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Omega-3 Fatty Acids in Thai Vegetables and Freshwater Algae

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Abstract-The aim of this study was to analyze polyunsaturated fatty acid (PUFA) composition in seventeen Thai vegetables, including six species of aquicolous, two freshwater algae, and nine terricolous species. For each sample, palmitic acid, linoleic acid and alpha-linolenic acid (18:3n-3) were the main fatty acids, which constituted nearly 90% of the total fatty acid composition of leaf tissues. The concentration ranges were 5.9 to 310 mg/100g (palmitic acid), 3 to 235 mg/100g (linoleic acid) and 2 to 227 mg/100g (alpha-linolenic acid), respectively. Green algae contained high level of C18 PUFA and low level of C20 PUFA. The algae and terricolous samples had ratios of n-6/n-3 ranged from 0.6 in Tao num to 2.0 in Phai, while aquicolous vegetable samples had a greater variation being ranged from 0.3 in Krached to 6.3 in Koon. Our findings on the fatty acid profile of vegetable showed n-3 fatty acid and ratio of n-6/n-3 might be of great nutritional interest.

Keywords: Thai vegetables, aquicolous, algae, terricolous, n-3 fatty acids

1. Introduction

Dietary and lifestyle patterns as well as energy balance have been reported to influence chronic non-communication diseases such as obesity (Kosti *et al*., 2008), diabetes mellitus, hypertension, stroke, cardiovascular disease (CVD) and some type of cancer, through a multitude of risk factors including lipids (Katcher *et al*., 2009), glucose tolerance, insulin tolerance (Oldroyd *et al*., 2006), eicosanoids (Kinsella, Broughton & Whelan, 1990), blood pressure (Sugiyama *et al*., 2007), coagulation and inflammation (Demosthenes *et al*., 2004). Current evidences support n-3 fatty acids supplementation, have multiple beneficial effects on plasma lipids (Laidlaw & Holub, 2003), blood pressure (Sirtori *et al*., 1998), cardiac function (Bao *et al*., 1998), arterial and venous thrombosis (Andriamampandry *et al*., 1999), endothelial functions (Engler *et al*., 2004) as well as potent anti-inflammatory qualities (Gil, 2002). Diets high in PUFA have a substantial effect on cholesterol and on decreases in coronary heart disease (CHD) mortality (Thomas *et al*., 1997; Okuda *et al*., 2005). However, total fat in the diet should not exceed 30% as recommended by WHO and FAO (WHO/FAO, 2002) and intake of dietary cholesterol should be kept below 300 g/day (WHO, 2003).

Many enzymes were considered to play a major role during de novo synthesis and subsequent modification of plant fatty acids. Such as chloroplast acetyl-CoA synthetase, Acetyl-CoA carboxylase (ACCase) which is the first committed step for fatty acid and acyl lipid synthesis, presumably inhibited by aryloxyphenoxypropionates (AOPPs) and the cyclohexanediones (CHDs). Sukenik and Livne (1991) found the marine alga, Isochrysis galbana the in vitro activity of ACCase correlated well with changes in synthesis in response to light intensity, and desaturation enzymes such as Δ9, Δ12, Δ15–desaturase were responsible for the major fatty acids of plants are the C18 compounds, oleic, linoleic and linolenic acids, which desaturated either by chloroplast (plastid) or by endoplamic reticulum reviewed by Harwood (1996). Pan *et al*. (2007) revealed that heterologous expression of the cDNAs have ablity to biosynthsize different fatty acid, recombinant SbDES2 converted palmitoleic acid (16:1Δ9) to hexadecadienoic acid (16:2Δ9,12), and that recombinant SbDES3 was capable of converting hexadecadienoic acid into hexadecatrienoic acid (16:3Δ9,12,15) in *Saccharomyces cerevisiae.*

Environmental characteristics (temperature, mentals, and nature products) effects on plant lipids have been reviewed by previous studies, that the level of unsaturation of membrane fatty acids was inversely correlated with growth temperature. Williams and coworkers suggested that low temperature-induced desaturation C16 and C18 fatty acid in both cytosolic and the chloroplast resulted in higher levels of unsaturated fatty acids in the brassica napus leaf (Williams *et al*., 1992). The results from Falcone, Ogas and Somerville (2004) revealed key changes in the membrane fatty acid composition were decreasing in trienoic fatty acids and consistent increasing in unsaturated 16:0 and in dienoic 18:2 levels that occur in response to elevated temperature in Arabidopsis. It had been reported that metal supply such as cadmium resulted in a change of lipid content but did not affect fatty acids composition (Nouairi *et al*., 2006). Kabala *et al*. (2008) found that exposure of plants to heavy metals such as Cd, Cu and Ni did not enhance the lipid peroxidation in the plasma membrane (PM) fraction. However, all metals caused an increase in the saturation of PM fatty acids and a decrease in the length of the fatty acid chain.

Evidence supported by Gao *et al* (2005) that uptake of organic chemicals such as phenanthrene and pyrened from soil and water exhibit significantly positive correlation with lipid contents (Gao, Zhu & Ling, 2005). Liang *et al.,* (2006) cultured the marine diatoms *Phaeodactylum tricornutum* and *Chaetoceros muelleri*, the result revealed that the maximum value of SFA was found in the ammonium treatment, that of MUFA in the nitrate treatment and for PUFA in the urea treatment irrespective of the UV radiation, respectively. Some nature products were associated with lipids and fatty acids synthesis. The results from Wang *et al* had indicate that eigallocatechin gallate (EGCG) the main component of tea polyphenols which is the specific inhibitor of fatty acid synthase from chicken liver, probably acting on β–ketoacyl reductase. The free carnitine occurred in the plant tissues of several species, such as cereals, legumes, and germinating seeds, which suggested to involve in diverse fatty acid metabolic pathways in Arabidopsis seedlings (Bourdin *et al*., 2007).

Good sources of n-3 fatty acids were fish, seafood and plant oils. Previous studies have been reported that edible vegetables such as mint (Pereira and Sinclair, 2001), purslane (Liu *et al*., 2000) and vervain (Guil, Torija, Gimenezn and Rodriguez, 1996) content high percentage of n-3 fatty acids. Wild plants including vegetables and seeds consumption have long been considered to have health benefits mainly due to vitamins, minerals and phytonutrients, various studies had been done in Thailand to assess the nutrients. Teaw had been proved having strong antioxidant properties (Maisuthisakul Pongsawatmanit and Gordon, 2007); Pak-paw, which was high in calcium (Kamchan *et al*., 2004), and guava, which showed the high anti-proliferative activity in vitro (Manosroi, Dhumtanom & Manosroi, 2006). This study reported for the first time, data on fatty acid composition and concentration of vegetables in Thailand, and provided an incentive to seek for an alternative nutritional source of PUFA.

2. Materials and Methods

2.1 Materials

In this study, we collected seventeen species of vegetables purchased from local market Mahasarakham Thailand. Including six species of aquicolous vegetables: Krached (*Neptunia oleracea* Lour), Bung Thai (*Ipomoea aquatica* Forsk), Chi nam (*Oenanthe stolonifera*), Koon (*Colocasia giganta* Hook.f.), Bon (*Colocasia esclenta Sahott*) and Buo Sai (*Nymphaea lotus* L); two species of algae: Pum (*Wolffia arrhiza* L. Wimm) and Tao num (*Spirogyra* sp); nine species of terricolous vegetables: Khayang (*Limophila aromatica* (Lak.) Merr), Kratin (*Leucaena leucocephala* de Wit), Kee-lek (*Cassia siamea* Lamk), Neamhuseu (*Coleus amboinicus* Lour), Kwinin (*Azadirachta indica* A. luss), Krad (*Spilanthes acmella* Murr), Phai (*Polygonum odoratum* Lour). All samples were conducted to analyze in more than triplicates (n≥3). For all the samples in this study, only the chloroplast-rich leaves or heads were analyzed, and stems were omitted from analysis.

2.2 Methods

Approximately 10g of fresh vegetables were cut to pieces, and homogenized in 50 volumes of methanol-chloroform (2:1, v/v) containing 10 mg/L butylated hydroxytoluene and 0.1 mg/ml of tricosanoic acid (C23:0, Fluka, Germany) as an internal standard, extracted for overnight. Then each sample was filtered; the residue was extraction by 10 ml chloroform and methanol twice. The extracts were pooled and concentrated, and transferred into a 10ml methylation tube by chloroform containing 10 mg/L BHT.

Preparation of ester derivatives of fatty acids for chromatographic analysis: The fatty acid methyl esters (FAMEs) of the total lipid extract were prepared by transesterficaion with 3 ml H_2SO_4 in methanol (0.9 mol/L) plus 1 ml toluene and incubating for 2 hours at 70°C. Before injected to GC, FAMEs were filtered by Sep-pak silica column (Altech, Associates Inc., USA). Samples for gas chromatographic analysis was followed as we prior reported (Yang *et al*., 2006), the GC temperature program of analysis, was initial 150°C held for 1min, raised to 180°C at the ratio 25°C /min, raised to 220°C at the ratio of 2.5°C /min held for 4min, raised to 230°C at 15°C /min and then held this temperature for 3min.

3. Results and Discussion

The fatty acids composition and concentration of total lipids determined by capillary gas chromatography were shown in (Table 1-4). There were 24 fatty acids identified in the samples examined. The major fatty acids were palmitic acid (16:0), Oleic acid (18:1), Linoleic acid (18:2n-6) and linolenic acid (18:3n-3), which constituted nearly 90% of the total fatty acid composition of leaf tissues.

3.1 N-3 Polyunsaturated Fatty Acids Composition and Concentration in Commonly Vegetables

Among the aquicolous vegetable and algae samples, we determined three n-3 fatty acids, which were hexadecatrienoic acid (16:3n-3), 18:3n-3 and eicosapentaenoic acid (20:5n-3). The most abundant fatty acid in these species was 18:3n-3, with the composition ranged from 5% of total fatty acids in Koon to 52.3% of total fatty acids in Krached. The 16:3n-3 and 20:5n-3 were present in small amounts in the aquicolous vegetables and algae samples, which were found in Buo Sai (2.9% and 8.5% of total fatty acids, respectively) and Pum (1.6% and 6.8% of total fatty acids, respectively); Pum was found mostly in tropical and subtropical water environments, exhibited the ability of absorbs large amounts of nitrogen and phosphorus (Fujita *et al*., 1999) which were associated with changes PUFA composition (Lin *et al*., 2007). There were no 16:3n-3 and 20:5n-3 presented in Krached, Chi nam, Koon and Bon, additionally. In (Table 1 and 2) showed that green algae had the highest level of C18 PUFAs and lowest in C20 PUFAs, the same results were found in algae from the Bohai Sea (Li *et al*., 2002). There were only two n-3 fatty acids identified in terricolous vegetable samples, they were 16:3n-3 and 18:3n-3. 18:3n-3 was the predominated n-3 fatty acid, detected in all terricolous samples, with the composition ranged from 19.5% in Wan to 35.8% in Krad, the concentration of 18:3n-3 ranged from 36.8 mg/100g in Neamhuseu to 282.1 mg/100g in Kratin. There was no 16:3n-3 identified in Neamhuseu, Wan and Tew Khoaw. Krad and Phai had the highest proportion of n-3 fatty acid, 35.8% and 35.3%, respectively, while Kwinin and Kratin had the most concentration, 323.7 mg/100g and 289.1 mg/100g, respectively. In our study, we found Thai vegetable was a novel source of n-3 fatty acid.

Table 1. Fatty acid composition (% of total fatty acid) in Thai aquicolous vegetables and freshwater algae.

	Aquicolous						Algae	
Fatty acids	**Krached**	**Buo Sai**	**Bung Thai**	**Chi nam**	**Koon**	**Bon**	**Pum**	**Tao num**
12:0	ND	ND	2.3±0.1	2.1±0.5	ND	ND	ND	ND
14:0	ND	5.3±0.4	3.2±0.2	1.1±0.3	12.6±0.3	ND	2.1±0.2	12.0±0.9
16:0	12.7±0.2	23.1±0.5	25.5±1.5	26.8±2.9	29.3±0.2	36.2±1.4	16.7±1.4	28.1±1.2
17:0	4.6±0.5	2.8±0.6	3.1±0.1	3.3±0.4	2.0±0.3	ND	3.8±0.8	5.6±0.2
18:0	2.0±0.1	2.0±0.2	2.8±0.2	1.8±0.3	2.5±0.2	3.2±0.1	1.4±0.3	8.2±0.9
20:0	10.1±1.0	3.6±0.4	2.5±0.1	1.1±0.2	4.6±0.7	ND	3.2±0.4	ND
SFA	29.4±1.1	36.8±0.7	39.5±1.9	36.2±1.6	50.9±1.3	39.3±1.3	27.2±0.6	53.9±2.0
16:1	1.1±0.1	2.3±0.2	0.5±0.0	1.2±0.1	1.9±0.4	ND	2.5±0.2	2.7±0.3
18:1	1.9±0.2	3.0±0.5	1.1±0.3	4.9±0.4	10.4±2.2	7.7±0.8	3.5±0.3	3.2±0.4
MUFA	3.0±0.1	5.3±0.7	1.6±0.2	6.1±0.4	12.3±1.9	7.7±0.8	6.0±0.5	5.9±0.7
16:3n-3	ND	2.9±0.6	ND	ND	ND	ND	1.6±0.4	ND
18:3n-3	52.3±0.8	7.5±0.3	32.9±0.8	20.7±1.4	5.0±0.4	8.0±0.6	35.9±1.2	25.9±3.1
20:5n-3	ND	8.5±1.4	2.6±0.3	ND	ND	ND	6.8±1.1	ND
Total n-3	52.3±0.8	18.9±1.7	33.5±1.2	20.7±1.4	5.0±0.4	8.0±0.6	44.2±1.4	25.9±3.1
18:2n-6	14.3±0.4	35.4±0.9	21.2±0.7	37.0±0.3	29.2±3.0	45.0±1.0	22.5±1.0	12.6±0.5
18:3n-6	1.0±0.2	ND	ND	ND	ND	ND	ND	1.7±0.4
20:4n-6	ND	ND	2.2±0.1	ND	2.6±0.5	ND	ND	ND
Total n-6	15.3±0.4	35.4±0.9	23.4±0.8	37.0±0.3	31.8±2.3	45.0±1.0	22.5±1.0	14.3±0.6
PUFA	67.7±1.1	54.3±1.2	58.9±1.8	57.7±1.6	36.8±3.0	53.0±0.4	66.8±1.0	40.2±2.4
n-6/n-3	0.3±0.0	4.2±0.4	0.8±0.0	1.8±0.1	6.3±0.3	5.7±0.5	0.8±0.0	0.6±0.1

ND = not detected, SFA = saturated fatty acid, MUFA = monounsaturated fatty acid, PUFA = polyunsaturated fatty acid

Table 2. Fatty acid concentration (mg/100g) in Thai aquicolous vegetables and algae

	Aquicolous						Algae	
Fatty acids	**Krached**	**Buo Sai**	**Bung Thai**	**Chi nam**	**Koon**	**Bon**	**Pum**	**Tao num**
12:0	ND	ND	5.6±0.1	2.1±0.5	ND	ND	ND	ND
14:0	ND	3.1±0.1	7.8±0.6	1.1±0.3	5.2±0.7	ND	9.9±1.3	2.5±0.2
16:0	42.7±1.6	13.6±0.7	61.2±1.8	26.2±2.3	12.1±1.2	11.6±0.6	76.5±6.3	5.9±0.2
17:0	15.7±2.5	1.7±0.4	7.5±0.1	3.2±0.4	0.8±0.2	ND	17.5±3.7	1.2±0.0
18:0	6.6±0.1	1.2±0.2	6.7±0.2	1.8±0.3	1.0±0.2	1.0±0.1	6.3±1.0	1.7±0.2
20:0	34.0±3.7	2.1±0.4	6.1±0.1	1.1±0.2	1.9±0.4	ND	14.6±2.3	ND
SFA	99.0±6.7	21.7±1.5	94.8±1.9	35.5±0.7	21.2±2.8	12.6±0.8	124.8±5.5	11.4±0.3
16:1	3.7±0.3	1.4±0.2	1.2±0.0	1.2±0.1	0.8±0.1	ND	11.4±0.8	0.6±0.1
18:1	6.4±0.9	1.8±0.4	2.8±0.7	4.8±0.4	4.4±1.4	2.5±0.4	15.9±0.8	0.7±0.1
MUFA	10.0±0.9	3.1±0.6	4.0±0.7	5.9±0.4	5.1±1.4	2.5±0.4	27.3±1.6	1.2±0.1
16:3n-3	ND	1.7±0.4	ND	ND	ND	ND	7.5±1.8	ND
18:3n-3	176.4±8.0	4.4±0.1	79.1±4.6	20.3±1.8	2.1±0.1	2.6±0.1	164.7±9.9	5.5±0.7
20:5n-3	ND	5.0±0.9	6.3±0.9	ND	ND	ND	31.3±5.7	ND
Total n-3	176.4±8.0	11.1±1.1	85.4±4.9	20.3±1.8	2.1±0.1	2.6±0.1	203.5±11.4	5.5±0.7
18:2n-6	48.3±2.0	20.8±0.9	51.2±3.5	36.3±1.1	12.0±0.1	14.5±1.4	103.2±4.0	2.7±0.1
18:3n-6	3.3±0.8	ND	ND	ND	ND	ND	ND	0.4±0.1
20:4n-6	ND	ND	5.3±0.4	ND	1.1±0.3	ND	ND	ND
Total n-6	51.6±2.3	22.9±1.1	56.5±3.9	36.3±1.1	13.1±0.6	14.5±1.4	103.2±4.0	3.1±0.3
PUFA	227.9±10.7	36.9±2.0	147.6±9.5	56.6±2.9	15.2±0.3	17.1±1.4	306.6±13.7	8.5±0.6

ND = not detected, SFA = saturated fatty acid, MUFA = monounsaturated fatty acid, PUFA = polyunsaturated fatty acid

3.2 N-6 Polyunsaturated Fatty Acids Composition and Concentration in Commonly Vegetables

The polyunsaturated fatty acids, linoleic acid and α-linolenic acid, are essential to the human diet because they cannot be synthesized by humans (Innis, 1996; Sinclair, 1990). Researches in human nutrition and health have shown the dietary importance of these essential fatty acids and their relationship to human health (Horrobin, 1993; Innis, 1996). Among the polyunsaturated fatty acid in aquicolous vegetables and algae samples, the 18:2n-6 was the predominant n-6 fatty acid presented in these species. Bon was rich in 18:2n-6, which made up 45% of total fatty acids, in the other hand, Tao num was low in 18:2n-6, containing 12.6% of total fatty acids. Linoleic acid synthesized from oleic acid through Δ12 desaturation which is an integral membrane-bound protein in a wide range of plants and microorganisms (Zhang *et al*., 2007). The 18:3n-6 and arachidonic acid (20:4n-6) were low presented in terricolous samples and 18:3n-6 was only detected in Krached and Tao num with concentration of 3.3 mg/100g and 0.4mg/100g for accounted 1% and 1.7% of total fatty acid, respectively. The 20:4n-6 was only identified in Koon and Bung Thai with the concentration at 1.1 mg/100g and 5.3 mg/100g, accounted for 2.6% and 2.2%. The total n-6 fatty acid composition and concentration varied from 14.3% in Tao num to 45% in Bon, and 3.1 mg/100g in Tao num to 103.2 mg/100g in Pum. Differ from aquicolous vegetables and algae samples, four n-6 fatty acids were present in terricolous samples, 18:2n-6, 20:4n-6, docosadienoic acid (22:2n-6) and docosatetraenoic acid (22:4n-6). Kee-lek had the highest percentage composition (35.2% of total fatty acid) and concentration (261.6 mg/100g) of 18:2n-6 which was the major n-6 fatty acid found in all terricolous samples we collected. Wan had the lowest composition of 18:2n-6 accounted for 13%, while Neamhuseu had the lowest concentration of 18:2n-6 accounted for 27.4 mg/100g. Kwinin was the only vegetable which was detected with 20:2n-6 and 22: 2n-6, with percentage composition of 2.9% and 5.8%, accounted for 36.3 mg/100g and 71.9 mg/100g, respectively. 20:4n-6 and 22:4n-6 were only both identified in two species of terricolous vegetables, and Kee-lek, with small percent of composition, 10.3 mg/100g and 11.2 mg/100g in Kratin; 1.7% 12.7 mg/100g and 8.3 mg/100g in Kee-lek, respectively.

3.3 Total PUFA Composition and Concentration in Commonly Vegetables

The total PUFA percentage of composition ranged from 36.8% in Koon (aquicolous species) which represented the low concentration of 15.2 mg/100g to 67.7% in Krached (aquicolous species) which represented the concentration of 227.9 mg/100g; total PUFA concentration ranged from 8.5 mg/100g in Tao num (aquicolous species) which accounted for 40.2% of total fatty acids to 612.6 mg/100g in Kwinin (terricolous species) which accounted for 49.5% of total fatty acids. The metabolic pathways of PUFA biosynthesis as reviewed by Sprecher (2000), recent progress in the cloning and expression of Δ6 and Δ5 desaturases has conclusively established that position-specific desaturases are required to synthesize 20-carbon acids with their first double bond at position 5. Animal and human dietary intervention and epidemiological studies both in vitro and in vivo suggested balance of intake n-6 and n-3 fatty acid associated with chronic non-communication disease (Gazani *et al*., 2001; Tsipas & Morphake, 2003; Clouet *et al*., 1995; Hogberg *et al*., 2003). The ratio of n-6 and n-3 essential fatty acids was evolved on the human beings diet. A lower ratio of n-6/n-3 fatty acids was more desirable in reducing the risk of many of the chronic diseases of high prevalence in Western societies (Simopoulos, 2002). The ratios of n-6/n-3 in aquicolous vegetable samples varied from 0.3 in Krached to 6.3 in Koon; while smaller variations were found in algae and terricolous samples ranged from 0.6 in Tao num to 2.0 in Phai.

Table 3. Fatty Acid Composition (% of total fatty acid) in Thai Terricolous Vegetables

Fatty acids	Khayang	Kratin	Kee-lek	Neamhuseu	Kwinin	Krad	Phai	Wan	Tew Khoaw
12:0	ND	2.4±0.1	ND	5.5±0.3	1.5±0.0	ND	12.4±0.2	1.3±0.3	ND
14:0	18.9±5.8	ND	1.1±0.1	ND	2.4±0.2	ND	ND	ND	9.2±0.9
15:0	1.5±0.2	0.9±0.1	ND	ND	0.8±0.1	1.8±0.5	1.1±0.0	0.8±0.2	ND
16:0	21.1±2.4	21.7±0.9	23.1±0.2	37.2±2.6	25.0±0.2	27.3±0.4	18.1±0.1	19.0±0.6	18.3±0.4
18:0	1.7±0.3	3.6±0.3	2.4±0.0	3.0±0.2	3.2±0.1	1.3±0.0	1.9±0.2	3.1±0.1	3.3±0.0
20:0	ND	ND	ND	ND	ND	ND	0.6±0.0	1.9±0.6	ND
22:0	1.1±0.1	ND	ND	ND	0.8±0.1	ND	0.8±0.1	2.3±0.1	ND
SFA	44.3±3.0	26.2±0.8	26.6±0.1	45.7±2.7	33.7±0.4	30.4±0.8	34.9±0.3	27.2±0.2	30.8±0.5
14:1	4.3±0.8	ND	ND	ND	ND	ND	ND	ND	9.9±0.7
15:1	ND	ND	ND	ND	4.3±0.3	ND	ND	ND	ND
16:1	2.2±0.1	0.9±0.2	1.1±0.0	ND	2.9±0.1	1.8±0.1	1.5±0.1	0.8±0.1	ND
17:1	0.9±0.1	ND	ND	ND	ND	ND	ND	ND	ND
18:1	3.4±1.2	2.8±0.1	2.6±0.1	10.6±0.7	6.0±0.6	1.8±0.1	6.6±0.1	30.8±0.9	5.4±0.1
20:1	2.5±0.5	3.0±0.0	3.1±0.0	ND	0.8±0.1	1.4±0.2	0.6±0.1	1.4±0.2	ND
24:1	ND	ND	ND	ND	2.9±0.4	ND	ND	ND	ND
MUFA	13.3±1.4	6.7±0.2	6.8±0.1	10.6±0.7	17.0±0.4	5.0±0.3	8.7±0.0	33.0±0.6	15.2±0.8
16:3n-3	1.1±0.0	0.8±0.2	0.6±0.0	ND	6.4±0.4	2.0±0.3	2.1±0.1	ND	ND
18:3n-3	23.1±1.4	33.4±2.2	28.0±0.1	25.1±3.0	19.7±0.5	35.8±0.4	35.3±0.6	19.5±0.7	30.0±1.0
Total n-3	24.2±1.5	34.2±2.6	28.6±0.1	25.1±3.0	26.1±1.1	37.8±0.6	37.4±0.8	19.5±0.7	30.0±1.0
18:2n-6	18.2±2.2	28.0±2.0	35.2±0.0	18.6±0.6	14.6±0.1	26.7±0.9	19.1±0.1	13.0±1.0	23.9±0.3
20:2n-6	ND	ND	ND	ND	2.9±0.3	ND	ND	ND	ND
20:4n-6	ND	1.2±0.2	1.7±0.1	ND	ND	ND	ND	ND	ND
22:2n-6	ND	ND	ND	ND	5.8±1.2	ND	ND	ND	ND
22:4n-6	ND	1.3±0.1	1.1±0.1	ND	ND	ND	ND	6.1±0.1	ND
Total n-6	18.2±2.2	30.5±2.2	38.0±0.1	18.6±0.6	23.3±1.5	26.7±0.9	19.1±0.1	19.1±1.1	23.9±0.3
PUFA	42.4±2.3	64.7±0.9	66.6±0.1	43.7±3.5	49.5±1.2	64.5±0.9	56.5±0.7	38.5±0.4	53.9±1.3
n-6/n-3	1.3±0.2	1.1±0.1	0.8±0.0	1.3±0.1	1.1±0.1	1.4±0.1	2.0±0.0	1.5±0.2	1.3±0.0

ND = not detected, SFA = saturated fatty acid, MUFA = monounsaturated fatty acid, PUFA = polyunsaturated fatty acid

Table 4. Fatty Acid Concentration (mg/100g) in Thai Terricolous Vegetables

Fatty acids	Khayang	Kratin	Kee-lek	Neamhuseu	Kwinin	Krad	Phai	Wan	Tew Khoaw
12:0	ND	20.0±0.9	ND	8.1±0.9	18.9±0.6	ND	79.9±3.0	5.6±1.1	ND
14:0	42.5±23.8	ND	8.3±0.3	ND	29.5±2.4	ND	ND	ND	48.4±5.2
15:0	3.2±0.5	8.0±1.1	ND	ND	9.4±1.2	5.5±1.9	7.0±0.4	3.3±0.6	ND
16:0	44.5±6.6	182.2±9.3	171.9±10.9	55.0±8.7	310.7±5.5	83.6±5.5	116.9±6.2	80.2±5.5	95.7±5.3
18:0	3.7±0.4	30.2±4.1	18.1±1.2	4.4±0.7	39.6±1.6	4.1±0.3	12.1±0.9	13.0±1.0	17.2±0.8
20:0	ND	ND	ND	ND	ND	ND	3.7±0.2	8.0±2.5	ND
22:0	2.4±0.5	ND	ND	ND	9.5±1.6	ND	5.4±0.5	9.8±0.4	ND
SFA	96.3±31.3	240.5±14.2	198.3±12.0	67.6±10.3	417.5±9.2	93.1±7.6	225.0±8.9	119.8±2.6	161.3±8.1
14:1	9.4±3.6	ND	ND	ND	ND	ND	ND	ND	51.6±3.3
15:1	ND	ND	ND	ND	53.5±4.2	ND	ND	ND	ND
16:1	4.8±1.3	7.7±2.4	8.4±0.3	ND	36.6±1.5	5.6±0.1	9.7±0.8	3.3±0.5	ND
17:1	1.9±0.2	ND	ND	ND	ND	ND	ND	ND	ND
C18:1	6.9±1.0	23.5±1.3	19.5±0.7	15.7±2.4	75.1±7.7	5.5±0.7	42.3±2.0	129.7±8.2	28.1±1.7
20:1	5.1±0.3	25.2±2.4	22.8±1.1	ND	9.7±1.4	4.2±1.0	3.9±0.2	5.7±0.8	ND
24:1	ND	ND	ND	ND	36.6±5.0	ND	ND	ND	ND
MUFA	28.0±4.3	56.4±5.7	50.6±2.0	15.7±2.4	211.5±6.7	15.4±1.7	55.8±2.5	138.7±7.2	79.7±4.4
16:3n-3	2.5±0.7	7.0±1.8	4.3±0.6	ND	79.2±5.6	6.3±1.0	13.4±0.5	ND	ND
18:3n-3	49.9±15.2	282.1±42.2	208.1±11.3	36.8±2.3	244.5±7.4	109.7±6.7	227.7±14.1	81.8±5.2	156.9±10.7
Total n-3	52.4±16.3	289.1±44.5	212.4±12.5	36.8±2.3	323.7±10.5	115.9±9.2	231.1±16.2	81.8±5.2	156.9±10.7
18:2n-6	38.3±5.3	235.3±18.6	261.6±14.7	27.4±1.8	180.8±0.5	81.5±2.0	123.2±6.3	54.4±3.2	125.3±7.3
20:2n-6	ND	ND	ND	ND	36.3±3.0	ND	ND	ND	ND
20:4n-6	ND	10.3±0.9	12.7±0.8	ND	ND	ND	ND	ND	ND
22:2n-6	ND	ND	ND	ND	71.9±14.2	ND	ND	ND	ND
22:4n-6	ND	11.2±2.1	8.3±0.8	ND	ND	ND	ND	25.7±1.1	ND
Total n-6	ND	256.8±23.4	282.6±17.3	27.4±1.8	289.1±16.1	81.5±2.0	123.2±6.3	80.1±4.7	125.3±7.3
PUFA	80.7±21.2	546.0±56.2	495.1±27.9	64.1±2.9	612.6±5.0	197.5±8.9	364.2±20.7	161.9±5.6	282.2±17.7

ND = not detected, SFA = saturated fatty acid, MUFA = monounsaturated fatty acid, PUFA = polyunsaturated fatty acid

3.4 MUFA Composition and Concentration in Commonly Vegetables

Results from epidemiological and dietary intervention studies have shown that consumption of MUFA has beneficial effects on reducing LDL cholesterol and fasting glucose, increasing immune response, which means having effects on reducing the risk of diabetes. In aquicolous vegetable and algae samples, there were two monounsaturated fatty acids (MUFA) found, palmitoleic acid (16:1) and Oleic acid (18:1), and there was no 16:1 identified in Bon. The predominant MUFA was 18:1, with the composition ranged from 1.1% in Bung Jeen to 10.4% in Koon. The amount of total MUFA was appreciably low, ranged from 1.6% in Bung Jeen to 12.3% in Koon of total fatty acids; the concentration of 18:1 and total MUFA ranged from 0.7 - 1.2 mg/100g in Tao num, 15.9 - 27.3 mg/100g in Pum, respectively. In terricolous vegetable samples, oleic acid was detected in all the samples from 1.8%-30.8%, with concentration accounted for 5.5 -129.7 mg/100g, and total MUFA ranged from 5%-33% accounted for 15.4 -137.8 mg/100g in Krad and Wan, respectively. There were another six MUFA found in some species, myristoleic acid (14:1), 16:1, 17:1, eicosenoic acid (20:1) and nervonic acid (24:1). 14:1 was detected in Khayang (4.3%) and Tew Khoaw (9.9%). 15:1 and 24:1 were only examined in Kwinin with the ratio of total fatty acids composition of 4.3% and 2.9%. 16:1 and 20:1 were presented together in six species vegetables, Khayang (2.2% and 2.5%), Kratin (0.9% and 3%), Kee-lek (1.1% and 3.1%), Kwinin (2.9% and 0.8%), Krad (1.8% and 1.4%), Phai (1.5% and 0.6%) and Wan (0.8% and 1.4%).

3.5 Saturated Fatty Acids Composition and Concentration in Commonly Vegetables

A recent study by Kelly *et al*. (2001) reported that diet enriched in palmitic acid (16:0) resulted in an increased ex vivo collagen and ADP induced whole blood platelet aggregation (Kelly, 2001), and study from Li *et al*. (2003) reported that diet rich in SFA may influence TXA2 formation via effect on tissue proportion of 20:4n-6 (Li *et al*., 2003). Palmitic acid was the most abundant saturated fatty acid in all species, ranging from 13% of total lipid in Krached to 37% in Neamhuseu, and presented as the majority fatty acid in four species of samples, including Koom (29%), Tao num (28%), Kwinin (25%) and Neamhuseu (37%). There were six saturated fatty acid presented in aquicolous vegetables, containing 12:0, myristic acid (14:0), 16:0, heptadecanoic acid (17:0), stearic acid (18:0) and arachidic acid (20:0), while seven saturated fatty acid identified in terricolous vegetables, including 12:0, 14:0, Pentadecanoic acid (15:0), 16:0, 18:0, 20:0 and docsosanoic acid (22:0). The total SFA ranged 26% in Kratin 54% in Pum and Tao num. The concentration of 16:0 and total SFA in aquicolous species were lower than 100 mg/100g, ranged from 12 mg/100g in Bon to 61 mg/100g in Bung Jeen, and 12.6 mg/100g in Bon to 99 mg/100g in Krached, respectively. There were four species of samples in terricolous vegetables had the concentration of 16:0 more than 100 mg/100g, Kratin (182 mg/100g), Kee-lek (172 mg/100g), Kwinin (311 mg/100g), and Phai (170 mg/100g); six species of samples from both algae and terricolous vegetables had the concentration of total SFA more than 100 mg/100g, Pum (125 mg/100g), Kratin (241 mg/100g), Kee-lek (198 mg/100g), Kwinin (417 mg/100g), Phai (225 mg/100g), Wan (120 mg/100g) and Tew Khoaw (161 mg/100g).

4. Conclusion

We have demonstrated that vegetables contained a good profile of fatty acids. Unlike some nuts or legume seeds, the vegetable oils contain low content of saturates and high amount of PUFAs. In addition, some vegetable oils analyzed in this study showed a substantial proportion of n-3 fatty acid especially 18:3 n-3. The desirable ratios of n-6/n-3 (0.3-6.3) might be of great nutritional interest. Apart from fiber and other nutrients, vegetable should be recommended as a good source for fatty acids.

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