Potential Health Benefits of Conjugated Linoleic Acid: An Important Functional Dairy Ingredient

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Authors’ contributions

This work was carried out in collaboration among all authors. Authors CKV and AG wrote the first draft of the article, while, author BT prepared the figure 2 and table 2 and edited the manuscript. Author MKS managed the literature search and prepared the table 3. All authors read and approved the final manuscript.

Article Information

DOI: 10.9734/EJNFS/2019/v11i430162

Editor(s):
(1) Dr. Johnson Akinwumi Adejuyitan, Senior Lecturer, Department of Food Science and Engineering, Ladoke Akintola University of Technology (LAUTECH), Nigeria.

Reviewer(s):
(1) Asaad Ahmed Ghanem, Mansoura University, Egypt.
(2) Jihan Seid Hussein, National Research Centre, Egypt.

Complete Peer review History: http://www.sdiarticle4.com/review-history/53755

Received 25 October 2019
Accepted 28 December 2019
Published 11 January 2020

ABSTRACT

Conjugated linoleic acid (CLA) refers to a class of positional and geometrical isomers of linoleic acid (cis-9, cis-12 octadecadienoic acid) having conjugate double bond system. CLA are synthesized in rumen of the ruminants by biohydrogenation of dietary fatty acids; and thus, can be obtained from dairy products as well as from the meat of sheep, lamb and other ruminants. Among the several isomers, c9, t11-CLA isomer is the most biologically active form and accounts approximately 80% of total isomers. A number of clinical and epidemiological studies have demonstrated the role of CLA as anti-atherogenic, anti-inflammatory, anti-oxidative, anti-carcinogenic, etc. Several researchers have suggested the positive association of CLA in weight management, hypercholesterolemia, immunomodulatory functions, and improved bone metabolism.

Keywords: Conjugated linoleic acid; biohydrogenation; anti-carcinogenic activity; anti-atherogenic; anti-obesity.

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1. INTRODUCTION

Conjugated linoleic acid (CLA) refers to a mixture of positional and geometric isomers of linoleic acid (C18:2). CLA are naturally synthesized from linoleic acid in the rumen and intestine of pastured ruminants like cattle, sheep and goat. Conjugated linoleic acids have conjugated dual bond and consist a class of geometric and positional isomers of essential linoleic fatty acid (cis-9, cis-12) by biohydrogenation. CLA isomers may be present in various double bond positions (7–9, 8–10, 9–11, 10–12, 11–13) or geometric orientation (trans-cis, cis-trans, trans-trans & cis-cis). However, cis-9, trans-11 is the most predominant and biologically active form. The c9, t11 isomer has been reported to have anti-carcinogenic effects as well as regulating body mass. Other isomer of CLA such as t10, c12 has also been reported to confer several health benefits such as preventing artery thickening, protecting the heart disease, preventing from cancer, and modulating immune system. Technically, conjugated linoleic acid is not an essential fatty acid. Unlike other fatty acids, CLA cannot be synthesized by the human body, and thus, needs to be taken from diet such as meat and dairy products. It is important to note that CLA has two double bonds in conjugated form, in which one is present in cis and other is present in trans configuration. As per the definition given by CODEX, polyunsaturated fatty acids having isolated (non-conjugated) double bonds in trans configuration only are known as trans fatty acids [1]. Therefore, the isomers of CLA are exempted from the trans-fat labelling [1]. Moreover, the equivalent mixture of c9, t11 and t10, c12 CLA isomers (1:1) have been granted GRAS (Generally recognized as safe) status by FDA in 2008.

1.1 Sources

The most common sources of natural CLA in the human diet are milk & milk products and meat of ruminant animals. The content of CLA in various products are given in below table (Table 1).

1.2 Global Market of CLA

CLA is a popular supplement for weight management worldwide. CLA is used for medical benefits like cancer fighting properties, muscle strengthening, improved metabolic functions. Conjugated Linoleic Acid (CLA) market is expected to grow 5.8% Compound Annual Growth Rate (CAGR) in terms of revenues. According to a recent report, the size of conjugated linoleic acid market is expected to reach US$ 50 million up to 2024, from US$ 36 million in 2019 [3]. China is the biggest producer of CLA supplements capturing 47.93% market share followed by North America (25.63%).

1.3 Biosynthesis of CLA

In ruminants, CLA is synthesized by two methods: 1) Ruminal Biohydrogenation (from linoleic acid), and 2) Endogenous synthesis (in tissues from trans Vaccenic acid). First the linoleic acid (C18:2, C9, C11) is converted into conjugated linoleic acid (C9, t11) in presence of linoleate isomerase. Thus, CLA formed goes to mammary glands and gets incorporated into the milk fat. Some of the portion of CLA is

<table>
<thead>
<tr>
<th>Common Name</th>
<th>ω-Position (from -CH3 end)</th>
<th>Structure</th>
<th>Systemic name (from -COOH end)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oleic acid</td>
<td>ω-9</td>
<td><img src="Image" alt="Oleic acid" /></td>
<td>(cis-9)-Octadecenoic acid</td>
</tr>
<tr>
<td>Linoleic acid</td>
<td>ω-6</td>
<td><img src="Image" alt="Linoleic acid" /></td>
<td>(cis-9, cis-12)-Octadecadienoic acid</td>
</tr>
<tr>
<td>9-CLA (Rumenic acid)</td>
<td>ω-7</td>
<td><img src="Image" alt="9-CLA" /></td>
<td>(cis-9, trans-11)-Octadecadienoic acid</td>
</tr>
<tr>
<td>10-CLA</td>
<td>ω-6</td>
<td><img src="Image" alt="10-CLA" /></td>
<td>(trans-10, cis-12)-Octadecadienoic acid</td>
</tr>
</tbody>
</table>

**Fig. 1.** Structure of CLA and other related fatty acids (Source: Benjamin et al. 2015 [2])
Table 1. Conjugated linoleic acid content (mg CLA/g fat) in various food products

<table>
<thead>
<tr>
<th>Dairy products</th>
<th>Mg of CLA/g of fat</th>
<th>Meat products</th>
<th>Mg of CLA/g of fat</th>
</tr>
</thead>
<tbody>
<tr>
<td>Milk</td>
<td>5.5</td>
<td>Veal</td>
<td>2.7</td>
</tr>
<tr>
<td>Condensed milk</td>
<td>7.0</td>
<td>Ground beef</td>
<td>4.3</td>
</tr>
<tr>
<td>Butter fat</td>
<td>6.1</td>
<td>Lamb</td>
<td>5.8</td>
</tr>
<tr>
<td>Cultured milk</td>
<td>5.4</td>
<td>Chicken</td>
<td>0.9</td>
</tr>
<tr>
<td>Sour cream</td>
<td>4.6</td>
<td>Pork</td>
<td>0.6</td>
</tr>
<tr>
<td>Butter</td>
<td>4.7</td>
<td>Ground turkey</td>
<td>2.6</td>
</tr>
<tr>
<td>Ice cream</td>
<td>3.6</td>
<td>Egg yolk</td>
<td>0.6</td>
</tr>
<tr>
<td>Yogurt (low fat)</td>
<td>4.4</td>
<td>Salmon</td>
<td>0.3</td>
</tr>
<tr>
<td>Plain yogurt</td>
<td>4.8</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Custard yogurt</td>
<td>4.8</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Medium cheddar</td>
<td>4.1</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Source: Chin et al., [4]

Fig. 2. Biosynthesis of conjugated linoleic acid (Adapted from Bauman et al. 2000 [5])

Conjugated linoleic acid (CLA) (C18:2) (c9, t11)

Incorporated into milk

Hydrogenation

Δ9 – desaturase

Linoleic acid (LA) (C18:2) (c9, c11)
(From Feed)

α-Linolenic acid (ALA) (C18:3) (c9, c11, c15)
(From Feed)

Linoleate isomerase

Conjugated linoleic acid (CLA) (C18:2) (c9, t11)

Hydrogenation

Octadecatrienoic acid (C18:3) (c9, t11, c15)

Hydrogenation

trans vaccenic acid (TVA) (C18:1) (t11)

Hydrogenation

Stearic acid (C18:0)

2. ROLE OF RUMEN BACTERIA IN CLA SYNTHESIS

For CLA synthesis, ruminants depend on microbial fermentation of feed and additional forage in rumen. Ruminant diet includes some polyunsaturated fatty acids (PUFAs) which are toxic to many of rumen microorganisms [6]. Nevertheless, in order to protect them from toxic effects, rumen microorganisms have pathways for hydrolysis and biohydrogenation of dietary lipid. Rumen bacteria play an important role in biohydrogenation. In biohydrogenation of lipids in rumen, >250 bacterial strains are involved. The most common are:

- Butyrovibrio
- Micrococcus
- Lactobacillus
- Ruminococcus
- Enterococcus
- Propionobacterium

3. HEALTH BENEFITS OF CLA

Several recent clinical and epidemiological studies have reported the important role of CLA as anticarcinogenic, antiatherogenic, immunomodulating, anti-diabetic and lean body mass enhancing, etc., which are discussed below:

Anticarcinogenic activity: Though no concrete evidences for the anticarcinogen activity of CLA have been documented yet, possible mechanisms could be attributed to antioxidant
mechanisms, pro-oxidant cytotoxicity, suppres-
sion of nucleotide biosynthesis, decrease in pro-
liferative activity and inhibition of carcinogen 
activation [7,8,9,10,11,12]. CLA is reported to 
show prooxidant activity in which they inhibit the 
oxidation causing substances [13]. A few studies 
have demonstrated that CLA decreases the pro-
liferative activity and suppress the mul-
tiplication of free radical formation [14,15]. In 
another study, it is suggested that CLA 
suppresses the nucleotide synthesis and thus, 
inhibit the DNA replication in cells which prevent 
the formation of tumor in the body. Recent 
clinical and epidemiological studies on the anti-
carcinogenic properties of CLA are shown in 
Table 2.

Antioxidant and anti-inflammatory properties: 
CLA is a more potent antioxidant than other 
antioxidants. It is more effective than butylated 
hydroxytoluene (BHT) & alpha-tocopherol. 
Furthermore, it is reported to be more potent 
than vitamin E and butylated hydroxy anisole 
(BHA) in suppressing the formation of thio-
obarbituric acid reactive substances (TBARS). 
CLA is one of the biomarkers which is also used 
to assess oxidation status in biological systems. 
Environmental mutagens or carcinogens act as 
an inhibitor and they block the carcinogenesis 
and show their antioxidant properties [16]. 
Superoxide dismutase and catalase are the 
antioxidative enzymes involved into the removal 
of toxic free radicals and thus, lead to 
amelioration of oxidative damage in cells. 
Glutathione-S transferase is involved in 
biotransformation of carcinogens, detoxification 
of xenobiotics, peroxides and free radicals by 
conjugating toxic component with GSH 
(Glutathione reduced) and due to this they 
ultimately protecting organ and cells against 
inducing toxicity [17]. For this reason, increasing 
this enzyme by synthetic or natural way, which 
results in the inhibition of hepatic cancer-causing 
substances; and CLA behaves like chemopre-
ventive agent, inhibits the oxidative stress & 
reduce the levels of detoxifying enzymes [18]. It 
is reported that CLA at the level of 0.25% or 
more in diet inhibits the mammary 
carcinogenesis and decreases the formation of 
TBARS into mammary tissue [19]. Kathirvelan 
[20] observed that CLA fortified ghee (clarified 
butter) increased the antioxidative activity and 
reduced the toxic causing enzymes in mammary 
gland and liver than that of soybean oil. Several 
clinical and epidemiological studies on the anti-
inflammatory and immunomodulatory properties 
of CLA are presented in Table 3.

Cholesterol-lowering and anti-obesity effects: 
Several recent animal studies have 
demonstrated a positive role of CLA in 
prevention of cardiovascular diseases, 
hypercholesterolemia and obesity [21,22,23], 
which are presented in Table 4. Lee et al. [24] 
reported that CLA was effective against different 
stage of cancer like progression and initiation 
and found anti-atherogenic effect of CLA (at 0.5 
g/d) in rabbits in a study of 22 days. On the other 
hand, Nicolosi et al., [25] reported that the 
hamsters fed together with CLA had significantly 
decrease the amount of total plasma cholesterol 
when compared to control. Kathirvelan [20] 
observerd that the high and low CLA intakes 
reduced the total cholesterol, and triglycerides, 
and increased HDL cholesterol when compared 
with control (soya oil fed rats). Kathirvelan [20] 
demonstrated that the antiatherogenic effects of 
CLA were shown by decrease in triglycerides, 
total cholesterol, atherogenic index & LDL 
cholesterol and a rise in HDL-cholesterol into 
blood plasma.

CLA and Bone metabolism: Watkins et al. [26] 
have reported a high level of bone formation in 
butterfly-fed chickens, which proposed to be 
likely due to higher CLA consumption. Dietary 
CLA contributed to variations in CLA abundance 
in bone marrow, specific tissue and organs, and 
periosteum having the highest amount of CLA 
and the low amount in the heart. CLA has been 
reported to increase cis-9, trans-11 in tissue lipid 
and also involved in bone biomarkers and 
development.

Methods to increase CLA concentration in 
dairy products: There are two methods of CLA 
enrichment: 1) Dietary modification of animal 
feed, and, 2) Direct enrichment of milk and dairy 
products. In dietary modification of animal feed, 
feed can be supplemented with rapeseed, 
cottonseed, soybean, corn, peanut, sunflower, 
canola, safflower and linseed or their oils. Oils 
can be added into the diet in the form of 
protected oils, free oils, processed oilseeds or 
whole oilseeds (extruded, crushed, roasted or 
ground). These seeds/ oils are high in linoleic 
or linolenic acid, which are precursors of CLA. Oil 
to be added in diet can be protected in the form of 
fatty acyl amides, calcium salts, a lipid 
encapsulation or formaldehyde-protein protection 
matrix.

Food applications: CLA-rich oils can be used 
as functional ingredients in a variety of foods 
such as milk, yoghurt/dahi, cheese and paneer,
Table 2. Major findings of clinical and animal studies based on anti-carcinogenic activity of CLA

<table>
<thead>
<tr>
<th>Subject</th>
<th>Duration of feeding</th>
<th>CLA concentration in diet</th>
<th>Results</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mice</td>
<td>NR</td>
<td>1 g CLA/100 g diet</td>
<td>Dietary CLA supplementation reduced disease activity, decreased colitis, and prevented adenocarcinoma formation in cancer-induced mice. Additionally, a significant decrease was also observed in the percentages of macrophages in lymph nodes and the gene expression for colonic tumor necrosis factor-α.</td>
<td>Evans et al., [8]</td>
</tr>
<tr>
<td>Rectal cancer patients (n=34)</td>
<td>6 weeks</td>
<td>3gCLA/d</td>
<td>On comparison with placebo-group, CLA-group showed significant reductions in the pro-inflammatory markers [TNF-α (P = 0.04), hsCRP (P = 0.03)], and biomarkers of angiogenesis (MMP-9). However, no significant change was observed in the level of IL-6 than that of control.</td>
<td>Mohammadzadeh et al., [10]</td>
</tr>
<tr>
<td>Rats</td>
<td>NA</td>
<td>NA</td>
<td>Polymeric nanoparticles containing linoleic acid conjugate (NPs) were developed. Results revealed that CLA-NPs were effective in growth inhibition of human colon cancer cells. Another important observation was that CLA-NPs could avoid the phagocytosis by macrophages and promote the uptake by cancer cell, suggesting the NPs could be promising candidates to treat colorectal cancer.</td>
<td>Cheng et al., [12]</td>
</tr>
<tr>
<td>Human colon cancer cell lines (Caco-2, HT-29 and DLD-1) (In vitro)</td>
<td>72 h</td>
<td>200 μM CLA</td>
<td>Cell proliferation of human colon cancer cell lines was inhibited by all the isomers of conjugated linoleic acid. The maximum inhibition was shown by t9,t11-CLA, followed by t10,c12-CLA, c9,c11-CLA and c9,t11-CLA, respectively. The extent of apoptosis was also shown by all the isomers, maximum by t9,t11-CLA. The other isomers exhibited much lower apoptosis effect on Caco-2 cells.</td>
<td>Beppu et al., [29]</td>
</tr>
<tr>
<td>Mice and colon cancer cell lines (in vitro)</td>
<td>4 weeks for in vivo</td>
<td>0.1% c9, t11 or t 10,c 12 CLA</td>
<td>In vitro: c9,t11 CLA significantly inhibited cancerous cell growth (P&lt;0.05), whereas t10,c12 CLA isomer had no effect on cell migration. In vivo: c9,t11 CLA isomer significantly (P&lt;0.05) inhibited the activity of matrix metalloproteinases (MMPs), which are actively involved and generated in angiogenesis and metastasis. However, t10,c12 CLA isomer did not inhibit the activity of MMPs. Furthermore, both the isomers were equally effective in inhibiting the colon cancer cell metastasis in vivo.</td>
<td>Soel et al., [7]</td>
</tr>
<tr>
<td>Colon cancer</td>
<td>72 h</td>
<td>25 and 50 μM CLA</td>
<td>Data suggested that t10,c12 CLA exhibited cytotoxic effect through</td>
<td>Pierre et al., [11]</td>
</tr>
<tr>
<td>Subject</td>
<td>Duration of feeding</td>
<td>CLA concentration in diet</td>
<td>Results</td>
<td>Reference</td>
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<td>---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------</td>
<td>-----------------------------------------</td>
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<tr>
<td>cells (in vitro)</td>
<td></td>
<td></td>
<td>reactive oxygen species (ROS) generation and a subsequent endoplasmic reticulum stress-dependent apoptosis in colon cancer cells. Overall, t10,c12 CLA showed an inhibition effect on the proliferation of colon cancer cells. It was also included that t10,c12 CLA was more efficient pro-apoptotic fatty acid than c9,t11 CLA.</td>
<td>Chaudhari et al., EJNFS, 11(4): 200-213, 2019; Article no.EJNFS.2019.026</td>
</tr>
<tr>
<td>MCF-7 breast cancer cells (in vitro)</td>
<td>24 h</td>
<td>50 μM CLA</td>
<td>Data exhibited that t9, t11 was the most efficient CLA isomer which decreased the proliferation and migration, and induced the apoptosis of MCF-7 breast cancer cells after 24 h of treatment. Another important observation was that the t9, t11 CLA treatment reduced the intracellular and membrane-associated cholesterol levels.</td>
<td>El Roz et al., [30]</td>
</tr>
<tr>
<td>Human colorectal adenocarcinoma cells (in vitro)</td>
<td>24 h</td>
<td>25, 50 and 100 μM CLA</td>
<td>Results revealed that t10, c12-CLA induced the expression of ATF3 mRNA and luciferase activity (of ATF3 promoter), which are the main factors associated with apoptosis in colorectal cancer. Overall, it was suggested that t10, c12 CLA isomer treatment can induce the apoptosis of colon cancer cells, but not the most common CLA isomer i.e. c9, t11 as reported by Lee et al., (2006) in a similar study.</td>
<td>Kim et al., [1]</td>
</tr>
</tbody>
</table>
Table 3. Major findings of clinical and animal studies based on anti-inflammatory and immunomodulatory activities of CLA

<table>
<thead>
<tr>
<th>Subject</th>
<th>Duration</th>
<th>CLA concentration in diet</th>
<th>Major findings</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mouse and in vitro</td>
<td>NR</td>
<td>-</td>
<td>Decreased pro-inflammatory cytokines and inhibited leukocyte recruitment in vivo. While, in vitro, attenuated NF-κB-dependent gene expression, decrease pro-inflammatory cytokine production and up-regulated Nrf2-regulated proteins</td>
<td>Villacorta et al., [31]</td>
</tr>
<tr>
<td>In vitro (bovine mammary epithelial cells: BME-UV1)</td>
<td>-</td>
<td>-</td>
<td>Bovine mammary epithelial cells treated with CLA showed significantly lower levels of ROS when compared with other cells treated with ALA, γ-linolenic acid or linoleic acid. Reduced gene expression was observed for the production of pro-inflammatory cytokines (TNF-α, IL-1β, IL-6 and IL-10). Whereas, greater expression was also observed for PPAR-γ (anti-inflammatory).</td>
<td>Dipasquale et al., [32]</td>
</tr>
<tr>
<td>Mice</td>
<td>4 weeks</td>
<td>0, 0.5, and 1.5% DHA in presence and absence of 0.5% CLA</td>
<td>Dietary CLA lowered EPA-, DHA-, and ALA-derived epoxides, PGF1α, PGF2α, and F2-isoprostanes. Overall, it was concluded that CLA elevated proinflammatory oxylipins, while DHA increased anti-inflammatory oxylipins and weakened the effect of CLA-induced pro-inflammatory oxylipins in adipose tissue.</td>
<td>Adkins et al., [33]</td>
</tr>
<tr>
<td>Human patients with Crohn’s disease (n=13)</td>
<td>12 weeks</td>
<td>6g/d (orally)</td>
<td>Orally CLA intake suppressed peripheral blood T cells to produce pro-inflammatory cytokines (IFN-γ, TNF-α and IL-17), reduced disease activity and increased the quality of life of patients with Crohn’s disease. Oral administration of CLA did not show any negative effects and was well tolerated.</td>
<td>Bassaganya-Riera et al., [34]</td>
</tr>
<tr>
<td>Human (n=90)</td>
<td>2 months</td>
<td>3 g/d</td>
<td>The level of high sensitivity C-reactive protein (hsCRP), IL-6 and malondialdehyde (MDA), which are the markers of inflammation and oxidative stress, decreased significantly from 7.48 to 5.95 mg/ml, 16.13 to 12.95 pg/ml and 3.7 to 2.4 mol/l, respectively in CLA group after 8 weeks. However, glutathione peroxidase (GPx) increased from 125±46.06 (week 0) to 171.4±68.90 (week 8) mmol/ml/min.</td>
<td>Eftekhari et al., [35]</td>
</tr>
<tr>
<td>Human (n=29) Healthy adults</td>
<td>8 weeks</td>
<td>20 g/day of butter enriched with CLA (1020±167 mg CLA/day)</td>
<td>Intake of CLA-enriched butter resulted in increased levels of anti-inflammatory IL-10 and reduced levels of pro inflammatory components (TNFα, IL-2, IL-8 and transcription factor NFκB).</td>
<td>Penedo et al., [36]</td>
</tr>
<tr>
<td>Subject</td>
<td>Duration</td>
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<tr>
<td>Human (n=10)</td>
<td>10 weeks</td>
<td>200 g/week of cheese enriched with CLA</td>
<td>Dietary supplementation of CLA enriched cheese exhibited significant (p &lt; 0.05) reduction in pro-inflammatory markers such as IL-6 (4.58±0.94 vs. 8.08±1.57 pg/mL), IL-8 (28.59±2.64 vs. 45.02±5.82 pg/mL), and TNF-α (32.09±17.42 vs. 53.58±25.67 pg/mL). Moreover, a substantial reduction was also observed in the extent of platelet aggregation (77.7±3.56 vs. 87.8±1.76%).</td>
<td>Sofi et al., [37]</td>
</tr>
<tr>
<td>Mice</td>
<td>2 weeks</td>
<td>0.5-1% CLA-supplemented diet</td>
<td>Data revealed that wound healing rate was significantly (P&lt;0.05) faster in group fed 1% CLA supplemented diet as compared to control and/or group fed 0.5% CLA-diet. However, no significant difference was observed between the would healing rate between 0.5% CLA group and control. Overall, results showed that CLA supplementation reduced the levels of oxidative stress and inflammatory markers in experimental animals.</td>
<td>Park et al., [38]</td>
</tr>
<tr>
<td>Human cells (Human THP-1 monocytes) (In vitro)</td>
<td>NR</td>
<td>NR</td>
<td>Suppressed levels of pro-inflammatory markers such as macrophage phenotype; reduced expression of cyclooxygenase (COX)-2 and cytosolic phospholipase-A2 (cPLA2) and monocyte chemoattractant protein-1 (MCP-1); reduced levels of prostaglandin E2 (PGE2) and matrix metalloprotease (MMP)-9. Overall, it was concluded that CLA reduce the inflammatory outputs of macrophages.</td>
<td>McClelland et al., [39]</td>
</tr>
<tr>
<td>Mice</td>
<td>3 weeks</td>
<td>1% CLA supplemented diet</td>
<td>When colitis-induced mice were fed with CLA-based diet, a significant suppression was observed in weight loss, signs of colitis and inflammatory infiltration than that of control. Contrarily, when the mice with no colitis fed with CLA-based diet, a condition ‘steatosis’ was developed in which lipid metabolism by liver gets impaired resulting abnormal accumulation of fats in cells and organs. Results suggested that CLA is safe for use during gut inflammation but not at steady state conditions.</td>
<td>Moreira et al., [40]</td>
</tr>
</tbody>
</table>
Table 4. Major findings of clinical and animal studies based on cholesterol-lowering and anti-obesity effects of CLA

<table>
<thead>
<tr>
<th>Subject</th>
<th>Duration of feeding</th>
<th>CLA Concentration in diet</th>
<th>Major findings</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Cholesterol-lowering effects</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Male, female</td>
<td>9 weeks</td>
<td>20 g/day (oleic acid: CLA::80:20)</td>
<td>High intakes of an 80:20 mixture of cis-9, trans-11 and trans-10, cis-12 CLA raised the total- to HDL-cholesterol ratio in healthy volunteers.</td>
<td>Wander et al., 2010 [41]</td>
</tr>
<tr>
<td>Rats</td>
<td>6 weeks</td>
<td>0.5% trans-10, cis-12 CLA</td>
<td>Resveratrol and CLA significantly reduced body fat but did not do so when combined.</td>
<td>Arise et al., 2011 [42]</td>
</tr>
<tr>
<td>Rats</td>
<td>100 days</td>
<td>0.5% trans–trans CLA isomers</td>
<td>The trans–trans CLA-rich soy oil lowered the serum cholesterol and low-density lipoprotein–cholesterol levels by 41 and 50%, respectively, also lowered the liver lipid content and decreased the liver weight in the obese rats.</td>
<td>Gilbert et al., 2011 [43]</td>
</tr>
<tr>
<td>Rats</td>
<td>21 days</td>
<td>1% CLA and 63.2% of fructose</td>
<td>CLA in high-fructose diet, decreases serum LDL + VLDL and TG and plasma MDA concentrations as well as liver weight and liver cholesterol.</td>
<td>Kostogrys et al., 2010 [44]</td>
</tr>
<tr>
<td>Mice</td>
<td>4 weeks</td>
<td>0.4 g of CLS mixed with 1 kg of hyperlipidemic feed or 5 g every day</td>
<td>Decreased serum total cholesterol (TC), serum triacylglycerols (TAGs), serum low-density lipoprotein cholesterol (LDL-C), atherogenic index (AI), liver weight (LW), liver index (LI), liver TC, and TAGs of mice.</td>
<td>Li, R et al., 2010 [45]</td>
</tr>
<tr>
<td><strong>Anti-obesity effects</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Children (6 to 10 year)</td>
<td>2 weeks</td>
<td>3 g/day (50:50 cis-9, trans-11 and trans-10, cis-12 isomers)</td>
<td>CLA supplementation decreased body fatness in 6–10 years old children who were overweight or obese</td>
<td>Racine et al., 2010 [46]</td>
</tr>
<tr>
<td>Mice</td>
<td>14 days</td>
<td>1% trans-10, cis-12-CLA</td>
<td>Trans-10, cis-12 isomer of conjugated linoleic acid (CLA) caused a rapid reduction of body and adipose mass in mice.</td>
<td>Ashwell et al., 2010 [47]</td>
</tr>
<tr>
<td>Male, female (human)</td>
<td>12 weeks</td>
<td>1.7 g CLA in 200 ml sterilized milk</td>
<td>CLA significantly decreased the body weight, body mass index, body fat mass, fat percentage, subcutaneous fat mass, and waist-to-hip ratio in overweight.</td>
<td>Chen et al., 2012 [48]</td>
</tr>
<tr>
<td>Rat</td>
<td>8 weeks</td>
<td>2% of the 50:50 (c-9, t-11: t-10, c-12) mixture of CLA and 2% phytosterols</td>
<td>Diet supplemenations with CLA, phytosterols or their combination for 65 days were effective in reducing body fat, adipose tissue and feed consumption, and CLA, but not phytosterols, modulated the action of leptin in obesity.</td>
<td>Furlan et al., 2013 [49]</td>
</tr>
</tbody>
</table>
Table 5. Intended food uses and maximum use-levels of CLA in various food products (USDA, 2006 [50])

<table>
<thead>
<tr>
<th>Food Category</th>
<th>Intended food use</th>
<th>Maximum CLA level (g/ serving)</th>
<th>Maximum Use-level (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Beverages &amp; beverages bases</td>
<td>Specific soy milk beverages</td>
<td>1.5</td>
<td>0.625</td>
</tr>
<tr>
<td>Grain products and pasta</td>
<td>Meal replacement bars</td>
<td>1.5</td>
<td>3.750</td>
</tr>
<tr>
<td>Milk and milk products</td>
<td>Flavored milk products</td>
<td>1.5</td>
<td>0.625</td>
</tr>
<tr>
<td></td>
<td>Milk</td>
<td>1.5</td>
<td>0.625</td>
</tr>
<tr>
<td></td>
<td>Specific yoghurt products</td>
<td>1.5</td>
<td>0.667</td>
</tr>
<tr>
<td>Processed fruits and fruit juices</td>
<td>Specific fruit juice products</td>
<td>1.5</td>
<td>0.625</td>
</tr>
</tbody>
</table>

milk-based fermented beverages, ice-creams, grains and pasta products, processed fruits and fruit juices, etc. Campbell et al., [27] fortified CLA oil (Clairinol G-80) in skim milk at the concentration of 1 & 2%. After HTST pasteurization, the concentration of cis-9/trans 11 isomers remains stable by 2 weeks of refrigerated storage. Sensory analysis revealed that in fortified milks, low intensities of a “grassy/vegetable oil” odor was perceived. Rodriguez-Alcala and Fontecha [28] supplemented milk powder, milk, yoghurt, fermented milk, fresh cheese and milk-juice blend with Tonalin-80 (CLA-oil, 80% CLA). Major of CLA isomers were not affected by thermal treatment and processing but the total CLA content decreased in fresh samples after 10 weeks of low temperature storage. Kim et al. [1] has reported that the consumption of CLA up to 6 g/day for 1 year or 3.4 g/day for up to 2 years is currently being considered safe based on the outcomes of previous clinical studies.

**Commercially available CLA-rich dietary supplements Safflorin™**

Safflorin is suitable as ingredient in dietary supplements in various forms, including softgels, capsules, and supplement bars and similar products. Chemically, Safflorin™ is a mixture of the cis-9, trans-11 [(better known as conjugated linoleic acid (CLA))] and trans-10, cis-12 isomers of octadecadienoic acid in a 40:60 ratio. Depending on the application, Safflorin™ can be supplied as free fatty acids or esterified in glyceride form. The latter form is tasteless and therefore suitable for use in dietary supplement bars and similar products. Physically, Safflorin™ is a clear, colorless to pale yellow liquid at ambient temperature, free from foreign odors or off flavors. It contains ≥74% CLA (cis-9, trans-12 & trans-10, cis-12) isomers.

**Tonalin® TG80 and Clarinol™ G-80**

CLA-Rich Oil is a food grade preparation derived from processed safflower oil. It consists of approximately 78% total conjugated linoleic acid (CLA) isomers and 74% of an approximately 50:50 mixture of cis-9, trans-11 and trans-10, cis-12 CLA isomers. CLA-rich oil is intended to be added to certain specified foods within the general categories of soy milk, meal replacement beverages and bars, milk products and fruit juices. CLA-rich oil would be added to these foods at a level of 1.5 g per serving.

**Fortification of CLA-rich oils in foods**

CLA-Rich Oil is intended for use in specific foods within the following general food categories:

- Beverages and beverage bases
- Grain and pasta products
- Milk and milk products
- Processed fruits and fruit juices

**4. CONCLUSION**

Conjugated linoleic acid has unique property of anti-carcinogenic activity.. Diverse physiological functions of CLA in preventing the risks of cancer, obesity, hypercholesterolemia, atherosclerosis, etc. studied in animal model are little convincing and require further intense research. However, a few attempts have been made to confirm the positive impacts of CLA on human; nevertheless, it is not clear whether CLA promotes all of these advantages to humans as well. Further research is required to establish the biological benefits of CLA’s activity, to come about efficient strategies of intake and recommended amount for human safety.

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5. LIMITATIONS

As far as CLA is concerned, most of the studies have been conducted on animals (rodents, pigs, dogs, etc.) to establish the health effects of CLA. A very few studies have been conducted on human beings. No clear/concrete mechanisms are established yet for its antioxidative, anticarcinogenic and weight-control activities. No RDA is given by any regulatory agency yet. Toxicological effects of CLA are lacking due to insufficient data and research. Further clinical studies are required to establish safe limit or dietary intake of CLA along with the health benefits.

ACKNOWLEDGEMENT

The authors are thankful to the Executive Director, Mansinhbhai Institute of Dairy and Food Technology (MIDFT) for his continuous support for writing the manuscript.

COMPETING Interests

Authors have declared that no competing interests exist.

REFERENCES


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Peer-review history:
The peer review history for this paper can be accessed here: http://www.sdiarticle4.com/review-history/53785