The Nutritive Value of Refined Rapeseed Oils: A Review[1]

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Abstract

Recent findings on the nutritive value of rapeseed oil (RSO) with high erucic acid content have been compared to those of canbra oil (CO), an oil extracted from newly bred Canadian rapeseed with no erucic acid. Erucic acid in diets retards animal growth even if food consumption is not altered. Growth performances of CO are as good as olive or peanut oil. The unbalanced ratio of palmitic acid to monoethylenic acids of CO does not affect rat growth rate. Because of its glyceride structure and high content of erucic acid, RSO has a lower digestibility (81%) than CO (96%) in the rat. Unabsorbed erucic acid is not preferentially excreted as calcium soaps. Interesterification of RSO which converts 31.7% of the erucic chains to the 2 position improves digestibility of erucic acid. 2-Monoerucin is more efficiently absorbed than the free acid. In vivo metabolic conversion of erucic to oleic acid has been proved in the rat. β-oxidation of injected 14-^{14}C labeled erucic acid proceeded at the same rate as oleic acid but the over-all yield of the reaction was lower. Fatty acid composition of tissues in animals fed RSO or CO is influenced on one hand by erucic and gadoleic ($C_{20:1}$) acids of RSO, and on the other hand by the unbalanced ratio of palmitic-monoethylenic acids and the linolenic acid content of both oils. Nonnegligible amounts of erucic acid are deposited in the body fats of rats, chickens, turkeys, lambs and found in the milk of female rats fed RSO. Almost no erucic acid is incorporated in liver and testicles in the rat and it is not recovered in chicken egg yolk. The effect of RSO on rat reproduction has been re-examined. Dietary lipid and vitamin levels are of great importance in the results obtained. RSO induces myocarditis in several animal species. Similar lesions, although less frequent and severe, have been observed also with CO in the rat. Some authors have reported that erucic acid of RSO was responsible for the effect on heart muscle. Common fatty acid patterns to both RSO and CO have to be further investigated to explain the persisting effect of CO.

[1] One of 9 papers presented at the Symposium, "Cruciferous Oilseeds," ISF-AOCS World Congress, Chicago, September 1970.

Introduction

Refined rapeseed oil high in erucic acid content (*cis*-Δ^{13}-docosenoic) is produced and consumed in large quantities in many countries. The nutritive value of the oil has been extensively studied with different animal species in several laboratories during the last 30 years. Recent bibliographical reviews of the subject can be usefully consulted (1,2).

In 1961 the first successful isolation and production of rape plants (*Brassica napus* and *campestris*) with no erucic and gadoleic (*cis*-Δ^{11}-eicosenoic) acids in the seed oil were obtained in Canada (3,4). Today other countries (Sweden, France, Poland) are also able to produce experimentally rapeseed oils containing less or no erucic acid.

This new edible oil, also called canbra oil (contracted name of *Canadian Brassica* suggested by Canada Packers Limited), extracted from selected seeds might be expected to have interesting different nutritional properties if compared to presently used normal rapeseed oil. Other rapeseed oil fatty acid modifications, such as increasing palmitic and decreasing linolenic acid contents, seem to be possible and are presently being investigated (5,6). These will certainly further affect nutritional effects of the oil.

This paper will review recent research completed concerning the nutritive value of refined rapeseed oils, including our present knowledge concerning canbra oil.

TABLE I

Main Fatty Acid Composition (%) of Rapeseed, Canbra and Peanut oils, of Fatty Acids in 2-Monoglyceride Fractions, and Proportion of Each Fatty Acid in 2 Position

Oil	Rapeseed oil[a]			Canbra oil[a]			Peanut oil[b]		
	1[c]	2[d]	3[e]	1	2	3	1	2	3
Identified fatty acids									
$C_{16:0}$	3.1	2.7	29	3.8	1.3	11	12	1	8
$C_{16:1}$	<1%	0.8	....	0.3	0.5	55	....	....	....
$C_{18:0}$	1.1	1.7	21	1.8	0.7	13	1	....	....
$C_{18:1}$	13.8	39.3	94	60.0	53.7	30	52	52	33
$C_{18:2}$	14.5	33.5	77	21.2	29.3	46	27	47	58
$C_{18:3}$	6.4	11.1	58	8.7	12.7	49	....	....	....
$C_{20:0}$	1.0	......	....	......	......	....	1	....	....
$C_{20:1}$[f]	10.0	1.6	5	2.3	......	....	....	....	....
$C_{22:0}$	<1%	......	....	<1%	......	....	3	....	....
$C_{22:1}$[g]	44.7	5.5	4	1.7	0.6	12	....	....	....
$C_{24:0}$	......	......	....	......	......	....	1	....	....
ΣSaturated	5.2			6.0					
ΣMonoethylenic	68.5			63.7					

[a] Values from our own gas liquid chromatography data. Although many factors can influence the fatty acid composition of the oils such as nutritional conditions of the plant (7), these figures can be considered as normal ones for most of rapeseed oils.
[b] Data from Mattson and Volpenhein (10).
[c] Fatty acid composition (%) of the oil triglycerides.
[d] Fatty acid composition (%) of 2-monoglyceride fraction.
[e] Proportion of each fatty acid in 2 position. Calculated from Mattson and Volpenhein (10) $= \dfrac{\%\ \text{fatty acid of 2-monoglyceride fraction}}{\%\ \text{fatty acid in triglyceride} \times 3} \times 100.$
[f] $C_{20:1}$ = *cis*–Δ^{11}–eicosenoic (gadoleic).
[g] $C_{22:1}$ = *cis*–Δ^{13}–docosenoic (erucic).

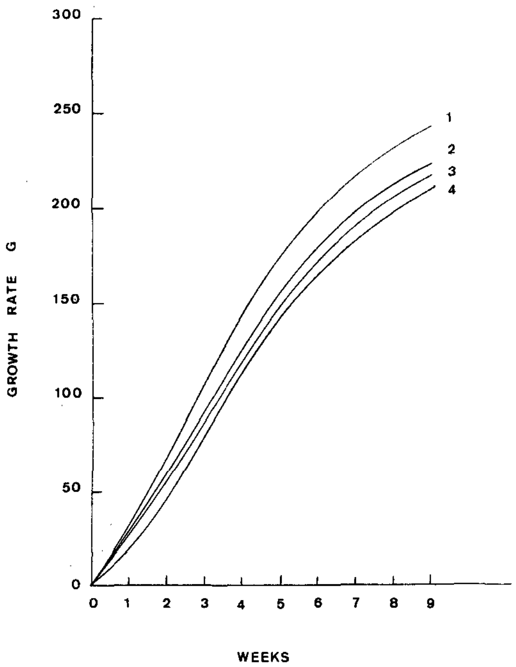

FIG. 1. Growth rate of rats fed 15% by weight different mixtures of simple triglycerides: (1) mixture of tripalmitin + triolein to provide 20% of $C_{16:0}$ and 60% of $C_{18:1}$ (% of the total dietary fatty acids); (2) Mixture of tripalmitin + trierucin (20% of $C_{16:0}$ and 60% of $C_{22:1}$); (3) Mixture of tripalmitin + triolein (10% of $C_{16:0}$ and 70% of $C_{18:1}$); (4) Mixture of tripalmitin + triolein + trierucin (8% of $C_{16:0}$, 15% of $C_{18:1}$ and 57% of $C_{22:1}$). The dietary linoleic acid supply was 8% of the total fatty acids for all groups.

Fatty Acid Composition of Rapeseed and Canbra Oils

Rapeseed oil like many cruciferous oilseeds contains large amounts of long chain monoethylenic acids ($C_{20:1}$, $C_{22:1}$), whereas canbra oil is deficient in these but is an oleic rich vegetable oil. The fatty acid composition of these oils is given in Table I. Both oils have similar low levels of saturated acids, mainly palmitic, as compared to other commonly used dietary vegetable oils. They also contain nonnegligible amounts of linolenic acid. Other minor fatty acids which do not figure in the present table have been identified lately (8,9) in rapeseed oil. Thus C_{20} and C_{22} polyunsaturated and also nervonic acid ($C_{24:1}$) have been characterized. From our own data (unpublished) we assume that these acids might be also present in canbra oil. One may note (9) that in some cases gadoleic acid of rapeseed oil might be a mixture of *cis*-Δ^{11}- and *cis*-Δ^{13}-eicosenoic isomers.

Glyceride Structures of Rapeseed and Canbra Oils

Fatty acid distribution between the 1, 3 and 2 positions and triglyceride composition of rapeseed oil high in erucic acid content have already been fully investigated (10–15). Long chain monounsaturated acids ($C_{20:1}$, $C_{22:1}$) of rapeseed oil are almost exclusively esterified in the outer positions whereas C_{18} unsaturated acids are mainly found in the 2 positions. There is practically no trierucin. Thus more than 85% of the total rapeseed oil triglycerides contain erucic acid in the 1 or 3 positions, or both. Oleic acid of canbra oil which replaces erucic and gadoleic acids does not follow such a distribution. Canbra glyceride structure is more closely related to peanut oil for instance (Table I).

Effects of Rapeseed and Canbra Oils on Animal Growth

It has often been shown that 20% or more by weight of rapeseed oil in rat experimental diets induces poorer food intakes and consequently reduced body weight gains of the animals. Moreover increasing amounts of erucic acid in the diet correlatively aggravate growth performances. Several authors (16–20) have recently proved that rapeseed oil does depress body growth in several animal species even if food consumption is not altered in ad libitum fed animals. Such diets containing up to 20% by weight of rapeseed oil as dietary lipid source had lower food efficiency (weight gain/food intake, × 100). Some authors maintain (21) that too low a level of saturated acids, mainly palmitic, in rapeseed oil along with large amounts of erucic acid might have an unfavorable effect on animal growth. Canbra oil with no erucic acid but a low concentration of palmitic acid similar to rapeseed oil (Table I) promotes as good body weight gains in the rat as olive (22) or peanut oil (17). The effect of an unbalanced ratio of saturated to monounsaturated fatty acids in the diet seems to influence animal growth only when the dietary linoleic acid supply decreases to 10% or less of the total fatty acids (23,24) (Fig. 1). Under these conditions unbalanced ratios of palmitic to oleic or erucic acids (groups 3 and 4 in Fig. 1) will decrease growth rate of rats. However when erucic acid is fed to rats in balanced ratio with palmitic acid (group 2), growth rate is still lower than that obtained with balanced dietary lipids containing oleic acid (group 1). Therefore erucic acid in rapeseed oil seems to have a predominant action on growth, even when food consumption is not altered.

Digestion, Absorption of Rapeseed and Canbra Oils and Their Constituent Fatty Acids

Because of its large amount of long chain monoethylenic fatty acids, rapeseed oil has a lower digestibility than other dietary vegetable oils (25,26). Apparent digestibilities of rapeseed oil and erucic acid are approximately 80% and 75% in the rat

TABLE II

Apparent Digestibilities[a] of Peanut, Rapeseed and Canbra Oils in the Rat

Dietary fat	Peanut	Rapeseed	Inter-esterified rapeseed	Canbra	Inter-esterified canbra	Tri-erucin[b]
Per cent by weight in the diet	15	15	15	15	15	9
Apparent digestibility of the fat	92.0	81.0	90.8	94.7	94.4	87.6
Apparent digestibility of erucic acid	......	72.8	84.8	......	......	88.5

[a] Apparent digestibility = $\frac{\text{fat ingested—fat excreted}}{\text{fat ingested}} \times 100.$

[b] Trierucin was given to rats mixed with tripalmitin, 3%, and linoleic acid, 3%, to make the whole lipid level of the diet equal to 15% as in other groups.

(25) and in the pig (27). Canbra oil (60% of shorter chain oleic acid) has a good digestibility (96%) (25). The reason for rapeseed oil's poorer digestibility has not as yet been fully explained. According to previous reports (28) rapeseed oil has a slower rate of intestinal absorption. Indeed more than 75% of the recovered fecal fatty acids are of erucic acid which does not seem to be preferentially excreted as calcium soaps but rather as free acid or partial glycerides (25). As already mentioned long chain monoethylenic acids of rapeseed oil are esterified at the 1–3 positions in the oil-mixed triglycerides. Intestinal hydrolysis of rapeseed triglycerides by pancreatic lipase will liberate large quantities of free erucic acid prior to absorption. Savary et al. (29) stated that although erucic acid was liquid at 37 C (MP = 33–34 C) and rather well incorporated into conjugated bile salt micellar solutions, it was not as well absorbed as oleic acid. In vitro hydrolysis of rapeseed triglycerides by pancreatic lipase has been compared to peanut and canbra oils in our laboratory. Lipase action on rapeseed triglycerides seems to be inhibited at least at the starting hydrolysis, whereas it is stimulated with canbra oil as compared to peanut oil. The relative initial rate of hydrolysis (μmoles of free fatty acids liberated per minute) of rapeseed oil is 82, of canbra oil 110, assuming that the initial rate of peanut hydrolysis is 100. Further investigations concerning this question are under study in our laboratory. Interesterification of rapeseed triglycerides converts 31.7% of erucic chains to the 2 positions and the trierucin content of the oil is increased from 0.1% to 9.1% (15). Studies of the digestibilities show a significant increase in digestibility of interesterified rapeseed oil whereas canbra oil digestibility is not affected by interesterification (Table II). Moreover we found that erucic acid fed to rats as trierucin mixed with tripalmitin had a higher digestibility (88%) than the naturally esterified mixed triglycerides of rapeseed oil (73%). This suggests that the 2-monoerucin must be well absorbed by rat intestine.

Storage and Metabolism of Main Characteristic Fatty Acids of Rapeseed and Canbra Oils

Erucic acid is not naturally found in animal tissue lipids, and rats fed rapeseed oil show less erucic and more oleic acids in their tissue lipids than in the diet. In vivo metabolic conversion of dietary long chain monoethylenic acids of rapeseed oil to oleic acid has been suggested for a long time (30–33) and more recently experimentally proved by Carreau et al. (34–35). These authors injected pure 14–^{14}C labeled

TABLE III

Specific Activities[a] of Rat Liver Fatty Acids, 2 hr After 14-^{14}C Erucic Acid Intravenous Injections in Rapeseed Oil Emulsions[b]

Diets	Fat free	Fat free + 1.6% sunflower oil	Fat free + 20% rapeseed oil
Methyl esters[c]			
Saturated	0.13	0.06	0.06
Erucic	7.70	8.96	8.70
Mono-ethylenic[d] (erucic not included)	2.30	3.30	3.70
Di-ethylenic	0.26	0.23	0.04
Tri-ethylenic	0.98	0.08	0.80
Poly-ethylenic	0.26	0.18	0.08

[a] Specific activity = $10^{-2} \times \mu$ Ci/mg.
[b] Data from Carreau et al. (35).
[c] Methyl esters of liver fatty acids were separated on TLC (silver nitrate impregnated silica gel).
[d] Oleic acid was the main constituent of this fraction.

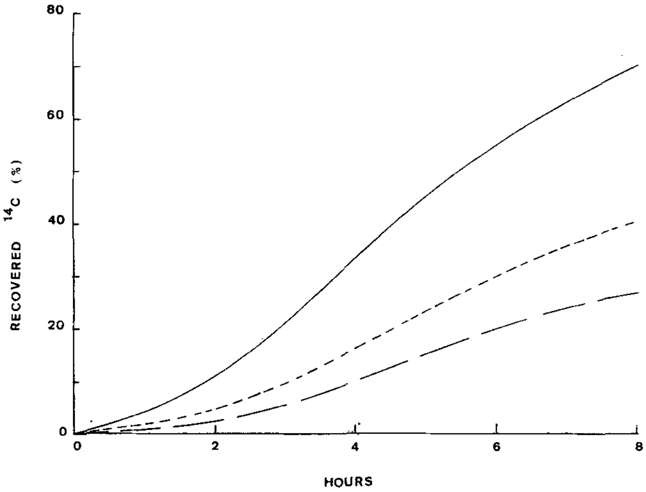

FIG. 2. Recovered ^{14}C (% of the injected dose) with time (Means of three determinations) administered fatty acids: ——— 1—^{14}C labeled oleic; - - - - 10—^{14}C labeled oleic; — — 14—^{14}C labeled erucic. Data from A. Bach et al. (38).

erucic acid to rats fed three different diets and checked for specific activities of liver fatty acids at spaced times after injection of the labeled erucic acid (Table III). Specific activities of liver fatty acids were influenced by the dietary lipid content fed to animals prior to injection of labeled materials. Moreover after studying the incorporation of labeled erucic acid in different rat tissues (liver, spleen, kidneys, brain, testicles, seminal vesicles) these authors stated (36) that erucic acid rapidly disappeared from all of these tissues, except from spleen. Slightly different results were previously obtained by Carroll (37) who showed that dietary erucic acid was deposited in the liver as free fatty acid and was metabolized more slowly than oleic acid. Recently Bach et al. (38) demonstrated that erucic acid oxidation proceeded at the same rate as oleic acid but the over-all yield was lower (Fig. 2). Fatty acid oxidation in various tissues involves an activation process of the molecule as the first step in the reaction (39). Although many animal tissues exhibit fatty acid activating enzymes, it would certainly be interesting, as suggested by Bach et al. (38), to examine erucic acid activation in several tissues as compared to other fatty acids.

Indeed erucic acid does not completely disappear from all tissues of rats fed rapeseed oil (40) (Table IV). Other recently published works (22) showed that 10% of gadoleic and 11.4% of erucic acids were recovered in total body fats of rats fed rapeseed oil as 20% by weight of diet in a 24 day experiment. In meat producing animals (chicken, turkey, lamb) large amounts of erucic and gadoleic acids were found in body fats (19,20,41). These acids were also present in milk of female rats fed rapeseed oil (42), whereas erucic acid was not incorporated in chicken egg lipids (43,44).

Both rapeseed and canbra oils have common fatty

TABLE IV

Deposition of Gadoleic, $C_{20:1}$, Erucic, $C_{22:1}$, and Linolenic, $C_{18:3}$, Acids in Various Tissue Lipids of 3-Month-Old Rats Fed 30 cal % Rapeseed Oil for Nine Weeks

Tissue, (fatty acid, %)	Epididymal fat	Abdominal fat	Liver	Heart	Brain	Muscle (gastrocnemius)
Gadoleic	6.6	7.2	1.7	3.1	3.5	5.6
Erucic	6.9	7.4	1.4	7.6	1.1	5.7
Linolenic	5.4	5.2	1.1	1.8	1.0	2.3

TABLE V

Linoleic, $C_{18:2}$, and Arachidonic, $C_{20:4}$, Acid Contents[a] in Liver and Heart of Rats Fed 30 cal % Different Vegetable Oils for Nine Weeks

Fatty acid	Linoleic		Arachidonic	
Tissue (Oil)	Liver	Heart	Liver	Heart
Peanut	9.8	16.6	17.8	21.8
Rapeseed	11.9	18.3	13.0	16.9
Canbra	10.2	19.6	12.5	12.9

[a] Per cent of total fatty acids.

acid patterns such as low level of palmitic acid, high level of monounsaturated acids and similar linolenic acid contents. These dietary fatty acids can also influence the nature and the level of tissue fatty acids in animals fed such dietary oils (22,45). According to Mohrhauer et al. (46–48) they might affect the in vivo linoleic acid metabolism and therefore the polyunsaturated acid profiles of tissues. This last aspect should be further investigated. So far like other authors we have observed but have not explained the tendency for arachidonic acid content of the liver and the heart to be lowered in rats fed either rapeseed oil (21,32) or canbra oil (Table V).

Physiological Effects of Rapeseed and Canbra Oils

The effects of dietary rapeseed oil on rat reproduction were studied some years ago (49,50) and recently reexamined in the rat (51) and in the pig (18). The most recent conclusions seemed to emphasize the effects of diet conditions met by the animals rather than a primary action of one or the other fatty acid of the oil. Hyperlipidic diets and inadequate supplies of vitamins such as vitamins E and A, can be determing factors in the results obtained. To our knowledge no such studies have been conducted with canbra oil.

Of great concern today is the physiological effects of rapeseed oils particularly on heart muscle. As early as 1960 Roine et al. (52) first observed but did not explain myocarditis in rats fed large amounts (50–70 cal %) of rapeseed oil high in erucic acid. A literature survey of the subject shows that myocarditis induced by dietary lipids other than rapeseed oil can be achieved in different animal species (53–59). In order to explain the observed pathological changes, Allain (54) pointed out that oxidation of fatty acids in the rat heart was incomplete if ethyl laurate in large amounts was fed to animals and that fatty infiltration, mainly free fatty acids, occurred prior to heart damages.

Since 1967 we have been gathering enough anatomical data to confirm Roine's results and to show myocarditic lesions in 2–12-month-old rats fed rapeseed oil as 15% by weight of diet (17,45,60). A control group fed peanut oil was anatomically normal. The lesions were nonreversible and no fatty hearts were found in 3-month-old rats. Similar results were obtained very recently by Beare-Rogers (61) and by Abdellatif and Vles (62) in the rat and in the duckling (63,64). It was shown that lipid accumulation in cardiac and skeletal muscles seemed to occur in the very early stage of feeding rapeseed oil and to decrease thereafter. Analyses of the nature of the accumulated lipids in heart tissue (65) showed a large increase (× 10) in the triglyceride content and a smaller increase of free fatty acids (× 2.4). Partially hydrogenated rapeseed and herring oils also induced heart lipid accumulation but to a somewhat smaller degree than liquid rapeseed oil (61). Since then confirmation has been found in our laboratory. Large increase of heart lipid content was obtained within a few days in weanling rats fed rapeseed oil as 15% by weight of diet (Table VI). Up to 40% of the total fatty acids of heart lipids in weanling rats fed rapeseed oil for three days has been found to be erucic acid. The effect of additional saturated fats to rapeseed oil in order to reduce the cardiac lipid accumulation and lesions has not as yet been clearly explained (64). Inability of isolated heart mitochondria to oxidize substrates (glutamate for instance) normally when erucic acid was fed to rats has been recently demonstrated by Houtsmuller et al. (65). Consequently the rate of ATP synthesis was depressed. Possible similar effects of other dietary long chain fatty acids, such as those in herring oil, were suggested by Beare-Rogers (61). Physiological effects of canbra oil on cardiac muscle have also been investigated. According to Abdellatif and Vles (66) heart damages were induced only by diets containing erucic acid and no lesions were observed in rats fed canbra oil. Under our own experimental conditions, the same as those used with rapeseed oil, we came to different conclusions: persistent, although less frequent and severe, cardiac lesions were obtained in rats fed canbra oil as 15% by weight of diet. However, it was impossible to show any heart lipid accumulation with canbra oil correlating with that observed with rapeseed oil in the weanling rat. The effect of an unbalanced ratio of palmitic-monoethylenic acids of the oils on heart muscle was then studied (45). So far we have not been able to induce myocarditis in rats fed diets containing palmitic and oleic acids in similar amounts to those provided by canbra oil.

Experimentally obtained myocarditis in different animal species fed rapeseed oils high or low in erucic acid must be further investigated. Myocardium lipid metabolism as influenced by dietary fatty acids has to be studied thoroughly. As a matter of fact the causal effect of cardiac lipid deposition induced by these particular dietary fatty acids to product myocardium lesions has to be ascertained. Finally canbra oil, predicted to be produced in large quantities, needs to have its nutritional properties better defined.

ACKNOWLEDGMENTS

Technical assistance of J.C. Peleran, The Saskatchewan Wheat Pool, Saskatoon, Canada and the Canada Packers, Limited, Toronto, Canada, provided canbra oil. Astra Calvé, France, provided the samples of synthetic tripalmitin, triolein and trierucin.

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TABLE VI

Total Lipid Content of Heart in Weanling Rats Fed Rapeseed or Canbra Oils as 15% by Weight of Diet For Five Days

Oil	Rapeseed oil, days on diet					Canbra oil, days on diet				
	1	2	3	4	5	1	2	3	4	5
Lipid content of heart[a]	6.0	9.5	11.5	8.2	9.0	4.0	4.4	3.9	3.9	4.0
Ingested erucic acid/rat/g	0.791	1.384	1.913	2.236	3.083					

[a] Per cent of fresh organ weight—means of three rats per day.

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[Received October 22, 1970]