 2003. Solid-liquid extraction. In: Tzia C, Liadakis G (eds) Extraction optimization in food engineering. Dekker, New York, pp: 35-55.
- Assami, K., D.Pingret, S.Chemat, B.Y.Meklati and F.Chemat, 2012. Ultrasound induced intensification and selective extraction of essential oil from *Carum carvi* L. seeds. Chemical Engineering and Processing: Process Intensification, 62: 99-105.
- Bao, J.Z., M.L.Swircord, C.C.Davis, 1996. Microwave dielectric characterization of binary mixtures of water, methanol, and ethanol. J. Chem. Phys. 104: 4441-4450.
- Boonkird, S., C.Phisalaphong and M.Phisalaphong, 2008. Ultrasound-assisted extraction of capsaicinoids from *Capsicum frutescens* on a lab- and pilot-plant scale. Ultrasonics Sonochemistry, 15(6): 1075-1079.
- Boonkird, S., C.Phisalaphong and M.Phisalaphong, 2008. Ultrasound-assisted extraction of capsaicinoids from *Capsicum frutescens* on a lab- and pilot-plant scale. Ultrasonics Sonochemistry, 15(6): 1075-1079. <http://doi.org/10.1016/j.ultsonch.2008.04.010>
- Bosland, P.W., E.J.Votava and E.M.Votava, 2012. Peppers: vegetable and spice capsicums (Vol. 22).
- Bosland, P.W., 1994. Chiles: history, cultivation, and uses. In: Charalambous, G. (Ed.), Spices, Herbs and Edible Fungi (Herbs). Elsevier Science publishers, Amsterdam, pp: 347-66.
- Bosland, P.W., 1996. Capsicums: innovative use of an ancient crop. In: Janick, J. (Ed.), Progress in New
- Bosland, P.W., E.J.Votava, 1999. Peppers: Vegetable and Spice Capsicums. CAB, UK.
- Brachet, A., P. Christen, J.L. Veuthey, 2002. Focused microwave-assisted extraction of cocaine and benzoylecgonine from coca leaves. Phytochem Anal, 13:162-169.
- Bucar, F., A.Wube and M.Schmid, 2013. Natural product isolation—how to get from biological material to pure compounds. Natural product reports, 30(4): 525-545.
- Camel, V., 2001. Recent extraction techniques for solid matrices—supercritical fluid extraction, pressurized fluid extraction and microwave-assisted extraction: their potential and pitfalls. Analyst, 126(7): 1182-1193.
- Caporaso, N., A.Paduano, A.Santini and R.Sacchi, 2014. Microwave and Ultrasound-Assisted Extraction of Capsaicinoids From Chili Peppers (*Capsicum annuum* L.) in Flavored Olive Oil. Journal of Food Research, 3(4): 51-59. <http://doi.org/10.5539/jfr.v3n4p51>
- Catchpole, O.J., J.B.Grey, N.B.Perry, E.J.Burgess, W.A.Redmond and N.G.Porter, 2003. Extraction of chili, black pepper, and ginger with near-critical CO₂, propane, and dimethyl ether: Analysis of the extracts by quantitative nuclear magnetic resonance. Journal of Agricultural and Food Chemistry, 51: 4853-4860. <http://doi.org/10.1021/jf0301246>
- Chan, C-H., R. Yusoff, G-C.Ngoh, FW-L.Kung, 2011. Microwave-assisted extractions of active ingredients from plants. J Chromatogr A 1218:6213-6225.
- Chemat Farid, Maryline Abert Vian, Giancarlo Cravotto, 2012. Green Extraction of Natural Products: Concept and Principles. International Journal of Molecular Science. doi: 10.3390/ijms13078615
- Chen, X., C.Wu, F.Wang, J.Liu and Y.Zou, 2015. A comparison of volatile fractions obtained from *Lonicera macranthoides* via different extraction processes: ultrasound, microwave, Soxhlet extraction, hydrodistillation, and cold maceration. Integrative Medicine Research, 4(3): 171-177. <http://doi.org/10.1016/j.imr.2015.06.001>
- Chiemsombat, P., N.Sae-Ung, S.Attathom, S.Patarapuwadol and P.Siriwong, 1998. Molecular taxonomy of a new potyvirus isolated from chilli pepper in Thailand. Archives of virology, 143(10): 1855-1863.
- Clark, D.E., D.C.Folz and J.K.West, 2000. Processing materials with microwave energy. Materials Science and Engineering: A, 287(2): 153-158.
- Craig, D.Q.M. and J.M.Newton, 1992. The dissolution of nortriptyline HCl from polyethylene glycol solid dispersions. International journal of pharmaceuticals, 78(1): 175-182.

- Ćujić, N., K.Šavikin, T.Janković, D.Pljevljakušić, G.Zdunić and S.Ibrić, 2015. Optimization of polyphenols extraction from dried chokeberry using maceration as traditional technique. *Food Chemistry*, 194(AUGUST), 135–142. <http://doi.org/10.1016/j.foodchem.2015.08.008>
- Derry, S., R.A.Moore, 2012. Topical capsaicin (low concentration) for chronic neuropathic pain in adults. *Cochrane Database of Syst. Rev.* 9, CD010111.
- Desai, M., J.Parikh and P.A.Parikh, 2010. Extraction of Natural Products Using Microwaves as a Heat Source. *Separation & Purification Reviews*, 39(1-2): 1-32. <http://doi.org/10.1080/15422111003662320>
- Desai, M., J.Parikh and P.A.Parikh, 2010. Extraction of Natural Products Using Microwaves as a Heat Source. *Separation & Purification Reviews*, 39(1-2): 1-32. <http://doi.org/10.1080/15422111003662320>
- Dumanovic, D., D.J.Kosanovic, D.Ardakovic, J.Jovanovic, 1992. Solubilization of ipronidazole by co-solvents. *Pharmazie*, 47: 603-607.
- Emmanuel-Ikpeme, C., 2014. Comparative Evaluation of the Nutritional, Phytochemical and Microbiological Quality of Three Pepper Varieties. *Journal of Food and Nutrition Sciences*, 2(3): 74. <http://doi.org/10.11648/j.jfns.20140203.15>
- Ferhat, M.A., B.Y.Meklati, J.Smadja and F.Chemat, 2006. An improved microwave Clevenger apparatus for distillation of essential oils from orange peel. *Journal of Chromatography A*, 1112(1-2): 121-126. <http://doi.org/10.1016/j.chroma.2005.12.030>
- Fernández-Ronco, M.P., I.Gracia, A.Lucas and J.F.Rodriguez, 2013. Extraction of Capsicum annum Oleoresin by Maceration and Ultrasound-Assisted Extraction: Influence of Parameters and Process Modeling. *Journal of Food Process Engineering*, 36(3): 343-352.
- Frost, S., and K.áP Evans, 1997. Extraction of hexaconazole from weathered soils: A comparison between Soxhlet extraction, microwave-assisted extraction, supercritical fluid extraction and accelerated solvent extraction. *Analyst*, 122(9): 895-898.
- Gao, M., B.Z.Song and C.Z.Liu, 2006. Dynamic microwave-assisted extraction of flavonoids from *Saussurea medusa* maxim cultured cells. *Biochemical Engineering Journal*, 32: 79-83.
- Gavahian, M., A.Farahnaky, K.Javidnia and M.Majzobi, 2012. Comparison of ohmic-assisted hydrodistillation with traditional hydrodistillation for the extraction of essential oils from *Thymus vulgaris* L. *Innovative Food Science & Emerging Technologies*, 14: 85-91.
- Giordano, C., L.Cristino, L.Luongo, D.Siniscalco, S.Petrosino, F.Piscitelli, I.Marabese, L.Gatta, F.Rossi, R.Imperatore, E.Palazzo, V.de Novellis, V.Di Marzo, S.Maione, 2012. TRPV1-dependent and -independent alterations in the limbic cortex of neuropathic mice: impact on glial caspases and pain perception. *Cereb. Cortex*, 22: 2495-2518.
- Gogus, F., M.Z.Ozel, H.Keskin, D.K.Yanik and A.C.Lewis, 2015. Volatiles of fresh and commercial sweet red pepper pastes: processing methods and microwave assisted extraction. *International Journal of Food Properties*, 18(8): 1625-1634.
- Gupta, M., S.Paul and R.Gupta, 2009. General Characteristics and Applications of Microwaves in Organic Synthesis, pp: 749-764.
- Gwendolyn A. Cross, Daniel Y.C. Fung and V.Robert, 2009. The effect of microwaves on nutrient value of foods. *Decareau Journal: C R C Critical Reviews in Food Science and Nutrition*, 16(4): 355-381.
- Haldar, S., G.C.Majumdar and H.N.Mishra, 2015. Modeling the kinetics of extracting oleoresin from dried turmeric (*Curcuma longa* L.) rhizome using acetone as solvent. *Journal of Food Engineering*, 146: 116-121. <http://doi.org/10.1016/j.jfoodeng.2014.09.009>
- Hemwimon, S., P.Pavasantand A.Shotipruk, 2007. Microwave-assisted extraction of antioxidative anthraquinones from roots of *Morinda citrifolia*. *Separation and Purification Technology*, 54: 44-50.
- Hong, N.I., V.A.Yaylayan, G.S.VijayaRaghavan, J.J.Paré and J.M.Bélanger, 2001. Microwave-assisted extraction of phenolic compounds from grape seed. *Natural product letters*, 15(3): 197-204.
- Howard, L.R., S.T.Talcott, C.H.Brenes and B.Villalon, 2000. Changes in phytochemical and antioxidant activity of selected pepper cultivars (*Capsicum* sp.) as influenced by maturity. *Journal of Agriculture and Food Chemistry*, 48:1713-1720.
- Ikeda, H., T.Suzue, M.Yukawa, T.Niiya, Y.Goto, 2002. Solvent effect on photoisomerisation of 3-methyl-1-phenylbutane-1,2-dione 2-oxime. *Chem. Pharm. Bull.*, 50: 969-971.
- Ivonne Domínguez-Martínez, Ofelia Gabriela Meza-Márquez, Guillermo Osorio-Revilla, José Proal-Nájera, Tzayhrí Gallardo-Velázquez, 2014. Determination of capsaicin, ascorbic acid, total phenolic compounds and antioxidant activity of *Capsicum annum* L. var. serrano by mid infrared spectroscopy (Mid-FTIR) and chemometric analysis. *Journal of the Korean Society for Applied Biological Chemistry*, 57(1): 133-142.
- Jain, N.K., S.N. Sharma, 2003. A Textbook of Professional Pharmacy. 4th ed. Delhi: VallabhPrakashan; pp: 296-8.
- Jassie, L., R. Ravesz, T. Kierstead, E. Hasty and S. Matz, 1997. Microwave-Assisted Extraction. In *Microwave-Enhanced Chemistry. Fundamental Sample Preparation and Applications*, Kingston HMS, Haswel S.J.(eds). American Chemical Society :Washington DC:569-609.

Jiang, Z.-T., X.Feng, R.Li and Y.Wang, 2013. Composition Comparison of Essential Oils Extracted by Classical Hydro distillation and Microwave-assisted Hydrodistillation from *Pimenta dioica*. *Journal of Essential Oil Bearing Plants*, 16(1): 45-50. <http://doi.org/10.1080/0972060X.2013.764178>

Jouyban, A., S.Soltanpour and H.K.Chan, 2004. A simple relationship between dielectric constant of mixed solvents with solvent composition and temperature. *International journal of pharmaceutics*, 269(2): 353-360.

Kaye, A.D., A.M.Kaye, A.Hegazi, R.Sabar, B.Deaton, J.Powell and R.Hofbauer, 2002. Nutraceuticals: Potential Roles and Potential Risks for Pain Management. *Pain Practice*, 2: 122-128. doi: 10.1046/j.1533-2500.2002.02013.x

Khajeh, M., Y.Yamini, F.Sefidkon and N.Bahramifar, 2004. Comparison of essential oil composition of *Carum copticum* Obtained by supercritical carbon dioxide extraction and hydrodistillation methods. *Food chemistry*, 86: 587-59.

Koleva, G., Liljana, Maksimova Viktorija, D.Serafimovska Marija, Gulabovski, 2013. The Effect of Different Methods of Extractions of Capsaicin on Its Content in The Capsicum Oleoresins Faculty of Agriculture , University Goce Delcev, Stip , R . of, pp: 917-922.

Koleva, G.L., V.Maksimova, D.Serafimovska, R.Gulabovski, J.Ivanovska, 2013. *Scientific Works Vol. LX, Food Sci., Engrg. and Tech.*, 18: 917-922.

Kormin, F., I.Ahmed, R.Mohd Yunus, Bin and Z.A.Yusof Mohd, 2010. The Potential of Modified Microwave Extraction System (Mmes) To Extract Bioactive Components From Ferns. *International Journal of Engineering & Technology*, 10(02): 7-21.

Kulankrakorn, K., C.Lorsuwansiri, P.Meesawatson, 2013. 0.025% capsaicin gel for the treatment of painful diabetic neuropathy: a randomized, double-blind, crossover, placebo-controlled trial. *Pain Pract.: Off. J. World Inst. Pain*, 13: 497-503.

Asnin, L. and S.W. Park, 2015. Isolation and Analysis of Bioactive Compounds in Capsicum Peppers. *Critical Reviews in Food Science and Nutrition*, 55(2): 254-289.

Asnin, L. and S.W. Park, 2015. Isolation and Analysis of Bioactive Compounds in Capsicum Peppers. *Critical Reviews in Food Science and Nutrition*, 55(2): 254-289.

Length, F., 2015. Phytochemical screening and antibacterial properties of selected Nigerian long pepper (*Capsicum frutescens*) fruits, 9(38): 2067-2078. <http://doi.org/10.5897/AJMR2014.7286>

Lou, J., T.A.Hatton, P.E. Laibinis, 1997. Effective dielectric properties of solvent mixtures at microwave frequencies. *J. Phys. Chem. A*, 101: 5262-5268.

Luque de Castro M.D. and Garcia-Ayuso L.E., 1998. Soxhlet extraction of solid materials. An outdated technique with a promising future., 369: 1-10.

Mageed Magda A. Abd El, Amr F. Mansour, Khaled F. El Massry, Manal M. Ramadan and S.Mohamed, 2013. *Shaheen Journal: Journal of Essential Oil Bearing Plants*, 14(2): 214-223.

Manzan, A.C.C.M., F.S.Toniolo, E.Bredow and N.P.Povh, 2003. Extraction of essential oil and pigments from *Curcuma longa* [L.] by steam distillation and extraction with volatile solvents. *Journal of Agricultural and Food Chemistry*, 51: 6802-6807.

Meda, V., V.Orsat and G.S.V.Raghavan, 2005. Microwave heating and the dielectric properties of foods. The microwave processing of foods, pp: 61-75.

Milan Suhaj, 2006. Spice antioxidants isolation and their antiradical activity: a review. *Journal of Food Composition and Analysis*, 19(6-7): 531-537. <http://doi.org/10.1016/j.jfca.2004.11.005>

Mohd-Said, S., F.A.Abdul Majid, W.A.Wan Mustapha and I.Jantan, 2013. Anti-Inflammatory Activity of Selected Edible Herbs and Spices on Cultured Human Gingival Fibroblasts. *The Open Conference Proceedings Journal*, 4(Supp-2, M9): 33-37. <http://doi.org/10.2174/2210289201304010236>.

Mokshapathy, S., 2013. Production and Export Performance of Black Pepper, 2(4): 36-44.

Nwokem, C.O., E.B.Agbaji, J.A. Kagbu, E.J.Ekanem, 2010. *New York Science Journal*, 3: 17-21.

Pandey, S.K., S.K.Yadav and V.K.Singh, 2012. Insecticidal activities : Antioxidant activity : Antimicrobial activities, 4(2): 821-828.

Reilly, C.A., D.J.Crouch and G.S.Yost, 2001. Quantitative analysis of capsaicinoids in fresh peppers, oleoresin capsicum and pepper spray products. *Journal of Forensic Sciences*, 46(3): 502-509.

Renoe, B.W., 1994. Microwave assisted extraction. *American laboratory*, 26(12): 34-40.

Robbins, 2000. *Clinical Applications of Capsaicinoids*. *Clinical Journal of Pain*: 16(2): S86-S89.

Rodriguez-Amaya, D.B., 1997. Carotenoids and food preparation: the retention of provitamin A carotenoids in prepared, processed and stored foods. Arlington, VA: John Snow Incorporated/OMNI Project.

Rouatbi, M., A.Duquenoy and P.Giampaoli, 2007. Extraction of the essential oil of thyme and black pepper by superheated steam. *Journal of Food Engineering*, 78(2): 708-714. <http://doi.org/10.1016/j.jfoodeng.2005.11.010>

Samuelsson, G., 2004. *Drugs of Natural Origin - A Textbook of Pharmacognosy*; Swedish Pharmaceutical Society, Swedish pharmaceutical Press: Stockholm, Sweden, 5th rev. ed.

Santos, P., A.C.Aguiar, G.F.Barbero, C.A.Rezende and J.Martínez, 2015. Supercritical carbon dioxide extraction of capsaicinoids from malagueta pepper (*Capsicum frutescens* L.) assisted by ultrasound. *Ultrasonics Sonochemistry*, 22: 78-88.

Sanyude, S., R.A.Locock and L.A.Pagliaro, 1991. Stability of aspartame in water: organic solvent mixtures with different dielectric constants. *Journal of pharmaceutical sciences*, 80(7): 674-676.

Satyajit, D., Sarker, Zahid Latif, Alexander I. Gray, 2005. *Natural Products Isolation book*; Totowa, New Jersey; 2nd ed.

Sci, C.J.F., Y.Dang, H.Zhang, Z.Xiu, L.Science and C.Engineering, 2014. Three-liquid-phase Extraction and Separation of Capsanthin and Capsaicin from *Capsicum annum* L. *Czech J. Food Sci.*, 32(1): 109-114. Retrieved from <http://www.agriculturejournals.cz/publicFiles/114007.pdf>

Shams, K.A., N.S.Abdel-azim, I.A. Saleh, M.F.Hegazy, M.M.El-missiry, F.M.Hammouda, E.Tahrir, 2015. Review Article Green technology: Economically and environmentally innovative methods for extraction of medicinal & aromatic plants (MAP) in Egypt, 7(5): 1050-1074.

Shams, K.A., N.S.Abdel-azim, I.A. Saleh, M.F.Hegazy, M.M.El-missiry, F.M.Hammouda, E.Tahrir, 2015. Review Article Green technology: Economically and environmentally innovative methods for extraction of medicinal & aromatic plants (MAP) in Egypt, 7(5): 1050-1074.

Sharma, S.K., A.S.Vij and M.Sharma, 2013. Mechanisms and clinical uses of capsaicin. *European Journal of Pharmacology*, 720(1-3): 55-62. <http://doi.org/10.1016/j.ejphar.2013.10.053>

Silva, L.P.S., A.C.Aguiar, G.F.De, Barbero and J.Martínez, 2013. Scale-Up of SFE from *Capsicum Pepper* using Supercritical Carbon Dioxide, (1): 1-6.

Silva, L.V., D.L.Nelson, M.F.B.Drummond, L.Dufossé and M.B.A.Glória, 2005. Comparison of hydro-distillation methods for the deodorization of turmeric. *Food Research International*, 38(8-9): 1087-1096. <http://doi.org/10.1016/j.foodres.2005.02.025>

Silva, L.V., D.L.Nelson, M.F.B.Drummond, L.Dufossé and M.B.A.Glória, 2005. Comparison of hydrodistillation methods for the deodorization of turmeric. *Food Research International*, 38(8-9): 1087-1096. <http://doi.org/10.1016/j.foodres.2005.02.025>

Singh, J., 2008. Maceration, percolation and infusion techniques for extraction of medicinal and aromatic plants. *Extraction Technologies for Medicinal and Aromatic Plants*, (66): 67-82.

Srogi, K., 2006. A Review: Application of Microwave Techniques for Environmental Analytical Chemistry. *Analytical Letters*, 39(7): 1261-1288. <http://doi.org/10.1080/00032710600666289>

Stahl, E., K.-W.Quirin, D. Gerard, 1988. *Dense Gases for Extraction and Refining*; Springer-Verlag: Berlin, Germany, pp: 81-112.

Strauss, C.R. and R.W.Trainor, 1995. Developments in microwave-assisted organic chemistry. *Australian Journal of Chemistry*, 48(10): 1665-1692.

SumateBoonkird, ChadaPhisalaphong, MuenduenPhisalaphong, 2008. Ultrasound-assisted extraction of capsaicinoids from *Capsicum frutescens* on a lab- and pilot-plant scale. *Ultrasonics Sonochemistry*, 15: 1075-1079

Surat, M.A., S.Jauhari and K.R.Desak, 2012. A brief review: Microwave assisted organic reaction. *Applied Science Research*, 4(1): 645-661.

Talebi, M., A.Ghassempour, Z.Talebpour, A.Rassouli and L.Dolatyari, 2004. Optimization of the extraction of paclitaxel from *Taxus baccata* L. by the use of microwave energy. *Journal of separation science*, 27(13): 1130-1136.

Tameshia, S.B., M.Parameswarakumar, Z.Kequan and O.Sean, 2010. Microwave-assisted extraction of phenolic antioxidant compounds from peanut skins. *Food Chemistry*, 120: 1185-1192.

Tandon, S., 2007. Hydro-distillation and steam distillation from aromatic plants, pp: 1-34.

Tepe, B., D.Daferera, A.Sokmen, M.Sokmen and M.Polissiou, 2005. Antimicrobial and antioxidant activities of the essential oil and various extracts of *Salvia tomentosa* Miller (Lamiaceae). *Food chemistry*, 90(3): 333-340.

Veggi, P.C., J.Martinez and M.A.A.Meireles, 2012. Fundamentals of microwave extraction. In *Microwave-assisted Extraction for Bioactive Compounds* (pp. 15-52). Springer US.

Vesna, R., J.Klopcevska, M.Srbinska and R.Slaveska-Raicki, 2011. Extraction of Oleoresin from Pungent Red Paprika Under Different Conditions. INTECH Open Access Publisher.

Viktorija, M., K.G.Liljana, R.Tatjana and G.Rubin, 2014. Antioxidative effect of *Capsicum oleoresins* compared with pure capsaicin. *IOSR Journal of Pharmacy*, 4(11): 44-48.

Yao, J., M.G.Nair, A.Chandra, 1994. Supercritical carbon dioxide extraction of scotch bonnet (*Capsicum annum*) and quantification of capsaicin and dihydrocapsaicin. *J. Agric. Food Chem.*, 42: 1303-1305.