UNIVERSITÀ
POLITECNICA
DELLE MARCHE

Dipartimento di Scienze Agrarie,
Alimentari ed Ambientali

INSECT LIPIDS

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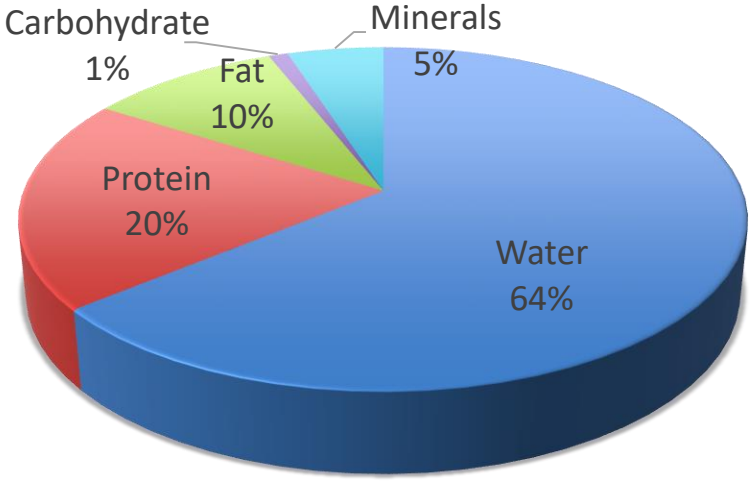
Acidi grassi

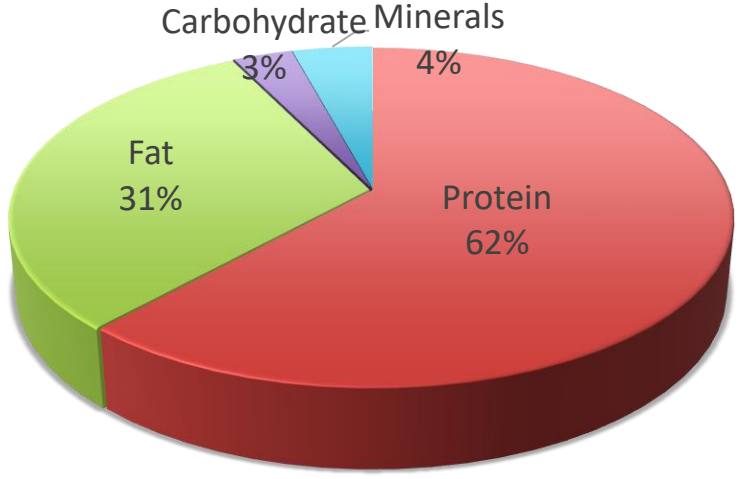
- acidi carbossilici che entrano nella costituzione dei lipidi complessi
- monocarbossilici
- generalmente a numero pari di atomi di carbonio da 4 a 32
- generalmente a catena lineare
- saturi o insaturi (mono-, poli-enoici)
- generalmente *cis* e isolati

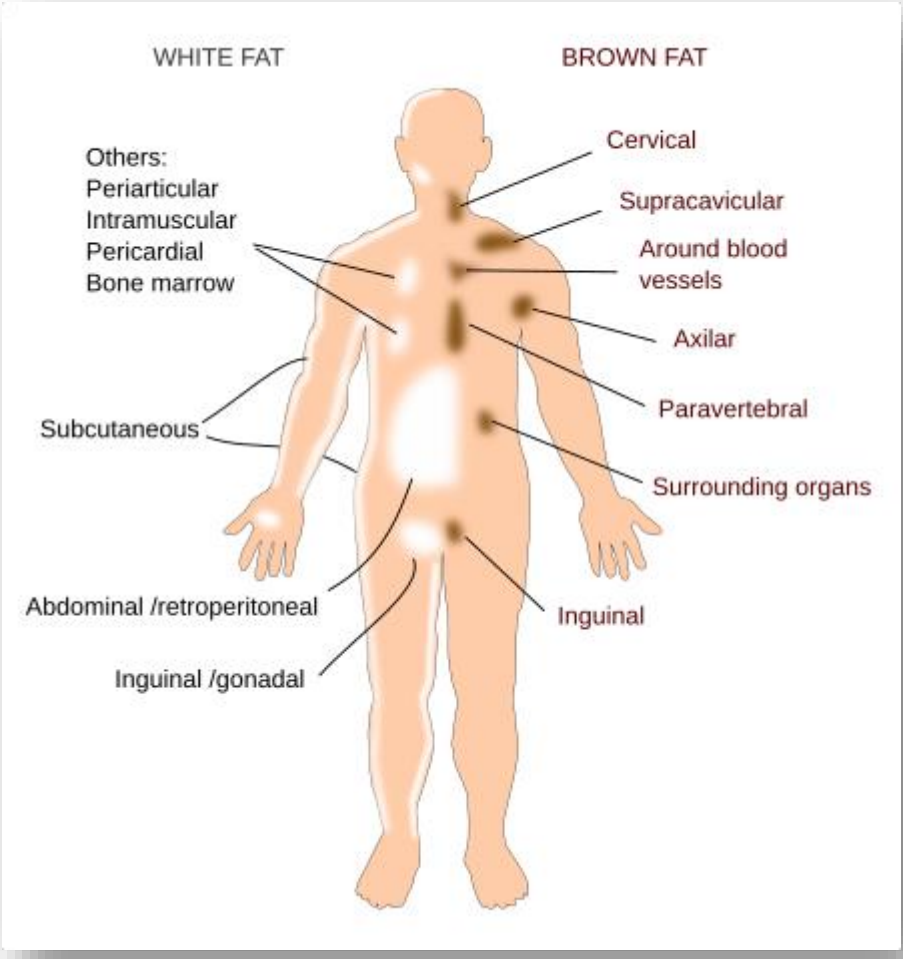
Lipidi

- complessi (saponificabili)
  - neutri
    - gliceridi
      - monoacilgliceroli
      - diacilgliceroli
      - triacilgliceroli
    - alchil-diacilgliceroli
    - estolidi
    - cere
    - steridi
  - polari
    - fosfatidi
      - glicerofosfolipidi (fosfogliceridi)
        - acidi fosfatidici
        - esteri fosfatidici
      - glicoglicerolipidi
    - sfingolipidi
      - sfingofosfolipidi
        - sfingomieline
        - fitoglicolipidi
      - cerebrosidi
      - gangliosidi
      - sulfatidi
- semplici (insaponificabili)
  - idrocarburi
  - vitamine liposolubili (A, D, E, K)
  - tocoferoli/tocotrienoli
  - steroli/metilsteroli
  - alcoli
    - alifatici
    - terpenici
    - dioli triterpenici
  - pigmenti liposolubili
    - carotenoidi
      - caroteni
      - xantofille
    - clorofille/feofitine

«grassi»: i lipidi totali, compresi i fosfolipidi (Reg. (UE) 1169/2011, All. I)







Distribution of **white** and **brown adipose tissue** in the human body

TABLE 2. FATTY ACID COMPOSITION OF EPICARDIAL AND SUBCUTANEOUS PERIPHERAL ADIPOSE TISSUE[a]

n = 42	*Subcutaneous*	*Epicardial*	*P*
12:0 (lauric acid)	0.90 ± 0.69	1.01 ± 0.75	0.329
14:0 (myristic acid)	2.47 ± 1.01	2.90 ± 0.98	0.002
16:0 (palmitic acid)	21.44 ± 3.58	27.10 ± 5.01	<0.001
16:1t (trance palmitoleic acid)	1.43 ± 0.48	1.38 ± 0.87	0.735
16:1n-7 (palmitoleic acid)	7.43 ± 3.34	5.10 ± 2.31	<0.001
18:0 (stearic acid)	2.40 ± 1.26	4.49 ± 1.69	<0.001
18:1t (trance oleic acid)	4.65 ± 0.98	4.58 ± 1.07	0.702
18:1n-9 (oleic acid)	38.15 ± 5.72	34.14 ± 6.44	0.002
18:1n-11 (oleic acid)	2.46 ± 1.32	2.65 ± 1.49	0.452
18:2t (trance linoleic acid)	2.01 ± 0.91	1.58 ± 0.79	0.004
18:2n-6 (linoleic acid)	12.99 ± 3.60	11.99 ± 2.94	0.032
18:3n-9 (linoleic acid)	0.67 ± 0.29	0.58 ± 0.23	0.041
CLA (conjugated linoleic acid)	0.72 ± 0.28	0.73 ± 0.41	0.769
20:4n-6 (arachidonic acid)	0.59 ± 0.31	0.60 ± 0.39	0.887
20:5n-3 (eicosapentaenoic acid)	0.16 ± 0.12	0.15 ± 0.13	0.532
22:6n-3 (docosahexaenoic acid)	0.18 ± 0.15	0.18 ± 0.16	0.103

[a]All values are mean percent of total ± SD.

EFA

METABOLIC SYNDROME AND RELATED DISORDERS, Volume 7, Number 2, 2009, Pp. 125–132

Parametri di genuinità relativi alla composizione percentuale degli acidi grassi per grassi animali ad uso alimentare

	Sego	Strutto	Cavallo	Pollo	Tacchino
Norma	NGD Ib 001-85	UNI 22011	NGD Ib 003-85	NGD Ib 004-85	NGD Ib 005-85
Palmitico %	25,0 - 29,0	20,0 - 27,0	26,0 - 32,0	22,0 - 25,0	22,0 - 25,5
Stearico %	20,0 - 28,0	11,0 - 18,0	3,5 - 6,5	5,5 - 7,5	6,5 - 10,5
Oleico %	20,0 - 28,0	38,0 - 46,0	33,5 - 37,5	41,0 - 45,0	34,0 - 37,0
Linoleico %	max 3,0	8,0 - 14,5	8,0 - 17,5	15,0 - 19,0	22,0 - 25,5

TABLE 1. *Fatty acid composition of PE and EPs in the developing human brain*

	PE			EPs		
	26–42 wk (n = 10)	0–6 mo (n = 4)	6 mo to 8 yr (n = 8)	26–42 wk (n = 10)	0–6 mo (n = 4)	6 mo to 8 yr (n = 8)
14:0	0.56 ± 0.13	0.37 ± 0.07	0.44 ± 0.11	1.61 ± 0.35	0.85 ± 0.17[a]	0.62 ± 0.14[c]
16:0	10.97 ± 1.00	9.16 ± 0.49[a]	8.25 ± 0.40[c]	8.89 ± 1.36	7.23 ± 1.87	5.16 ± 0.96[c]
16:1n-9	0.45 ± 0.06	0.27 ± 0.05[b]	0.15 ± 0.04[c]	0.85 ± 0.21	0.77 ± 0.18	0.37 ± 0.11[c]
16:1n-7	0.30 ± 0.08	0.32 ± 0.10	0.19 ± 0.09	0.21 ± 0.11	0.31 ± 0.15	0.39 ± 0.10[a]
18:0	37.63 ± 2.43	38.35 ± 1.84	36.93 ± 3.02	7.95 ± 1.54	5.24 ± 1.61	3.30 ± 0.88[c]
18:1n-9	6.54 ± 0.98	6.53 ± 0.34	8.78 ± 2.35	6.10 ± 1.28	10.68 ± 3.53[a]	19.77 ± 4.51[c]
18:1n-7	2.27 ± 0.53	2.30 ± 0.21	3.01 ± 0.81	0.77 ± 0.18	1.21 ± 0.37[a]	1.78 ± 0.28[c]
18:2n-6	0.21 ± 0.06	0.29 ± 0.09	0.42 ± 0.16[a]	0.22 ± 0.10	0.26 ± 0.13	0.27 ± 0.10
20:0	0.08 ± 0.02	0.10 ± 0.03	0.13 ± 0.05[a]	0.23 ± 0.10	0.29 ± 0.06	0.30 ± 0.12
20:1n-9	0.33 ± 0.08	0.29 ± 0.03	0.66 ± 0.26	0.58 ± 0.13	1.00 ± 0.38[a]	2.61 ± 0.92[c]
20:2n-9	0.24 ± 0.11	0.38 ± 0.09	0.45 ± 0.09[b]	0.50 ± 0.20	1.41 ± 0.71[a]	1.86 ± 0.14[c]
20:3n-9	1.07 ± 0.35	0.99 ± 0.50	0.43 ± 0.28[b]	0.87 ± 0.25	1.32 ± 0.76	0.78 ± 0.32
20:3n-6	0.91 ± 0.17	1.77 ± 0.21[c]	1.60 ± 0.28[c]	0.69 ± 0.21	1.49 ± 0.37[b]	2.14 ± 0.36[c]
20:4n-6	15.33 ± 0.77	15.26 ± 1.40	12.72 ± 1.47[b]	18.21 ± 1.99	18.38 ± 1.49	17.36 ± 2.13
22:4n-6	9.15 ± 1.06	8.68 ± 1.20	8.44 ± 0.46	21.74 ± 2.19	23.52 ± 2.68	25.58 ± 1.81[a]
22:5n-6	4.31 ± 0.57	3.55 ± 0.55	2.74 ± 1.30[a]	7.73 ± 1.54	4.60 ± 0.35[a]	2.53 ± 0.92[c]
22:5n-3	0.26 ± 0.07	0.32 ± 0.07	0.34 ± 0.06	0.75 ± 0.19	1.03 ± 0.27	0.79 ± 0.20
22:6n-3	9.22 ± 1.39	10.87 ± 1.29	14.07 ± 1.78[c]	21.54 ± 2.90	19.83 ± 4.91[a]	13.61 ± 1.47[b]

TABLE 2. *Fatty acid composition of PS and PC in the developing human brain*

	PS			PC		
	26–42 wk (n = 10)	0–6 mo (n = 4)	6 mo to 8 yr (n = 8)	26–42 wk (n = 10)	0–6 mo (n = 4)	6 mo to 8 yr (n = 8)
14:0	0.63 ± 0.16	0.39 ± 0.09	0.37 ± 0.11[b]	4.19 ± 0.84	2.19 ± 0.62[a]	2.64 ± 3.36
16:0	3.54 ± 0.65	2.87 ± 0.77	2.24 ± 0.45[b]	57.09 ± 3.24	52.12 ± 2.39	45.06 ± 3.59[c]
16:1n-9	0.61 ± 0.16	0.35 ± 0.10	0.14 ± 0.04[c]	4.11 ± 0.30	2.57 ± 0.53[c]	1.30 ± 0.19[c]
16:1n-7	0.08 ± 0.05	0.11 ± 0.02	0.07 ± 0.04	1.38 ± 0.33	0.95 ± 0.22	0.95 ± 0.27[a]
18:0	49.02 ± 1.91	47.72 ± 1.66	47.92 ± 1.60	8.42 ± 1.13	11.09 ± 1.59[a]	13.16 ± 0.84[c]
18:1n-9	4.59 ± 0.84	9.63 ± 3.46[b]	20.07 ± 4.33[c]	14.35 ± 1.56	17.70 ± 1.45[a]	23.48 ± 3.37[c]
18:1n-7	0.90 ± 0.19	1.31 ± 0.25[b]	2.42 ± 0.55[c]	4.30 ± 0.38	5.14 ± 0.45[a]	4.86 ± 0.31[a]
18:2n-6	0.15 ± 0.11	0.12 ± 0.07	0.23 ± 0.05	0.23 ± 0.06	0.46 ± 0.16[a]	0.77 ± 0.24[c]
20:0	0.26 ± 0.06	0.26 ± 0.04	0.23 ± 0.03	0.04 ± 0.02	0.06 ± 0.03	0.09 ± 0.02[c]
20:1n-9	0.49 ± 0.13	0.44 ± 0.07	1.24 ± 0.55[b]	0.31 ± 0.05	0.31 ± 0.02	0.36 ± 0.07
20:2n-9	0.21 ± 0.10	0.61 ± 0.35[a]	1.13 ± 0.33[b]	0.13 ± 0.06	0.19 ± 0.03	0.13 ± 0.02
20:3n-9	0.28 ± 0.10	0.31 ± 0.20	0.30 ± 0.07	0.17 ± 0.06	0.20 ± 0.10	0.10 ± 0.04
20:3n-6	1.16 ± 0.26	1.94 ± 0.38[b]	1.29 ± 0.24	0.34 ± 0.08	0.79 ± 0.17[c]	0.81 ± 0.16[c]
20:4n-6	4.35 ± 0.97	3.15 ± 0.39	1.98 ± 0.23[c]	3.57 ± 1.46	4.60 ± 0.70	4.23 ± 0.54
22:4n-6	9.66 ± 0.68	7.92 ± 1.94	4.91 ± 0.98[c]	0.43 ± 0.11	0.49 ± 0.10	0.57 ± 0.11
22:5n-6	7.78 ± 1.16	5.77 ± 0.11[a]	3.30 ± 1.74[c]	0.19 ± 0.07	0.18 ± 0.04	0.18 ± 0.06
22:5n-3	0.38 ± 0.23	0.38 ± 0.12	0.22 ± 0.08	0.03 ± 0.01	0.04 ± 0.01	0.06 ± 0.02[a]
22:6n-3	15.69 ± 1.62	16.49 ± 3.05	11.66 ± 2.48[b]	0.55 ± 0.19	0.73 ± 0.19	1.00 ± 0.23[b]

Fat content and randomly selected fatty acids of several edible insect species consumed in Cameroon

Edible insect species	Fat content (% of dry matter)
African palm weevil (*Rhynchophorus phoenicis*)	54%
Edible grasshopper (*Ruspolia differens*)	67%
Variegated grasshopper (*Zonocerus variegates*)	9%
Termites (*Macrotermes* sp.)	49%
Saturniid caterpillar (*Imbrasia* sp.)	24%

Zoo Biology 21:269–285 (2002)

TABLE 1. Average weight and proximate analysis of selected invertebrates on an as is basis

	Superworms *Zophobas morio*	Giant mealworm (larvae) *Tenebrio molitor*	Mealworm (larvae) *Tenebrio molitor*	Mealworms (adult) *Tenebrio molitor*	Waxworms *Galleria mellonella*	Silkworms *Bombyx mori*	Crickets (adult) *Acheta domesticus*	Crickets (nymph) *Acheta domesticus*	Earthworms *Lumbricus terresstris*
Weight (mg/insect)	610	304	126	136	314	1,045	465	97	204
Moisture (g/kg)	579	610	619	637	585	827	692	771	836
Protein (g/kg)	197	184	187	237	141	93	205	154	105
Fat (g/kg)	177	168	134	54	249	14	68	33	16
NFE (g/kg)	11	1	27	–14	–14	44	–8	9	36
Neutral detergent fiber (g/kg)	þ9	29	57	115	81	11	68	36	ND
Acid detergent fiber (g/kg)	27	25	25	74	34	11	32	22	1
Ash (g/kg)	10	12	9	12	6	11	11	11	6
Metabolizable energy (kcla/kg)	2,423	2,252	2,056	1,378	2,747	674	1,402	949	708
Fat % DM	**42.0**	**43.1**	**35.2**	**14.9**	**60.0**	**8.1**	**22.1**	**14.4**	**9.8**

Proximate composition of marketed dried edible insects

Acheta domesticus

Locusta migratoria

Tenebrio molitor

	Orthoptera				Coleoptera			
	Cricket powder* (samples 1–2)	Small crickets* (samples 3–4)	Locusts* (samples 5–6)	Locusts*** (samples 9–10)	Mealworm larvae* (samples 7–8)	Mealworm larvae** (samples 11–12)	Mealworm larvae*** (samples 13–14)	Mealworm larvae*** (samples 15–16)
Proximate composition								
Dry matter (%)	97.29 ± 1.55^{a}	97.27 ± 1.45^{a}	97.58 ± 1.61^{a}	92.20 ± 1.01^{c}	97.53 ± 1.02^{a}	94.31 ± 0.13^{b}	93.46 ± 0.15^{b}	93.18 ± 1.18^{b}
Water (%)	2.71 ± 0.03^{c}	2.73 ± 0.01^{c}	2.42 ± 0.04^{c}	7.80 ± 0.01^{a}	2.47 ± 0.03^{c}	5.69 ± 0.02^{b}	6.54 ± 0.03^{b}	6.82 ± 0.04^{b}
Protein (% d.m.)	59.46 ± 0.58^{a}	51.82 ± 0.43^{b}	46.78 ± 0.76^{d}	53.69 ± 0.28^{b}	49.05 ± 0.84^{c}	49.53 ± 0.55^{c}	53.97 ± 0.70^{b}	53.94 ± 0.22^{b}
Fat (% d.m.)	15.18 ± 1.65^{f}	23.17 ± 0.56^{d}	35.32 ± 0.51^{a}	19.36 ± 0.61^{e}	27.07 ± 0.32^{b}	29.19 ± 0.36^{b}	23.51 ± 1.51^{d}	25.05 ± 1.60^{c}
Ash (% d.m.)	4.66 ± 0.02^{a}	4.43 ± 0.05^{b}	2.34 ± 0.11^{d}	3.71 ± 0.12^{c}	3.84 ± 0.01^{c}	3.80 ± 0.02^{c}	3.90 ± 0.12^{c}	3.85 ± 0.06^{c}

Means ± standard deviations of duplicate independent experiments are shown

Within each row, means followed by different letters are significantly different ($P < 0.05$)

d.m., dry matter; cfu, colony-forming units

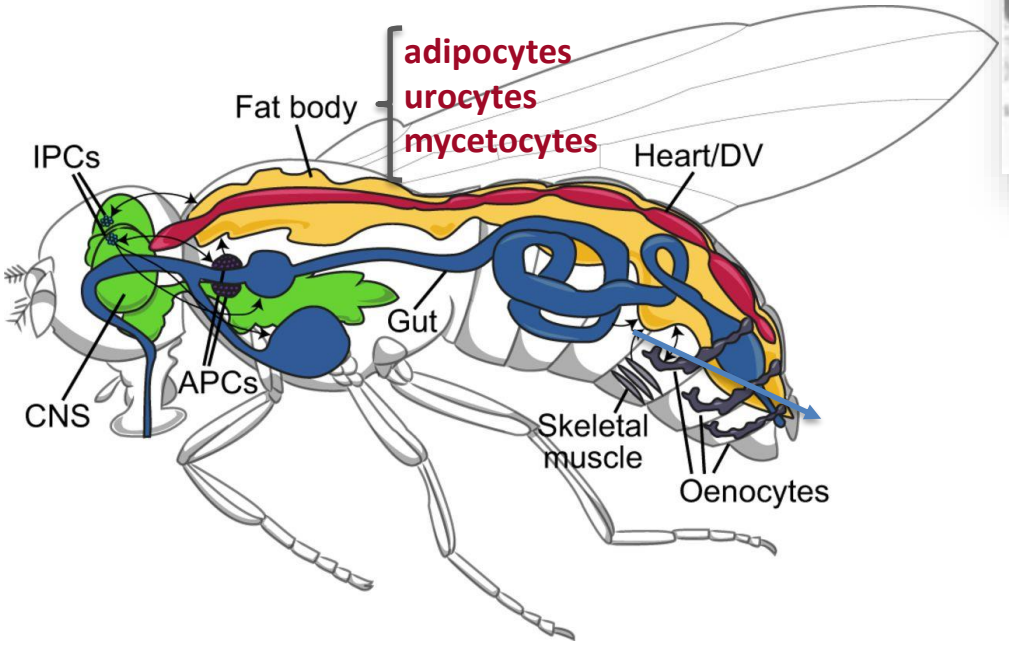
* Producer 1 (The Netherlands)

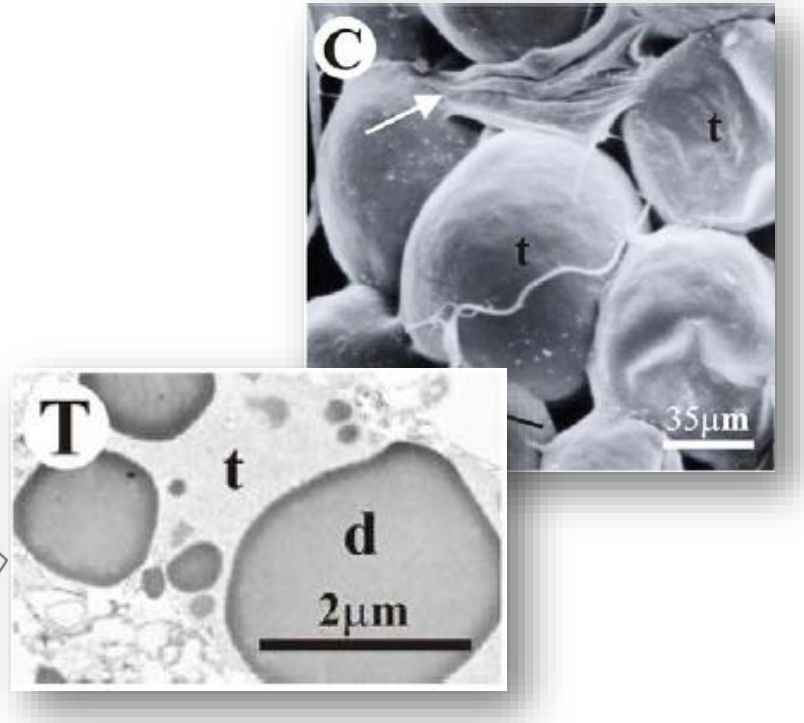
** Producer 2 (The Netherlands)

*** Producer 3 (Belgium)

Osimani et al., Eur Food Res Technol (2017) 243:1157–1171

Fat body: it has been described as an equivalent to a combination of the adipose tissue (**storage function**) and liver (major **metabolic functions**) of vertebrates, but this comparison does not do full justice to the fat body, which is also a major **endocrine organ**, and central to **systemic immunity** of insects. In addition, the fat body monitors and responds to the physiological needs of the insect during different developmental stages and under different environmental conditions, thereby **coordinating insect growth** with **metamorphosis** and **reproduction**.





(C) Scanning electron microscopy of the fat body cells from workers of M. parallelus gynes.
(T) Ultrastructural cytochemistry for lipids detection in the trophocytes of C. rimosus gynes

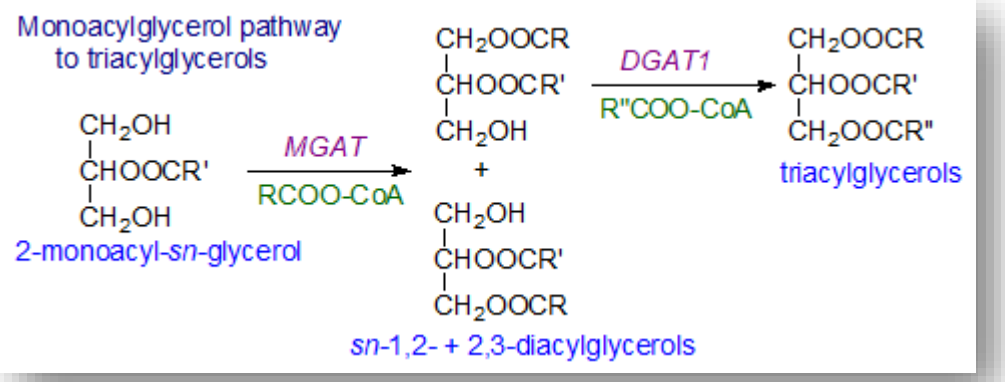
Current information indicates that insects share with mammals and other organisms several aspects of the mechanisms of deposition and mobilization of **triglycerides**. This information validates the use of insect models to investigate basic questions related to the processes of lipid storage and mobilization.

ACCUMULATION OF ENERGY RESERVES

- anhydrous form
- higher caloric content per unit of weight

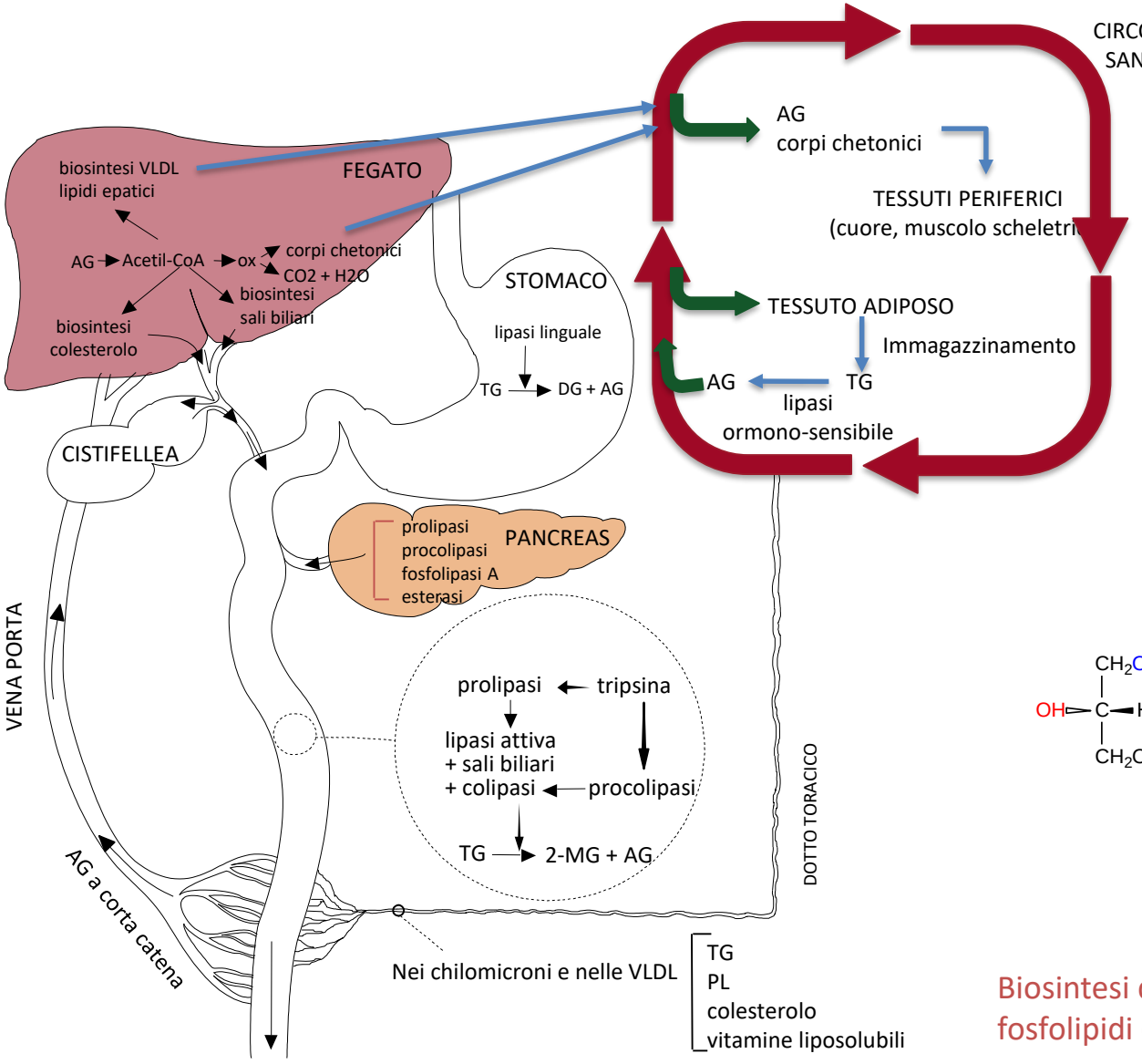
The direct precursor for TAG synthesis is DAG, which can be formed from

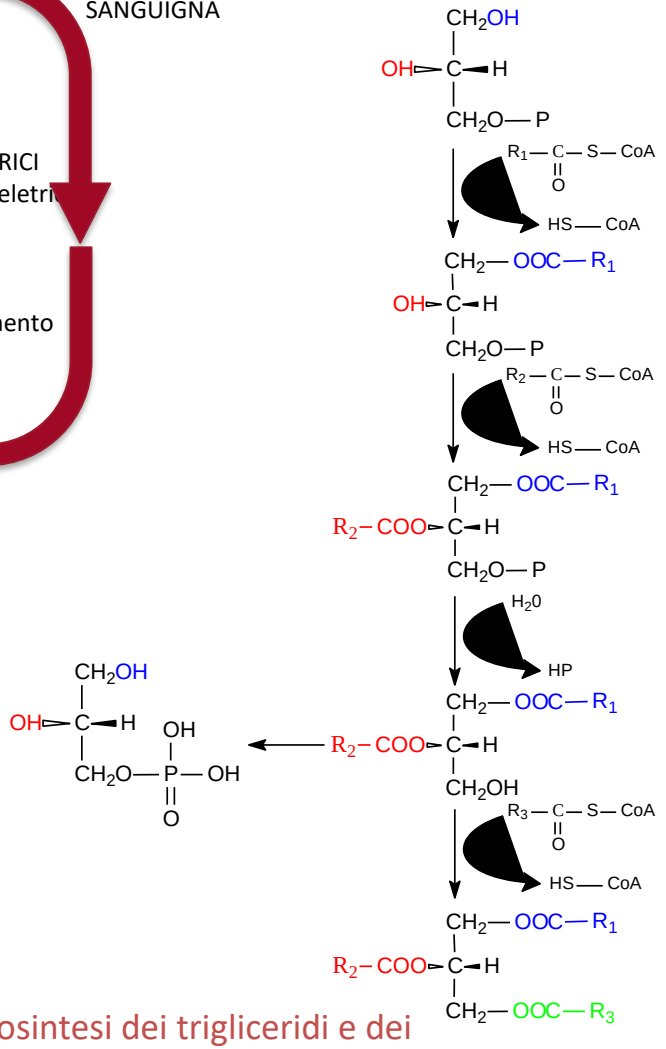
(a) phosphatidic acid, produced by the **glycerophosphate pathway**
(b) the **monoacylglycerol pathway**
(c) degradation of phospholipids
(d) deacylation of TAG catalyzed by lipases



- **The conversion of carbohydrates, a major component of the insect diet, to lipid in the fat body is well documented.**
- **The capacity of the fat body for lipogenesis from glucose is much higher than that for glycogen synthesis**

DIGESTIONE E ASSORBIMENTO DEI LIPIDI ALIMENTARI



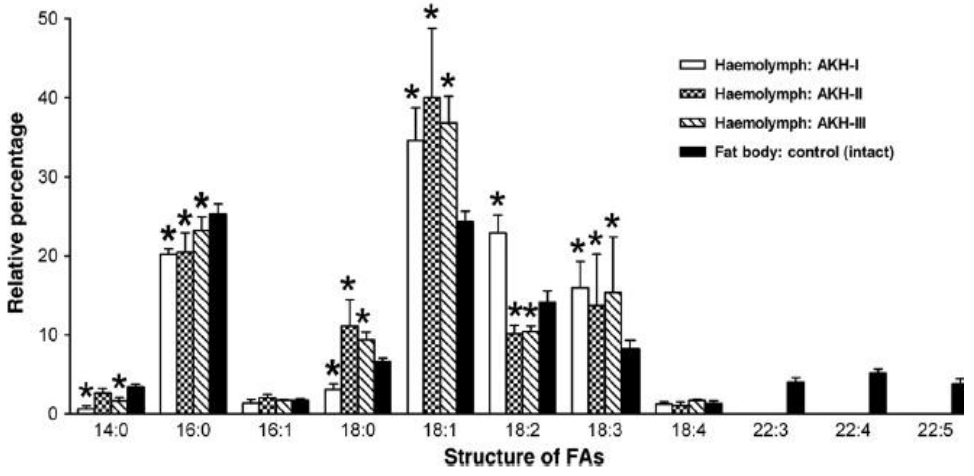


Biosintesi dei trigliceridi e dei fosfolipidi (via dell'a-glicerofosfato)

LIPID TRANSPORT

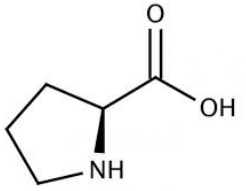
Fat body — **TAGs > 90% of total lipids**

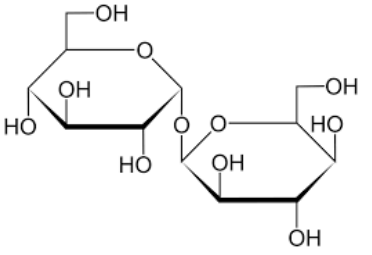
Hemolymph — **DAGs, predominantly bound to carrier protein lipophorins, represent the major haemolymph lipids (sn-1,2 isomers > 90%)**



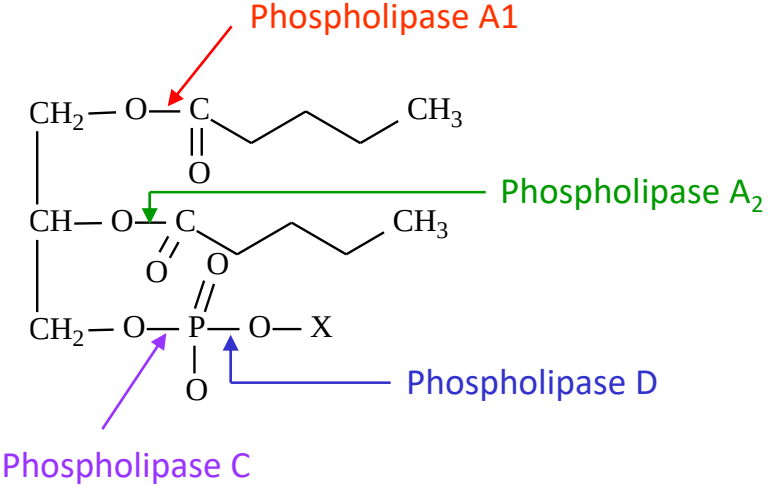
Relative percentage of the FAs contained in the haemolymph DGs mobilized by Locmi-AKHs (Locusta migratoria adipokinetic hormones) and their comparison with FAs in the intact FB TGs

MOBILIZATION OF LIPID RESERVES





- provision of energy to flight muscles (proline, threalose, DAGs)
- provision of lipids to the ovaries
- immune response
- overall maintenance of
- the metabolic activity of tissues (fat body included)



- **insect adipose triglyceride lipase (ATGL)**
  - belongs to the calcium-independent phospholipase A2 family
  - phospholipases that also display lipase and transacylase activity

- **triglyceride lipase (TGL)**
  - main triglyceride and diglyceride hydrolase activities
  - significant phospholipase A1 activity

TOTAL FA COMPOSITION OF INSECT SAMPLES

FA	Orthoptera				Coleoptera				Mean comparison between species$		
	Cricket powder* (samples 1–2)	Small crickets* (samples 3–4)	Locusts* (samples 5–6)	Locusts*** (samples 9–10)	Mealworm larvae* (samples 7–8)	Mealworm larvae** (samples 11–12)	Mealworm larvae*** (samples 13–14)	Mealworm larvae*** (samples 15–16)	*Acheta domesticus*	*Locusta migratoria*	*Tenebrio molitor*
12:0	0.56 ± 0.07	0.32 ± 0.01	0.28 ± 0.03	0.26 ± 0.04	0.35 ± 0.09	0.38 ± 0.08	0.04 ± 0.00	0.07 ± 0.00			
13:0	n.d.	n.d.	n.d.	0.01 ± 0.00	0.07 ± 0.01	0.07 ± 0.00	n.d.	n.d.			
14:0	1.61 ± 0.03	2.28 ± 0.13	2.21 ± 0.14	1.97 ± 0.18	4.22 ± 0.01	3.50 ± 0.38	0.82 ± 0.19	0.73 ± 0.01			
15:0	0.08 ± 0.03	0.11 ± 0.02	0.11 ± 0.00	n.d.	0.19 ± 0.03	0.17 ± 0.01	0.18 ± 0.02	0.22 ± 0.02	b	b	a
16:0	25.55 ± 1.10	35.40 ± 1.54	35.32 ± 2.47	25.30 ± 2.07	20.71 ± 0.18	19.18 ± 0.12	24.08 ± 0.67	22.13 ± 0.86	a	a	b
16:1	1.32 ± 0.11	0.93 ± 0.10	1.18 ± 0.08	1.26 ± 0.11	1.69 ± 0.02	1.67 ± 0.29	0.29 ± 0.09	0.32 ± 0.00			
17:0	0.26 ± 0.01	0.92 ± 0.07	0.77 ± 0.03	0.43 ± 0.03	0.65 ± 0.03	0.58 ± 0.00	0.48 ± 0.07	0.44 ± 0.04			
17:1 Δ10	0.05 ± 0.02	n.d.	0.14 ± 0.06	n.d.	n.d.	n.d.	n.d.	n.d.			
18:0	8.62 ± 0.14	13.65 ± 1.18	10.80 ± 0.49	9.88 ± 0.19	6.45 ± 0.06	5.55 ± 0.09	7.79 ± 0.01	6.86 ± 0.21	a	a	b
18:1 Δ9	26.30 ± 0.78	33.60 ± 2.30	35.57 ± 1.77	30.90 ± 0.03	45.00 ± 0.72	40.04 ± 0.29	27.80 ± 0.04	28.59 ± 0.16			
18:1 trans	0.08 ± 0.11	0.12 ± 0.01	0.09 ± 0.07	n.d.	0.05 ± 0.07	n.d.	n.d.	0.12 ± 0.17			
18:1 Δ11	0.69 ± 0.00	n.d.	n.d.	n.d.	n.d.	0.72 ± 0.23	0.30 ± 0.43	0.67 ± 0.12			
18:2 n-6	30.88 ± 0.24	7.54 ± 0.24	8.51 ± 0.09	12.15 ± 1.10	17.08 ± 0.18	24.44 ± 1.13	34.25 ± 0.28	34.97 ± 0.36	ab	b	a
18:2 trans	0.26 ± 0.01	0.10 ± 0.07	0.12 ± 0.09	n.d.	0.02 ± 0.03	0.24 ± 0.04	0.17 ± 0.04	0.20 ± 0.02			
18:3 n-3	1.50 ± 0.09	2.86 ± 0.08	3.02 ± 0.20	16.24 ± 0.67	1.22 ± 0.06	1.81 ± 0.09	2.18 ± 0.08	2.08 ± 0.02	b	a	b
20:0	0.42 ± 0.02	0.42 ± 0.08	0.35 ± 0.07	0.26 ± 0.32	0.17 ± 0.10	0.24 ± 0.04	0.35 ± 0.01	0.35 ± 0.02			
20:1 Δ11	0.13 ± 0.01	0.07 ± 0.02	0.29 ± 0.35	0.17 ± 0.01	0.09 ± 0.01	0.06 ± 0.04	0.08 ±	0.15 ± 0.05			
20:2 Δ11,14	0.11 ± 0.03	0.82 ± 0.21	0.75 ± 0.46	0.21 ± 0.05	0.87 ± 0.45	0.29 ± 0.25	0.05 ± 0.05	0.23 ± 0.22			
20:3 Δ11,14,17	0.10 ± 0.03	0.11 ± 0.01	0.06 ±	0.19 ± 0.02	0.07 ± 0.02	0.07 ± 0.03	n.d.	0.26 ± 0.04			
20:4 n-6	0.17 ± 0.01	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.			
20:5 n-3	0.49 ± 0.06	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.			
22:0	n.d.	0.09 ± 0.01	0.07 ± 0.01	n.d.	0.03 ± 0.04	n.d.	n.d.	n.d.			
24:0	0.17 ± 0.06	0.12 ± 0.11	0.08 ± 0.06	n.d.	0.08 ± 0.01	0.08 ± 0.02	n.d.	0.01 ± 0.02	a	b	b
Others FAs	0.65 ± 0.35	0.54 ± 0.31	0.27 ± 0.06	0.77 ± 0.62	1.02 ± 0.22	0.89 ± 0.02	1.14 ± 0.11	1.59 ± 0.29			
SFA	37.29 ± 0.83	53.31 ± 2.60	50.00 ± 2.92	38.11 ± 2.19	32.90 ± 0.09	29.75 ± 0.39	33.73 ± 0.40	30.83 ± 0.60			
MUFA	28.56 ± 0.79	34.71 ± 2.41	37.27 ± 2.21	32.33 ± 0.13	46.83 ± 0.65	42.50 ± 0.38	28.48 ± 0.48	29.84 ± 0.50			
PUFA	33.50 ± 0.31	11.43 ± 0.13	12.46 ± 0.66	28.79 ± 1.70	19.25 ± 0.34	26.86 ± 0.80	36.65 ± 0.19	37.74 ± 0.18			

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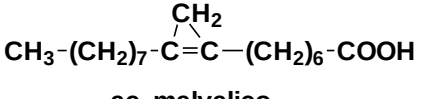
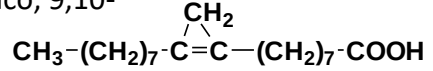
- apporto dietetico complessivo
- rapporto S/M/P
- contenuto EFA e rapporto n-3/n-6
- contenuto CLA
- contenuto monoinsaturi in configurazione geometrica *trans*
- struttura TAGs
- potenziale pericolosità di alcuni acidi grassi
- potenziale pericolosità di alcuni prodotti di ossidazione

- Acido erucico (C22:1 Δ13*cis*) → *Brassicaceae* (colza)
  → in Italia è vietato l'impiego nell'alimentazione umana di oli/grassi con erucico > 5% acidi grassi totali
- Acidi grassi ciclopropenoici → *Malvaceae* (malva, cotone)
  → *Sterculiaceae*
  → *Bombacaceae*



ac. malvalico

- Acidi grassi idrossilati → ricinoleico (12-idrossi,9-*cis*-ottadecenoico; 9,10-diidrossistearico)
  → *Ricinus communis*



ac. sterculico

NUTRITIONAL QUALITY INDEXES OF INSECT LIPIDS

FA	Orthoptera				Coleoptera				Mean comparison between species$		
	Cricket powder* (samples 1–2)	Small crickets* (samples 3–4)	Locusts* (samples 5–6)	Locusts*** (samples 9–10)	Mealworm larvae* (samples 7–8)	Mealworm larvae** (samples 11–12)	Mealworm larvae*** (samples 13–14)	Mealworm larvae*** (samples 15–16)	*Acheta domesticus*	*Locusta migratoria*	*Tenebrio molitor*
PUFA/SFA	0.90 ± 0.01	0.21 ± 0.01	0.25 ± 0.03	0.76 ± 0.09	0.59 ± 0.01	0.90 ± 0.04	1.09 ± 0.01	1.22 ± 0.02			
n-6/n-3	14.94 ± 0.31	2.82 ± 0.09	3.00 ± 0.01	0.75 ± 0.03	13.99 ± 0.28	13.19 ± 1.31	15.74 ± 0.69	15.07 ± 0.08	a	b	a
AI	0.53 ± 0.02	0.98 ± 0.07	0.90 ± 0.09	0.55 ± 0.06	0.57 ± 0.00	0.49 ± 0.02	0.42 ± 0.00	0.37 ± 0.02			
TI	0.99 ± 0.03	1.67 ± 0.14	1.48 ± 0.17	0.51 ± 0.05	0.86 ± 0.00	0.72 ± 0.01	0.86 ± 0.02	0.75 ± 0.02			
h/H	2.22 ± 0.11	1.19 ± 0.10	1.28 ± 0.15	2.19 ± 0.24	2.57 ± 0.00	2.97 ± 0.07	2.59 ± 0.06	2.91 ± 0.12	b	b	a

- PUFA/SFA **> 0.4**
- n-6/n-3 **1:1 to 5:1**
- AI, atherogenic index = (C12:0 + 4 × C14:0 + C16:0)/(Σn-6 + Σn-3 + ΣMUFA) **< 1.0**
- TI, thrombogenic index = (C14:0 + C16:0 + C18:0)/[0.5 × ΣMUFA + 0.5 × Σn-6 + 3 × Σn-3 + (Σn-3/Σn-6)] **< 1.0**
- h/H, hypocholesterolemic/hypercholesterolemic ratio = (C18:1 + C18:2 + C18:3 + C20:2 + C20:4 + C20:5 + C22:5 + C22:6)/(C14:0 + C16:0) **low**

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- **feed composition**
- rearing conditions
- developmental stage

→ how feeding could affect the lipid content and the FA composition of yellow mealworms, in order to exploit this coleopteran oil as a diet supplement for humans

Fat content and fatty acid composition of the rearing substrates (mean ± SD)

S1 = organic wheat flour (100); S2 = Farinaccio (100); S3 = Farinaccio (75), olive pomace (25); S4 = Farinaccio (50), olive pomace (50); S5 = Farinaccio (25), olive pomace (75)

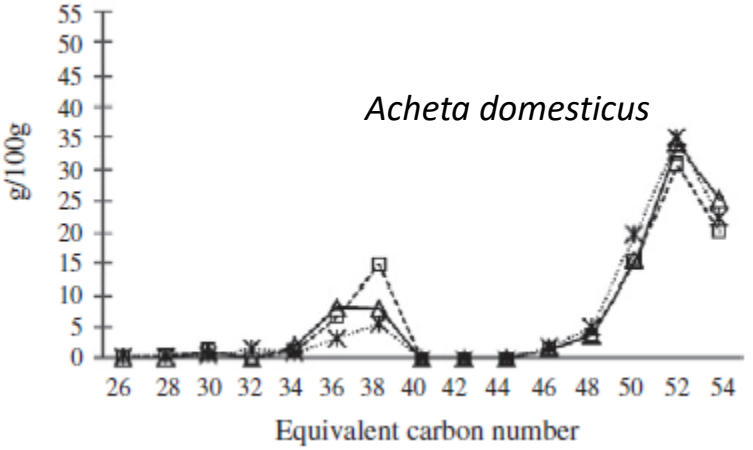
Substrate[a]	S1	S2	S3	S4	S5
Total lipid content [% DM]	2.51 ± 0.33^{d}	8.22 ± 0.57^{c}	8.58 ± 0.36^{c}	10.35 ± 0.31^{b}	12.67 ± 1.02^{a}
FA [w/w %]					
C16:0	17.67 ± 0.55^{a}	15.80 ± 0.65^{bc}	17.23 ± 0.46^{ab}	16.99 ± 0.65^{abc}	15.64 ± 0.60^{c}
C18:0	1.47 ± 0.04^{a}	1.05 ± 0.06^{b}	1.38 ± 0.04^{a}	1.59 ± 0.09^{a}	1.00 ± 0.23^{b}
C18:1Δ9	17.61 ± 0.84^{e}	20.02 ± 0.76^{d}	33.91 ± 0.77^{c}	45.33 ± 0.66^{b}	56.54 ± 0.46^{a}
C18:2 n-6	56.49 ± 0.68^{a}	55.15 ± 0.22^{b}	40.73 ± 0.65^{c}	29.40 ± 0.33^{d}	20.80 ± 0.27^{e}
C18:3 n-3	3.84 ± 0.16^{b}	4.34 ± 0.19^{a}	2.95 ± 0.06^{c}	2.18 ± 0.12^{d}	1.45 ± 0.03^{e}

Fat content and fatty acid composition of *T. molitor* larvae reared on five different substrates (mean ± SD)

M1 = organic wheat flour (100); M2 = Farinaccio (100); M3 = Farinaccio (75), olive pomace (25); M4 = Farinaccio (50), olive pomace (50); M5 = Farinaccio (25), olive pomace (75)

Substrate[a]	M1	M2	M3	M4	M5
Total lipid content [% DM]	49.93 ± 0.95^{a}	38.27 ± 3.11^{c}	36.59 ± 1.47^{c}	39.77 ± 2.61^{bc}	42.01 ± 1.55^{ab}
FA [w/w %]					
C16:0	16.72 ± 0.77^{ab}	18.16 ± 0.58^{a}	16.10 ± 0.85^{bc}	15.94 ± 0.56^{bc}	14.93 ± 0.26^{c}
C18:0	2.58 ± 0.18^{b}	2.73 ± 0.02^{ab}	3.01 ± 0.17^{a}	2.54 ± 0.07^{b}	2.51 ± 0.04^{b}
C18:1Δ9	52.63 ± 1.23^{b}	45.06 ± 1.92^{c}	55.98 ± 0.75^{a}	56.58 ± 0.22^{a}	58.04 ± 0.22^{a}
C18:2 n-6	18.81 ± 0.22^{b}	25.37 ± 2.41^{a}	17.71 ± 0.96^{b}	18.53 ± 0.47^{b}	18.50 ± 0.16^{b}
C18:3 n-3	0.30 ± 0.00^{c}	1.00 ± 0.13^{a}	0.42 ± 0.01^{bc}	0.51 ± 0.02^{b}	0.47 ± 0.02^{b}

➢ TAG composition

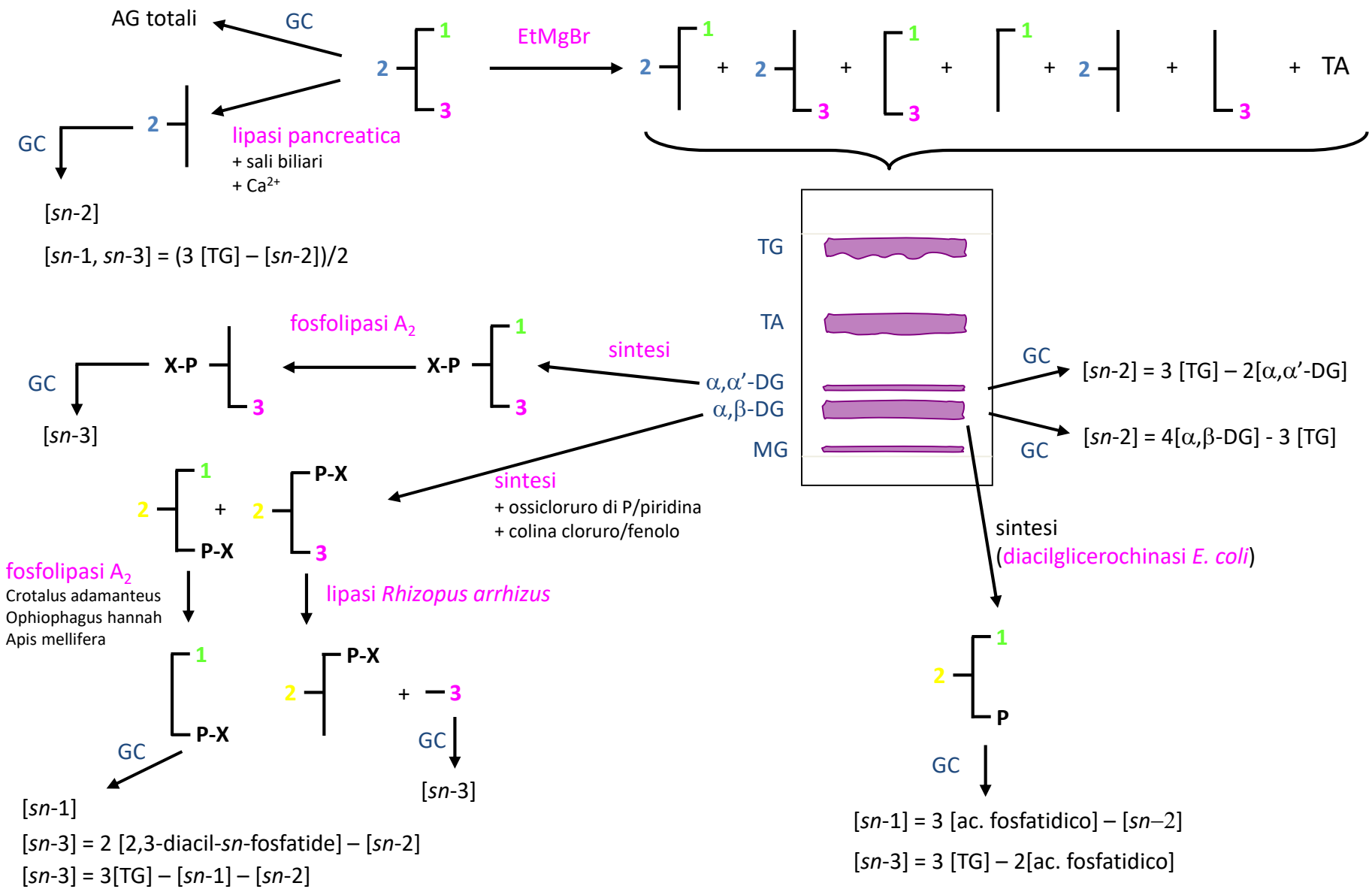


Tzompa-Sosa, D. A.; Yi, L.; van Valenberg, H. J. F.; van Boekel, M. A. J. S.; Lakemond, C. M. M. Insect lipid profile: aqueous versus organic solvent-based extraction methods. FOOD RESEARCH INTERNATIONAL, 62, 1087-1094 (2014)

CN:DB[a]	MW[b]	Triacylglycerols	mol% ± sd[c]
48:1	804.7	14:0–16:0–18:1	6.71 ± 0.111
		14:0–16:1–18:0	2.82 ± 0.067
		14:1–16:0–18:0	3.19 ± 0.173
		16:0–16:0–16:1	2.26 ± 0.093
48:2	802.7	**14:0–16:1–18:1** +	2.40 ± 0.729
		14:1–16:0–18:1	
		16:0–16:1–16:1	0.63 ± 0.007
		14:1–16:1–18:0	0.13 ± 0.084
		12:0–18:1–18:1	0.23 ± 0.005
48:3	800.7	14:1–16:1–18:1	0.84 ± 0.103
		14:0–16:0–18:3	0.70 ± 0.095
		12:0–18:1–18:2	0.38 ± 0.082
49:0	820.7	15:0–16:0–18:0 +	0.72 ± 0.333
		16:0–16:0–17:0	
49:1	818.7	16:0–16:1–17:0	0.36 ± 0.010
		15:0–16:0–18:1	0.90 ± 0.003
		14:0–18:1–17:0	0.26 ± 0.095
49:2	816.7	15:0–16:1–18:1	0.26 ± 0.001
50:0	834.7	16:0–16:0–18:0	2.77 ± 0.158
		18:0–14:0–18:0	0.59 ± 0.277
50:1	832.7	16:0–16:0–18:1	5.72 ± 0.716
		16:0–16:1–18:0	0.94 ± 0.07
		18:0–14:0–18:1	1.60 ± 0.048
		14:0–16:0–20:1	0.44 ± 0.070
50:2	830.7	16:0–16:1–18:1	2.43 ± 0.17
		18:1–14:0–18:1	1.72 ± 0.25
		14:1–18:0–18:1	0.92 ± 0.095
		16:1–16:1–18:0	0.77 ± 0.006
50:3	828.7	14:0–18:1–18:2	0.28 ± 0.049
		14:1–18:1–18:1	1.66 ± 0.077
50:4	826.7	**14:0–18:1–18:3** +	0.23 ± 0.026
		16:0–16:1–18:3	
51:0	848.7	17:0–16:0–18:0	0.23 ± 0.014
51:1	846.7	17:0–16:0–18:1	1.03 ± 0.035
		17:0–16:1–18:0	0.33 ± 0.029
		15:0–18:0–18:1	0.61 ± 0.035
51:2	844.7	18:1–15:0–18:1	0.41 ± 0.017
		17:0–16:1–18:1	0.29 ± 0.008
		17:0–16:0–18:2	0.12 ± 0.003
52:0	862.7	18:0–16:0–18:0	0.61 ± 0.011
52:1	860.7	18:0–16:0–18:1	5.30 ± 0.154
		18:0–16:1–18:0	0.21 ± 0.003
		16:0–16:0–20:1	0.42 ± 0.091

Haddad, I.; Mozzon, M.; Strabbioli, R. & Frega, N. G. Electrospray ionization tandem mass spectrometry analysis of triacylglycerols molecular species in camel milk (Camelus dromedarius). International Dairy Journal, 2011, 21, 119-127

➢ positional analysis


AG totali
GC
EtMgBr
TA
lipasi pancreatica
+ sali biliari
+ Ca2+
[sn-2]
[sn-1, sn-3] = (3 [TG] – [sn-2])/2
TG
TA
α,α'-DG
α,β-DG
MG
fosfolipasi A2
sintesi
[sn-3]
[sn-2] = 3 [TG] – 2[α,α'-DG]
[sn-2] = 4[α,β-DG] - 3 [TG]
sintesi
+ ossicloruro di P/piridina
+ colina cloruro/fenolo
fosfolipasi A2
Crotalus adamanteus
Ophiophagus hannah
Apis mellifera
lipasi Rhizopus arrhizus
[sn-1]
[sn-3] = 2 [2,3-diacil-sn-fosfatide] – [sn-2]
[sn-3] = 3[TG] – [sn-1] – [sn-2]
sintesi
(diacilglicerochinasi E. coli)
[sn-1] = 3 [ac. fosfatidico] – [sn–2]
[sn-3] = 3 [TG] – 2[ac. fosfatidico]

Intrapositional distribution (% mol mean values ± standard deviation, n = 5) of fatty acids in camel milk TAGs[a].

Fatty acids	TAGs	Grignard hydrolysis			Lipase digestion		Differences
	Original	*sn*-1	*sn*-2	*sn*-3	*sn*-2	TAGs[b]	
SFAs							
$C_{8:0}$	0.50 ± 0.09	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
$C_{10:0}$	0.30 ± 0.04	0.14 ± 0.25	0.75 ± 0.67	0.00 ± 0.00	0.00 ± 0.00	0.27 ± 0.23	n.s.
$C_{12:0}$	1.66 ± 0.20	0.68 ± 0.28	3.06 ± 1.06	0.70 ± 0.17	2.03 ± 0.84	1.91 ± 0.67	n.s.
$IsoC_{12:0}$	0.02 ± 0.04	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
$C_{13:0}$	0.06 ± 0.09	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
$C_{14:0}$	14.91 ± 0.66	10.23 ± 1.76	18.16 ± 2.53	12.46 ± 2.02	15.93 ± 1.67	16.28 ± 2.15	n.s.
$IsoC_{14:0}$	0.90 ± 0.06	0.65 ± 0.08	0.30 ± 0.53	0.58 ± 0.52	1.05 ± 0.09	1.00 ± 0.11	n.s.
$C_{15:0}$	2.03 ± 0.06	1.65 ± 0.12	2.91 ± 0.28	1.93 ± 0.25	2.62 ± 0.13	2.20 ± 0.14	n.s.
$IsoC_{15:0}$	0.50 ± 0.02	0.22 ± 0.19	0.42 ± 0.37	0.45 ± 0.05	0.63 ± 0.05	0.51 ± 0.02	n.s.
$C_{16:0}$	28.50 ± 0.71	29.81 ± 0.30	40.81 ± 0.34	28.98 ± 1.90	37.72 ± 0.57	29.48 ± 0.63	*
$IsoC_{16:0}$	1.72 ± 0.35	1.22 ± 0.18	1.23 ± 0.50	1.25 ± 0.04	1.66 ± 0.09	1.42 ± 0.14	n.s.
$C_{17:0}$	0.91 ± 0.08	1.24 ± 0.04	0.67 ± 0.38	1.01 ± 0.09	0.93 ± 0.04	0.93 ± 0.10	n.s.
$C_{18:0}$	10.52 ± 0.55	17.36 ± 1.16	2.26 ± 0.13	14.57 ± 1.93	4.67 ± 0.65	9.97 ± 1.35	*
$C_{20:0}$	0.24 ± 0.05	0.26 ± 0.05	0.14 ± 0.25	0.36 ± 0.16			
$C_{22:0}$	0.07 ± 0.04	n.d.	n.d.	n.d.			
$\sum C_{8:0}$–$C_{22:0}$	62.84 ± 0.42	63.48 ± 0.71	70.71 ± 2.17	62.36 ± 2.27			
UFAs							
$C_{14:1\Delta 9c}$	2.92 ± 0.18	2.04 ± 0.36	3.20 ± 0.15	2.46 ± 0.51			
$C_{15:1}$	0.28 ± 0.51	n.d.	n.d.	n.d.			
$C_{16:1\Delta 7c}$	1.19 ± 0.14	1.11 ± 0.02	0.65 ± 0.56	1.28 ± 0.24			
$C_{16:1\Delta 9c}$	6.34 ± 0.21	5.03 ± 0.25	6.94 ± 0.67	5.74 ± 0.42			
$C_{17:1\Delta 11c}$	0.57 ± 0.07	0.51 ± 0.04	0.42 ± 0.19	0.47 ± 0.13			
$C_{18:1\Delta 9t}$	0.55 ± 0.13	0.06 ± 0.10	0.00 ± 0.00	0.17 ± 0.29			
$C_{18:1\Delta 11t}$	2.46 ± 0.17	3.38 ± 0.37	0.43 ± 0.38	3.52 ± 0.90			
$C_{18:1\Delta 9c+\Delta 11c}$	18.39 ± 0.72	20.93 ± 0.42	14.02 ± 2.35	21.67 ± 1.74			
$C_{18:2\Delta 9t,\Delta 12t}$	0.25 ± 0.08	0.23 ± 0.20	0.00 ± 0.00	0.00 ± 0.00			
$C_{18:2\Delta 9c,\Delta 12c}$	2.05 ± 0.08	1.80 ± 0.09	1.78 ± 1.09	1.68 ± 0.28			
$C_{18:3\omega 3}$	1.24 ± 0.51	0.42 ± 0.04	0.14 ± 0.25	0.36 ± 0.17			
$C_{20:1\Delta 11c}$	0.66 ± 0.09	0.75 ± 0.43	0.12 ± 0.21	0.28 ± 0.24			
$C_{20:4\omega 6}$	0.04 ± 0.05	n.d.	n.d.	n.d.			
$\sum$UFA	36.93 ± 0.34	36.25 ± 0.50	27.28 ± 2.18	37.64 ± 2.17			
MUFA	33.35 ± 0.31	33.80 ± 0.35	25.36 ± 3.22	35.60 ± 1.78			
PUFA	3.58 ± 0.48	2.45 ± 0.15	1.92 ± 1.08	2.04 ± 0.40			
UFA:SFA	0.57 ± 0.01						
$C_{18:2}$:$C_{18:3}$	1.84 ± 0.57						

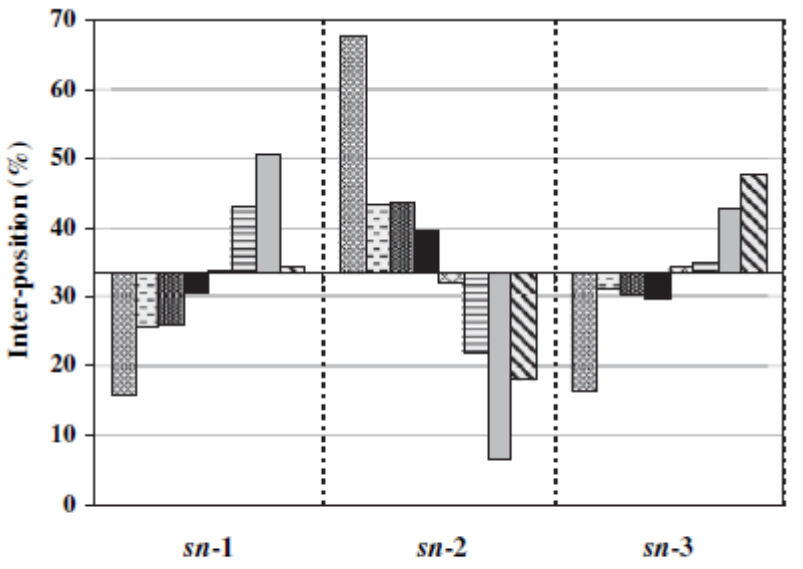


Fig. 1. Inter-positional distribution of saturated fatty acids in camel milk TAGs. 33.33% represent the proportion of each fatty acid expected on the basis of a random positional distribution: 12:0; 14:0; 15:0; 16:0; iso16:0; 17:0; 18:0; 20:0.

Haddad I, Mozzon M, Strabbioli R, Frega NG. Stereospecific analysis of triacylglycerols in camel (Camelus dromedarius) milk fat. International Dairy Journal 20 (2010) 863-867

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Exploring the potential of grease from yellow mealworm beetle (*Tenebrio molitor*) as a novel biodiesel feedstock

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R10 TDI: 1° assoluto 2006, 2007, 2008
R15 TDI: 1° assoluto 2010
R18 TDI: 1° assoluto 2011
R18 e-tron quattro: 1° assoluto 2012, 2013, 2014

Grazie per l'attenzione!