Revisiting Dadd's Mosquito Theory

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- The opinions of the author expressed herein do not necessarily state or reflect those of the United States Government and shall not be used for advertising or product endorsement purposes.

Reginald H. Dadd

- 1951-1969: Meal worm, locus, wax moth, and aphid nutrition
- 1969-1992: Mosquito nutrition

Table 2 Composition of holidic synthetic dietary medium for mosquito larvae

Ingredients	Concentration % W/V[a]	Nutrient status or other function	Potential sources of nutrients
18 amino acids	1.50	11 or 12[b] essential	All organisms, mostly as protein
Sugar: maltose, sucrose, glucose, mixed	0.75	Beneficial	All organisms, mostly as storage carbohydrate
10 mineral ions	0.33	9 essential	All organisms, also silt
8 water-soluble vitamins (includes choline)	<0.01	All 8 essential	All live organisms; vitamins soon lost from dead tissue
5 nucleotides	0.15	2 or 3[b] essential	All organisms, mostly from genomic nucleic acid
Cholesterol or phytosterol	<0.01	Essential	Absent from prokaryotes
Arachidonic/eicosapentaenoic acid	<0.01	Essential	Animal tissues, mainly
Synthetic dipalmitoyl lecithin	<0.01	Improves lipid use	Natural phospholipids in most tissues
Ascorbyl palmitate	<0.01	Antioxydant	Many organisms have natural antioxidants
Agarose	0.01	Optimizes drinking	Natural colloids associated with slimes

[a] Weight/volume.
[b] Different for different species.

Merritt R.W., Dadd R.H., and E.D. Walker. 1992. Feeding behavior, natural food, and nutritional relationships of larval mosquitoes. *Annu. Rev. Entomol.* 37: 349–374.

Table 2. Arachidonic and eicosapentaenoic acid content by food type. Fatty acid content is expressed as greater than 1% of total lipid profile (+), trace, or less than 1% of total lipid profile (T), lacking any C_{20} PUFAs (-), and unknown (?).

Food type	AA [20:4, w-6]	EPA [20:5, w-3]	Source
Fish food	?	+	Tetra, personal communication
Planothidium lanceolatum [1]	+	+	Caramujo et al. 2008
Bacillus cereus	-	-	Kämpfer 1994
Chlamydomonas reinhardtii	-	-	Kajikawa et al. 200 6
Cryptomonas ovata	+	+	Beach et al. 2006
Daphnia pulicaria [2]	+	+	Brett et al. 2006
Oscillatoria prolifera [3]	-	-	Jahnke et al. 1989
Rotifers [4]	+	+	Kennari et al. 2008
Saccharomyces cerevisiae	T	T	Chakaorty et al. 2007
Spirogyra communis [5]	+	+	Stefanov et al. 1996

1 Listed as the synonymn *Acananthes lanceolatum* . 2 Data are for the closely related *Daphnia pulex* .

3 Data are for the closely related *O. limnetica* . 4 Data are for *Brachionus calyciflorus* . 5 Data are for *Spirogyra crassa* .

Beasley D.A. and W.E. Walton. 2016. Suitability of monotypic and mixed diets for *Anopheles hermsi* larval development. *J. Vector Ecol.* 41: 80–89.

Figure 1.7: Maximum stage of development reached by food type follows a kingdom trend.

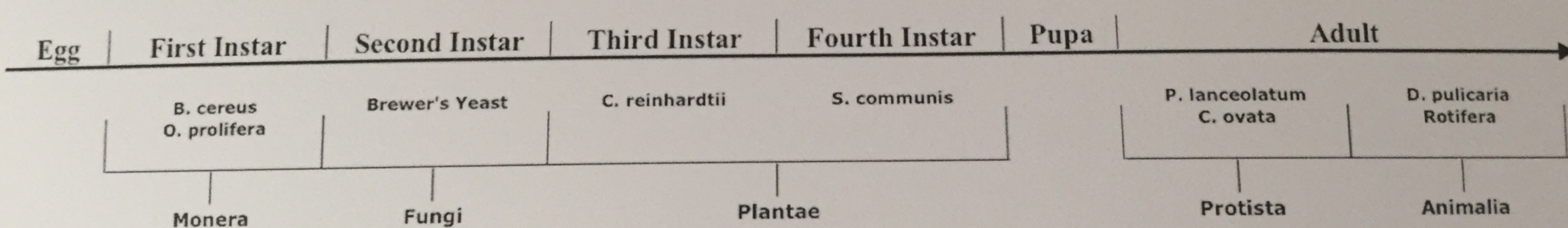
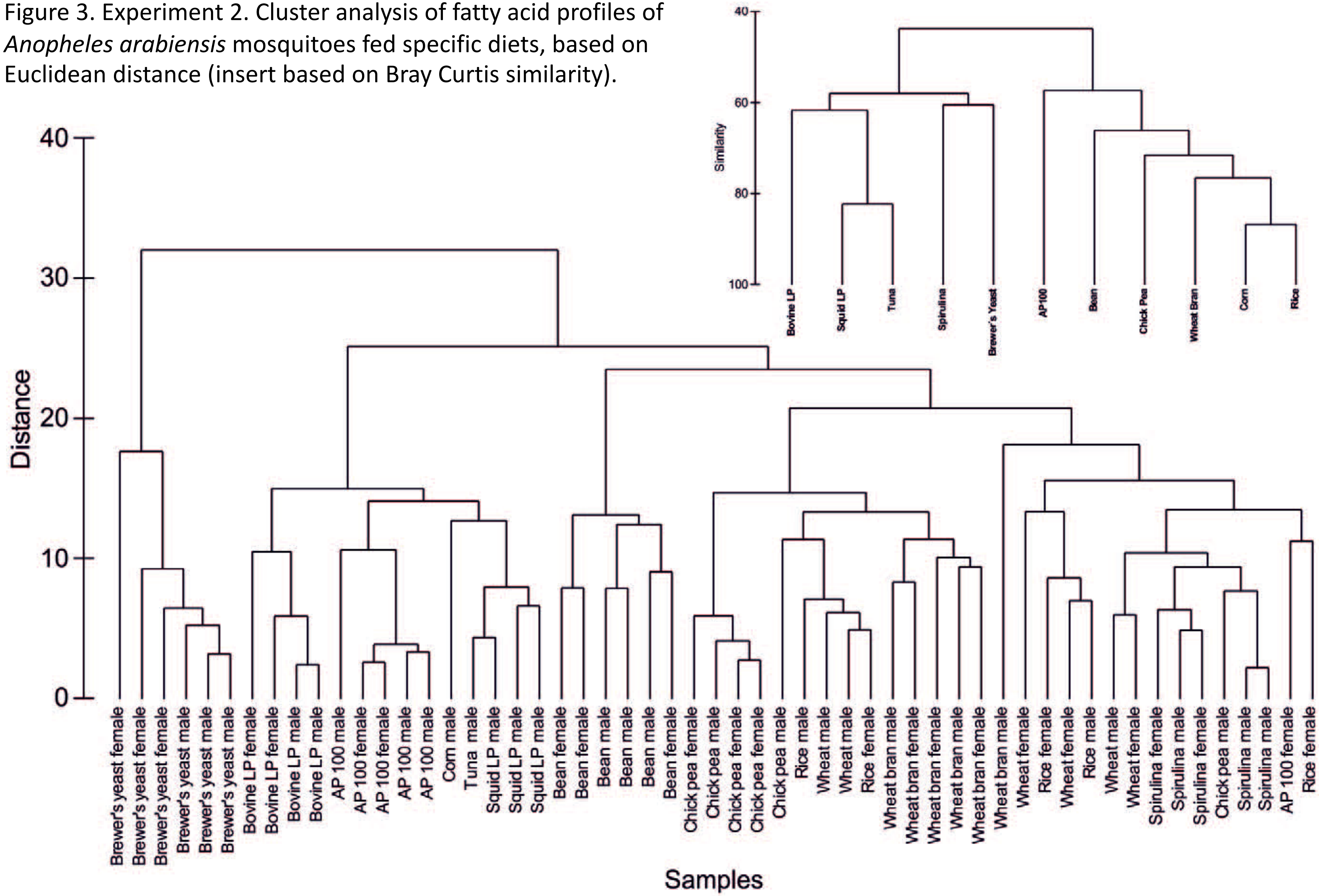


Figure 3. Experiment 2. Cluster analysis of fatty acid profiles of *Anopheles arabiensis* mosquitoes fed specific diets, based on Euclidean distance (insert based on Bray Curtis similarity).



Hood-Nowotny R., Schwarzinger B., Schwarzinger C., Soliban S., Madakacherry O., Aigner M., Watzka M., and J. Gilles. 2012. An Analysis of Diet Quality, How It Controls Fatty Acid Profiles, Isotope Signatures and Stoichiometry in the Malaria Mosquito *Anopheles arabiensis*. *PLoS ONE* 7(10): e45222.

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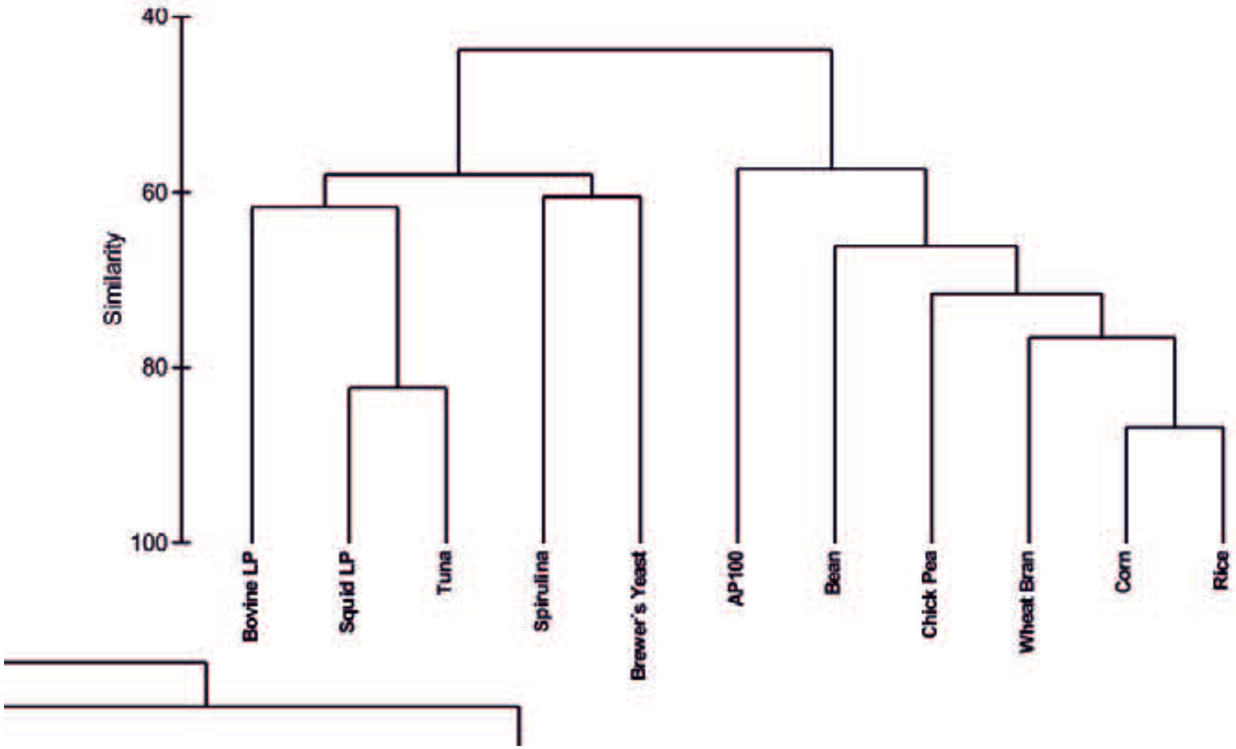
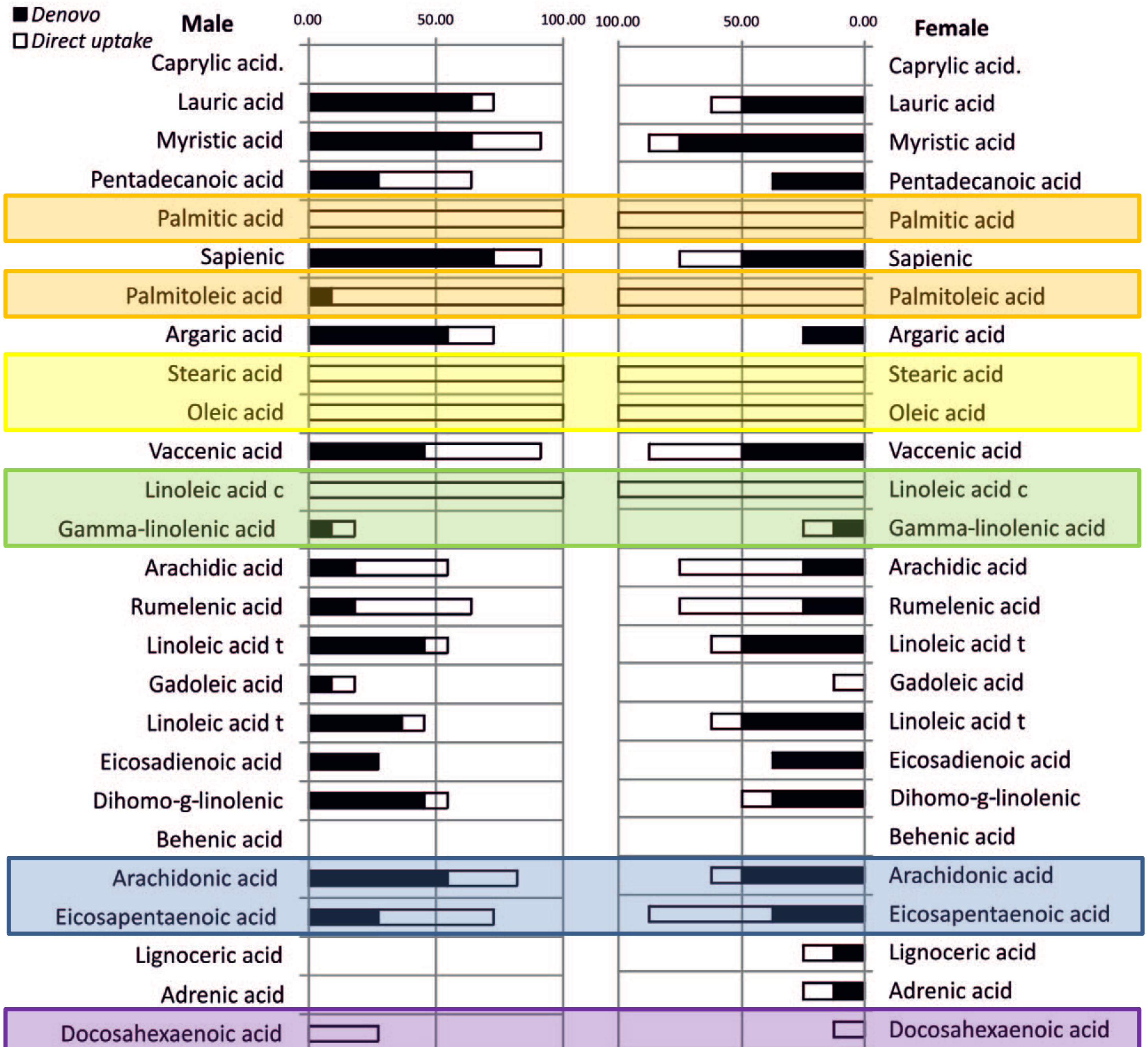
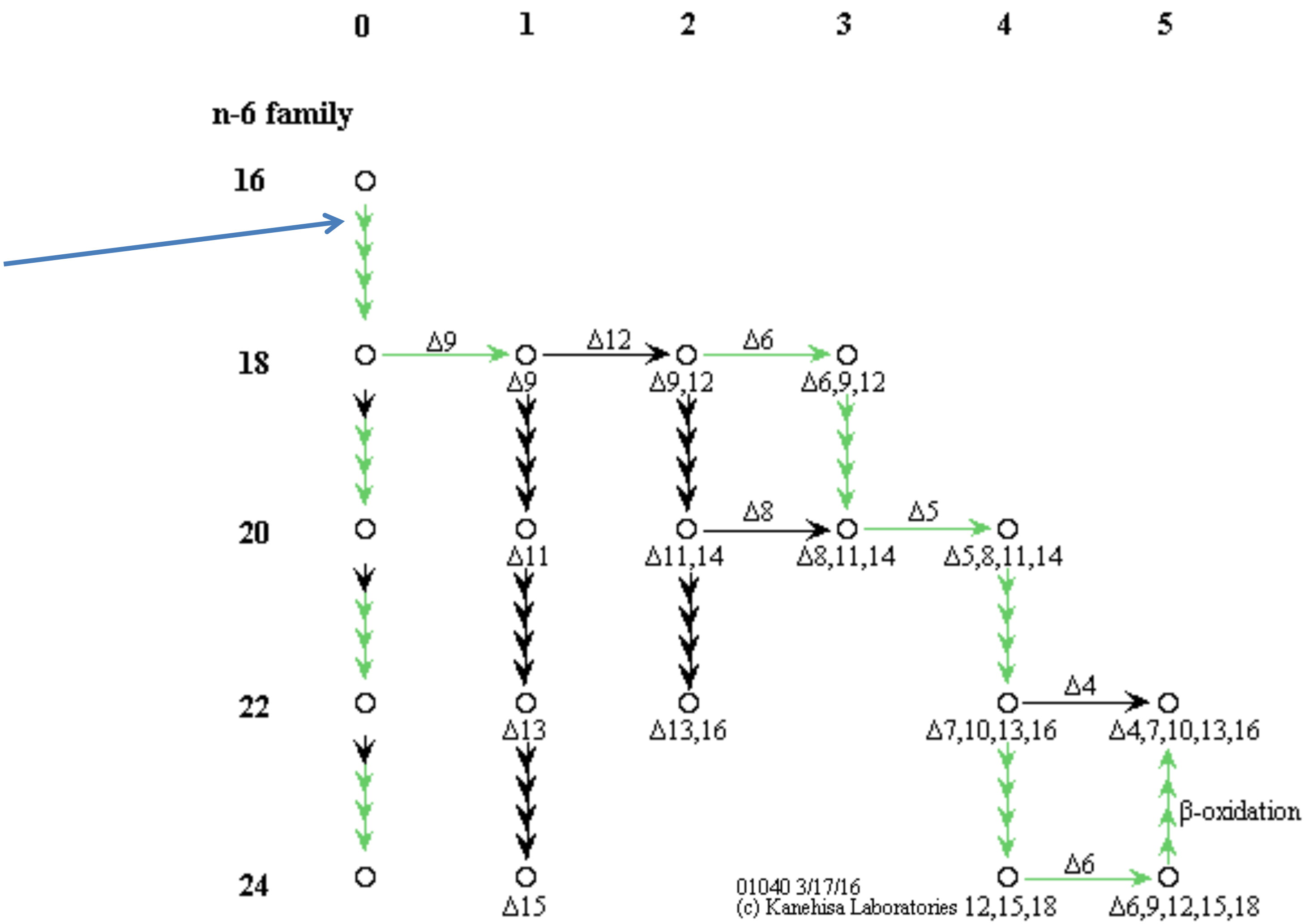


Hood-Nowotny R., Schwarzinger B., Schwarzinger C., Soliban S., Madakacherry O., Aigner M., Watzka M., and J. Gilles. 2012. An Analysis of Diet Quality, How It Controls Fatty Acid Profiles, Isotope Signatures and Stoichiometry in the Malaria Mosquito *Anopheles arabiensis*. *PLoS ONE* 7(10): e45222.

Figure 4. Experiment 2. Graphic showing the occurrence of de-novo synthesis or direct uptake as a percentage of the total population analysed. NB. Any number under 100% indicates the fatty acid was not present in all the *Anopheles arabiensis* mosquitoes analysed.



Homo sapiens Biosynthesis of PUFAs



http://www.genome.jp/kegg-bin/show_pathway?map01040

Entry	79071 CDS T01001
Gene name	ELOVL6, FACE, FAE, LCE
Definition	(RefSeq) ELOVL fatty acid elongase 6 (EC:2.3.1.199)
KO	K10203 elongation of very long chain fatty acids protein 6 [EC:2.3.1.199]
Organism	hsa Homo sapiens (human)
Pathway	hsa00062 Fatty acid elongation hsa01040 Biosynthesis of unsaturated fatty acids hsa01212 Fatty acid metabolism
Module	hsa_M00415 Fatty acid biosynthesis, elongation, endoplasmic reticulum
Brite	KEGG Orthology (KO) [BR:hsa00001] Metabolism Overview 01212 Fatty acid metabolism 79071 (ELOVL6) Lipid metabolism 00062 Fatty acid elongation 79071 (ELOVL6) 01040 Biosynthesis of unsaturated fatty acids 79071 (ELOVL6) Enzymes [BR:hsa01000] 2. Transferases 2.3 Acyltransferases 2.3.1 Transferring groups other than aminoacyl groups 2.3.1.199 very-long-chain 3-oxoacyl-CoA synthase 79071 (ELOVL6) Lipid biosynthesis proteins [BR:hsa01004] Elongase PUFA 79071 (ELOVL6)
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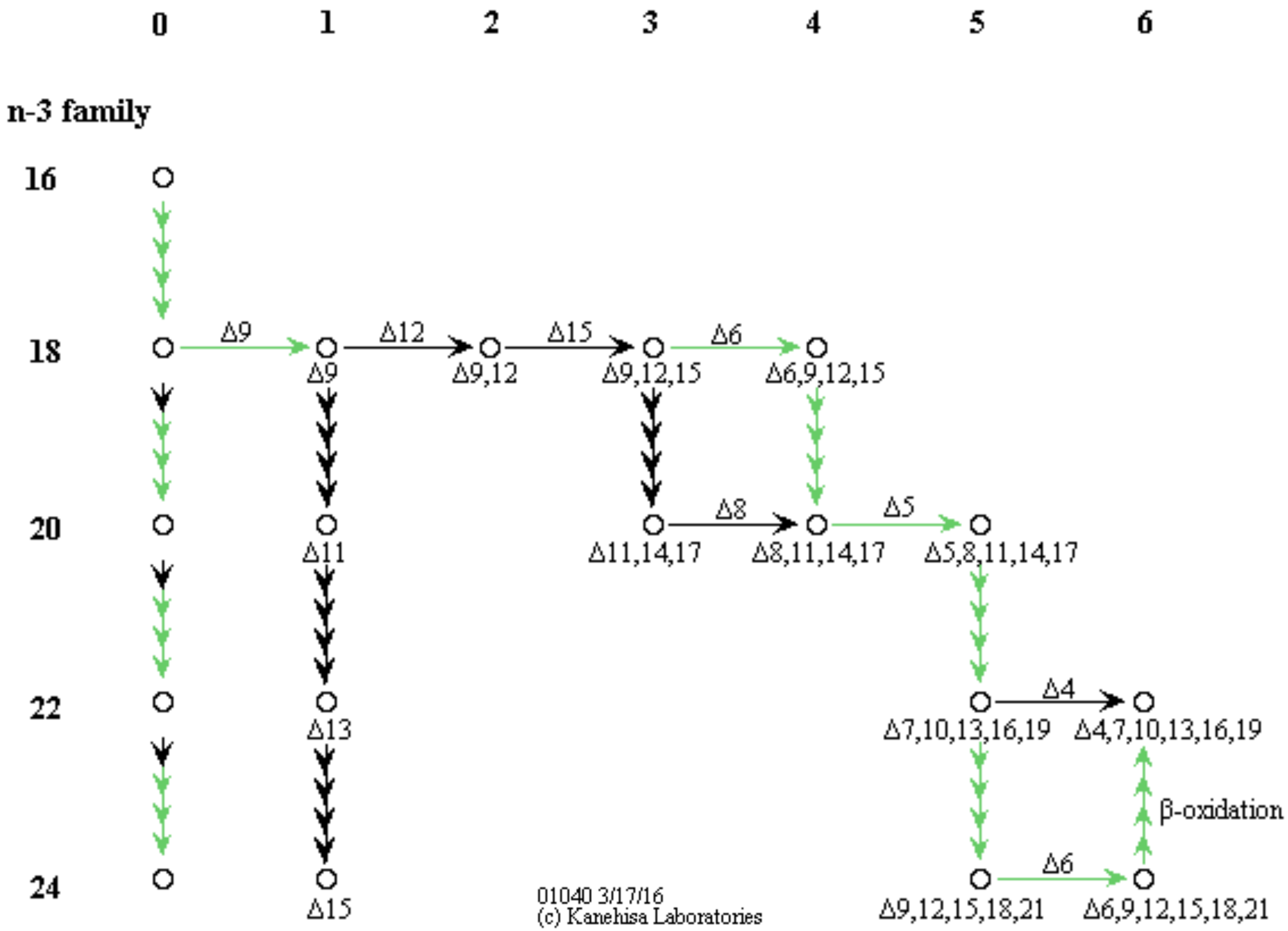
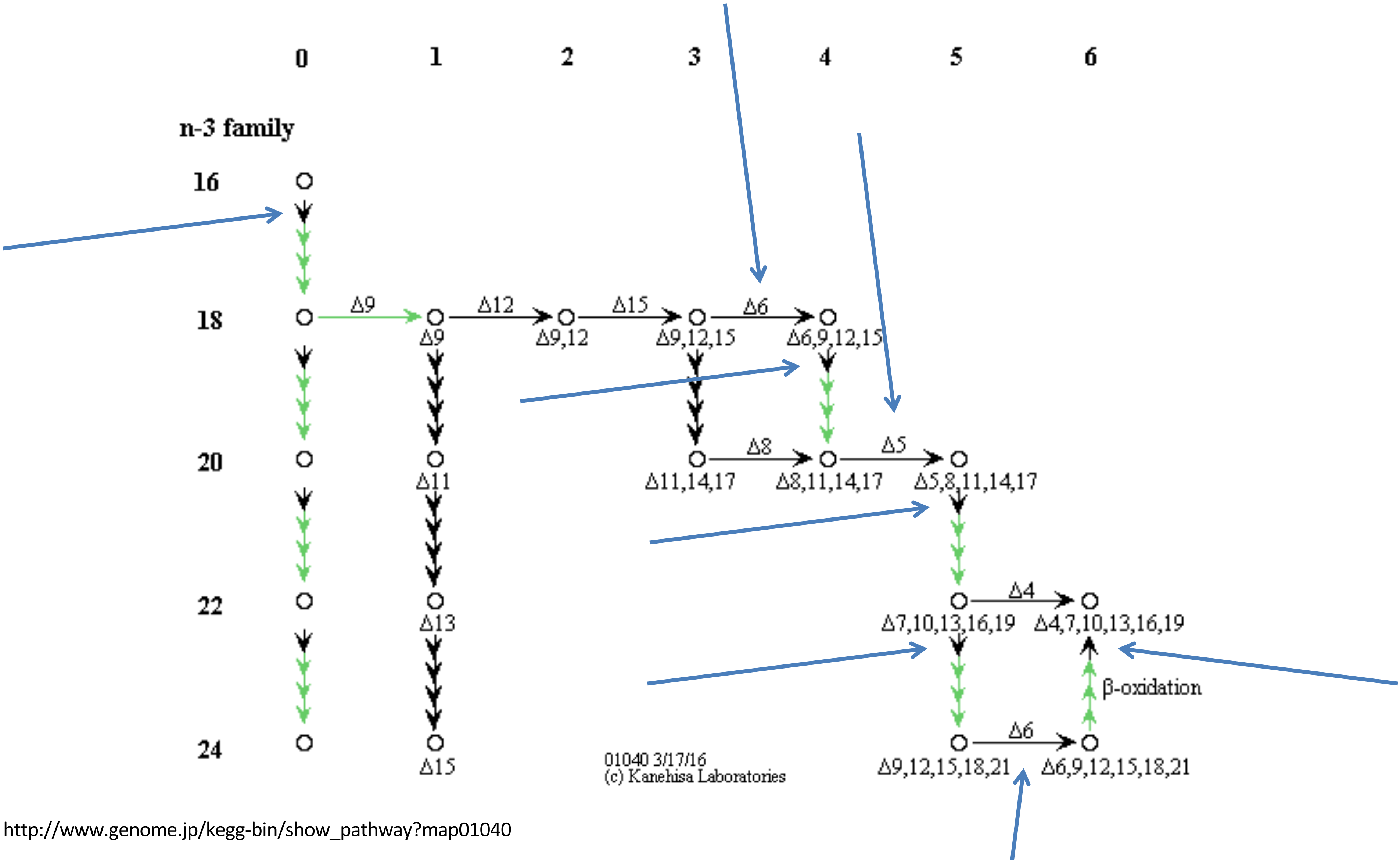
NT seq	798 nt NT seq atgaacatgtcagtgttgactttacaagaatatgaattcgaaaagcagttcaacgagaat gaagccatccaatggatgcaggaaaactggaagaaatctttcctgttttctgctctgtat gctgcctttatattcggtggtcggcacctaatgaataaacgagcaaagtttgaactgagg aagccattagtgctctggtctctgacccttgcagtcttcagtatattcggtgctcttcga actggtgcttatatggtgtacattttgatgaccaaaggcctgaagcagtcagtttgtgac cagggtttttacaatggacctgtcagcaaattctgggcttatgcatttgtgctaagcaaa gcacccgaactaggagatacaatattcattattctgaggaagcagaagctgatcttcctg cactggtatcaccacatcactgtgctcctgtactcttggtactcctacaaagacatggtt gccgggggaggttggttcatgactatgaactatggcgtgcacgccgtgatgtactcttac tatgccttgcgggcggcaggtttccgagtctcccggaagtttgccatgttcatcaccttg tcccagatcactcagatgctgatgggctgtgtggttaactacctggtcttctgctggatg cagcatgaccagtgtcactctcactttcagaacatcttctggtcctcactcatgtacctc agctaccttgtgctcttctgccatttcttctttgaggcctacatcggcaaaatgaggaaa acaacgaaagctgaatag

Homo sapiens Biosynthesis of PUFAs



http://www.genome.jp/kegg-bin/show_pathway?map01040

D. melanogaster Biosynthesis of PUFAs

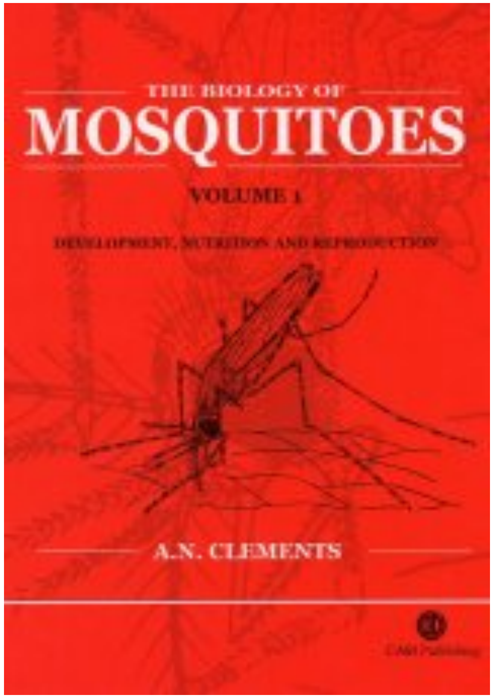


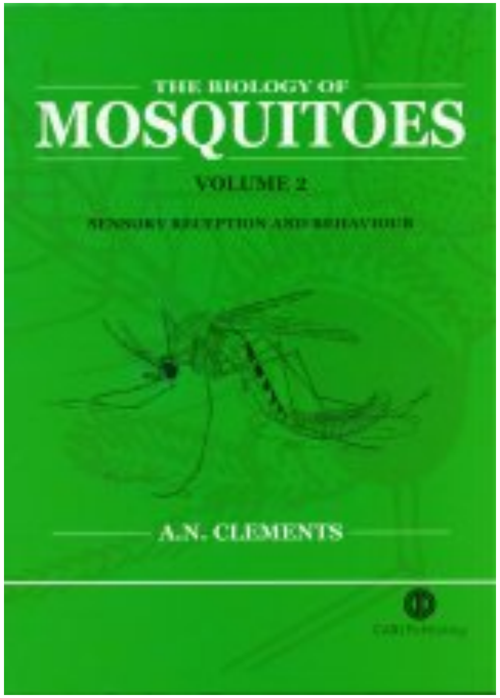
http://www.genome.jp/kegg-bin/show_pathway?map01040

So What?

- In Search of Unique Characteristics

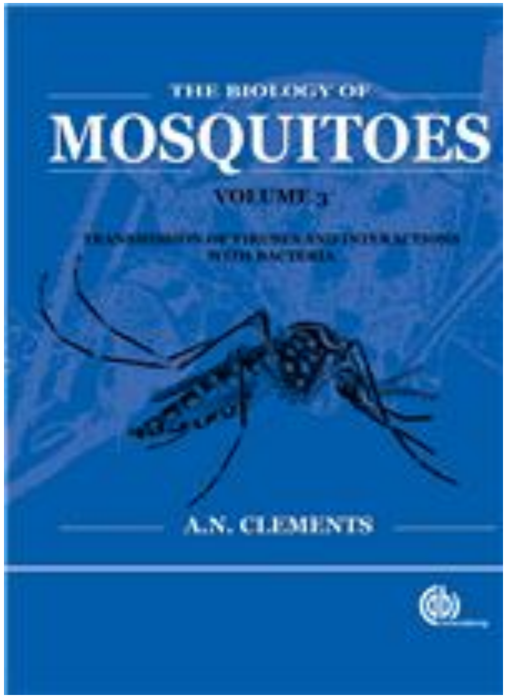
Development, Nutrition
and Reproduction





Sensory Reception and Behaviour.

Transmission of Viruses and
Interactions with Bacteria



Most mosquito larvae are omnivores. Their mixed diet provides the proteins necessary for growth and also the vitamins, nucleotides and sterol that are essential for metabolism and development (Chapter 5). It seems unlikely that any class of food organism has key nutritional importance for culicids unless it is those that provide C_{20} polyunsaturated fatty acids.

Clements, A.N. 2000. The Biology of Mosquitoes, Vol. 1: Development, Nutrition and Reproduction. 2nd ed. CABI Publishing, New York, N.Y.

So What?

- In Search of Unique Characteristics
- Ecology

Direct and Indirect Effects of Animal Detritus on Growth, Survival, and Mass of Invasive Container Mosquito *Aedes albopictus* (Diptera: Culicidae)

DONALD A. YEE[1], **BANUGOPAN KESAVARAJU**, and **STEVEN A. JULIANO**
Department of Biological Sciences, Illinois State University, Normal, IL 61790-4120

Abstract

Compared with plant detritus, animal detritus yields higher growth rates, survival, adult mass, and population growth of container-dwelling mosquitoes. It is unclear whether the benefit from animal detritus to larvae results from greater microorganism growth, direct ingestion of animal detritus by larvae, or some other mechanism. We tested alternative mechanisms by which animal detritus may benefit the invasive container-dwelling mosquito *Aedesalbopictus* (Skuse) (Diptera: Culicidae). In the laboratory, larvae were reared under three conditions with access to 1) detritus, but where microorganisms in the water column were reduced through periodic flushing; 2) water column microorganisms, but larvae had no direct access to detritus; or 3) both water column microorganisms and detritus. Access treatments were conducted for three masses of animal detritus: 0.005, 0.010, and 0.020 g. Water column bacterial productivity (measured via incorporation of [^{3}H]leucine) decreased significantly with flushing and with larval presence. Removing microorganisms through flushing significantly reduced mass of adult mosquitoes (both sexes), and it significantly prolonged developmental times of females compared with treatments where water column microorganisms or microorganisms and detritus were available. Survival to adulthood was greatest when larvae had access to both water column microorganisms and 0.020 g of detritus, but it declined when only water column microorganisms were available or when 0.005 g of detritus was used. These findings indicate both direct (as a food source) and indirect (assisting with decomposition of detritus) roles of microorganisms in producing the benefit of animal detritus to container mosquito larvae.

Yee D.A., Kesavaraju B, and SA Juliano. 2007. Direct and Indirect Effects of Animal Detritus on Growth, Survival, and Mass of Invasive Container Mosquito *Aedes albopictus* (Diptera: Culicidae). *J Med Entomol*. 44(4): 580–588.

So What?

- In Search of Unique Characteristics
- Ecology
- Autogeny

ECOLOGY OF AUTOGENY IN MOSQUITOES

Table 1. Autogenous mosquitoes with piercing mouthparts.[1]

Anopheles	(7)	*Tripteroides*	(2)
Wyeomyia	(2)	*Coquillettidia*	(1)
Uranotaenia	(1)	*Armigeres*	(1)
Opifex	(1)	*Culiseta*	(4)
Culex	(8)	*Deinocerites*	(3)
Aedes	(35)	*Eretmapodites*	(1)

( ) Number of species

[1]Updated from Rioux *et al*. (1975).

O'Meara G.F. 1985. Ecology of Autogeny in Mosquitoes. In: Lounibos L.P., Rey J.R., and J.H. Frank. (eds.) *Ecology of Mosquitoes: Proceedings of a Workshop*. Pp. 459-471. Florida Medical Entomology Laboratory, Vero Beach, FL

So What?

- In Search of Unique Characteristics
- Ecology
- Autogeny
- Eicosanoids

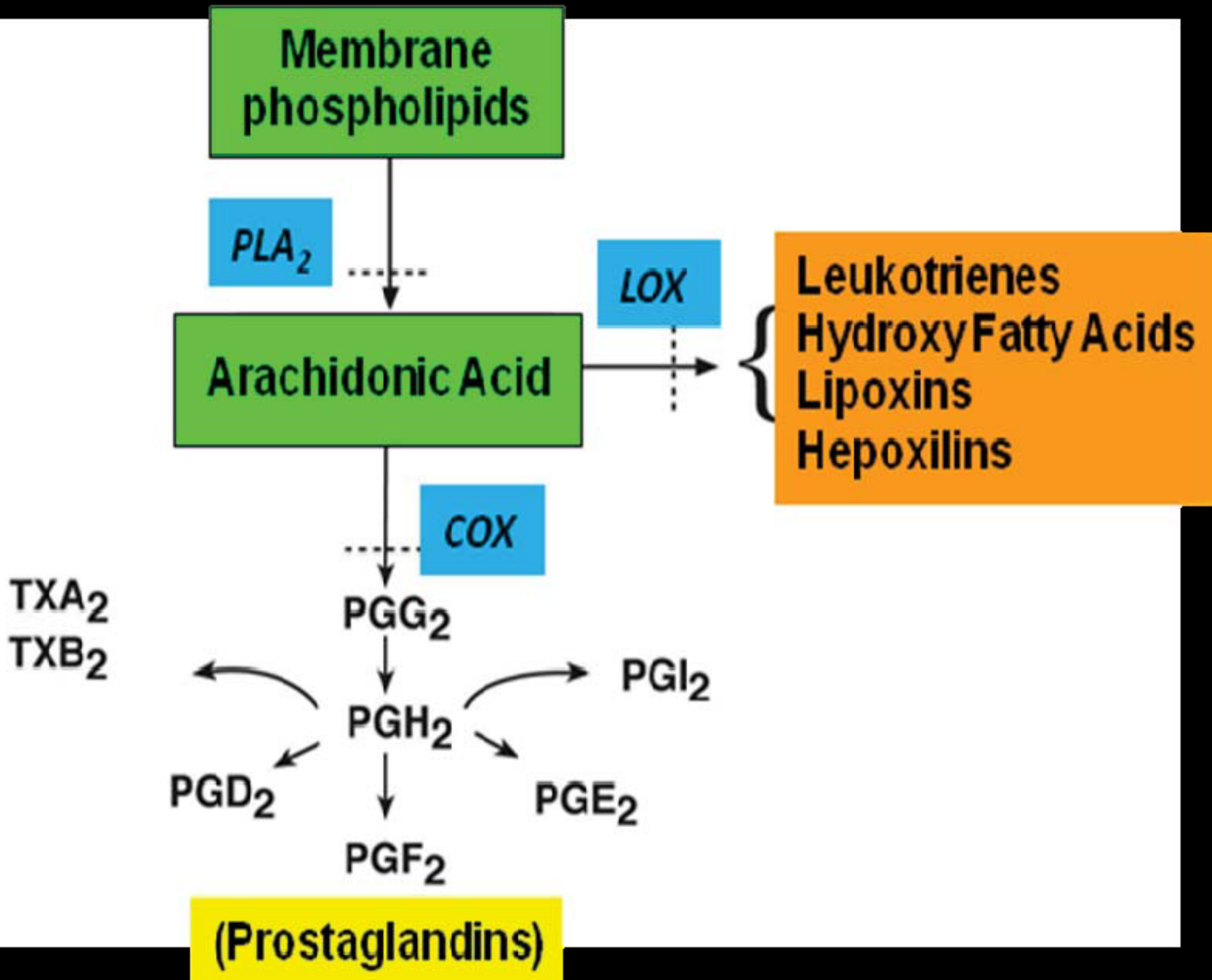

Membrane phospholipids
PLA2
Arachidonic Acid
LOX
Leukotrienes
Hydroxy Fatty Acids
Lipoxins
Hepoxilins
COX
PGG2
TXA2
TXB2
PGI2
PGH2
PGD2
PGE2
PGF2
(Prostaglandins)

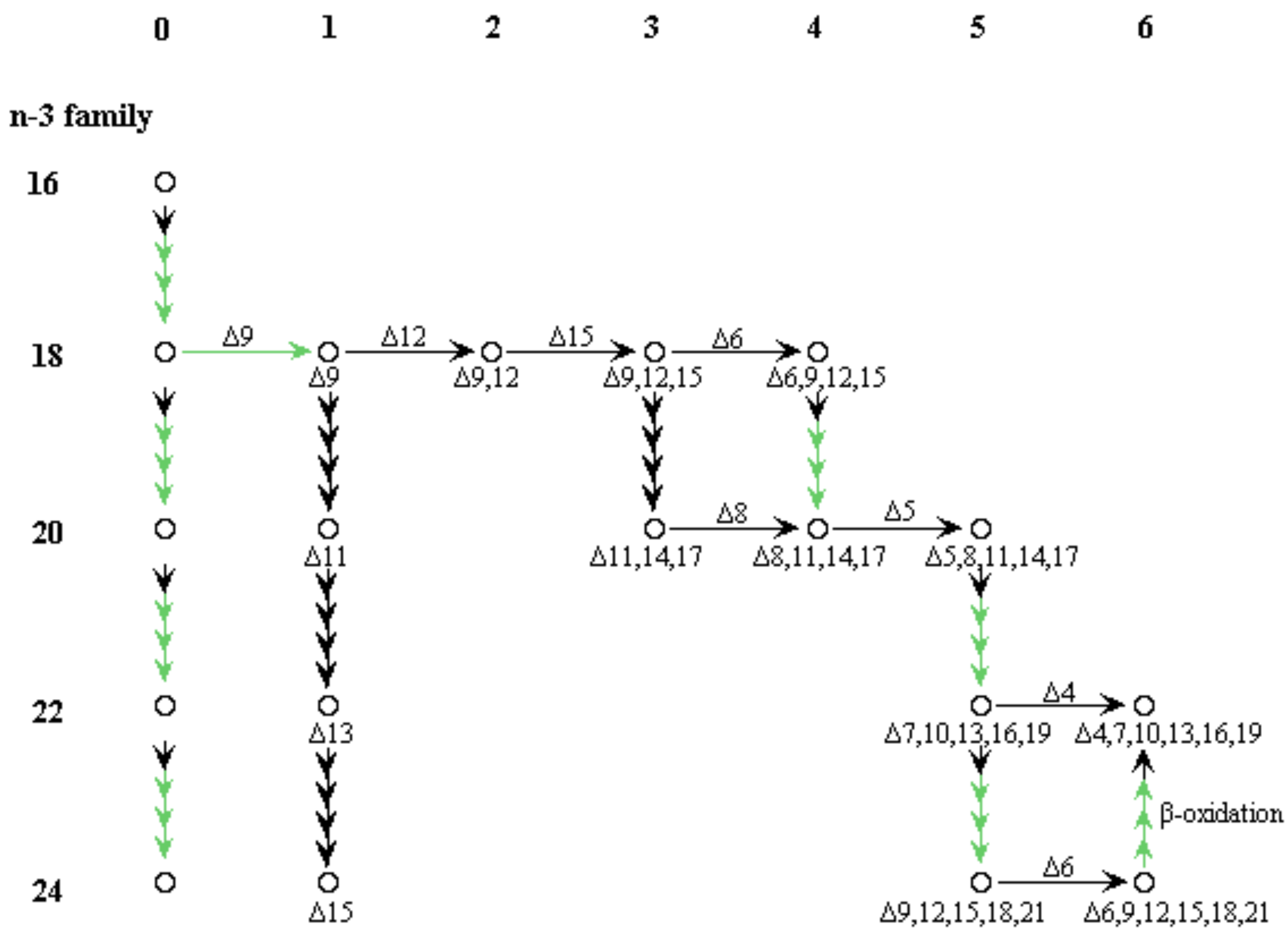
Table 1. Eicosanoids mediate cellular immune reactions to immune challenge in juvenile and adult representatives of seven insect orders.

Species	Life stage	Immune elicitor	Reference
Lepidoptera			
Manduca sexta	larvae	*Serratia marcescens*	[22]
		Beauveria bassiana	[63]
		Metarhizium anisopliae	[58]
Agrotis ipsilon	larvae	*S. marcescens*	[77]
P. unipuncta	larvae	*S. marcescens*	[77]
G. mellonella	larvae	glass beads	[30]
Bombyx mori	larvae	*S. marcescens*	[71]
Colias eurytheme	larvae	*S. marcescens*	[70]
Spodoptera exigua	larvae	*Xenorhabdus nematophila*	[44]
		BAWNPV	[69]
S. frugiperda	larvae	SfNPV	[69]
Ostrinia nubilalis	larvae	*S. marcescens*	[74]
Galleria mellonella	larvae	Virus	[55]
Pieris brassicae	larvae	*B. bassiana*	[72]
Lymantria dispar	larvae	LdMNPV	[68]
Helicoverpa zea	larvae	HzSNPV	[69]
Coleoptera			
Zophobas attraus	larvae	*S. marcesens*	[64]
		Lipopolysaccharide	[54]
Tribolium castaneum	larvae	*E. coli*	[51]
Diptera			
D. melanogaster	larvae	*L. boulardi* eggs	[56]
Neobellieria bullata	larvae	laminarin	[60]
Anopheles albimanus	adult	*Micrococcus luteus*	[61]
		Klebsiella pneumonia	[61]
Chryusomya megacephala	larvae	*Ureaplasma urealyticum*	[76]

Stanley D, Haas E, and J Miller. 2012. Eicosanoids: Exploiting Insect Immunity to Improve Biological Control Programs. *Insects* 3: 492-510.

So What?

- In Search of Unique Characteristics
- Ecology
- Autogeny
- Eicosanoids
- Genome mapping



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n-3 family
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Δ9
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Δ6
Δ9
Δ9,12
Δ9,12,15
Δ6,9,12,15
Δ8
Δ5
Δ11
Δ11,14,17
Δ8,11,14,17
Δ5,8,11,14,17
Δ4
Δ13
Δ7,10,13,16,19
Δ4,7,10,13,16,19
β-oxidation
Δ6
Δ15
Δ9,12,15,18,21
Δ6,9,12,15,18,21

Entry	79071 CDS T01001
Gene name	ELOVL6, FACE, FAE, LCE
Definition	(RefSeq) ELOVL fatty acid elongase 6 (EC:2.3.1.199)
KO	K10203 elongation of very long chain fatty acids protein 6 [EC:2.3.1.199]
Organism	hsa Homo sapiens (human)
Pathway	hsa00062 Fatty acid elongation hsa01040 Biosynthesis of unsaturated fatty acids hsa01212 Fatty acid metabolism
Module	hsa_M00415 Fatty acid biosynthesis, elongation, endoplasmic reticulum
Brite	KEGG Orthology (KO) [BR:hsa00001] Metabolism Overview 01212 Fatty acid metabolism 79071 (ELOVL6) Lipid metabolism 00062 Fatty acid elongation 79071 (ELOVL6) 01040 Biosynthesis of unsaturated fatty acids 79071 (ELOVL6) Enzymes [BR:hsa01000] 2. Transferases 2.3 Acyltransferases 2.3.1 Transferring groups other than aminoacyl groups 2.3.1.199 very-long-chain 3-oxoacyl-CoA synthase 79071 (ELOVL6) Lipid biosynthesis proteins [BR:hsa01004] Elongase PUFA 79071 (ELOVL6)
AA seq	265 aa AA seq DB search MNMSVLTLQEYEFEKQFNENEAIQWMQENWKKSFLFSALYAAFIFGGRHLMNKRAKFELR KPLVLWSLTLAVFSIFGALRTGAYMVYILMTKGLKQSVCDQGFYNGPVSKFWAYAFVLSK APELGDTIFIIILRKQKLIFLHWYHHITVLLYSWYSYKDMVAGGGWFMTMNYGVHAVMYSY YALRAAGFRVSRKFAMFITLSQITQMLMGCVVNYLVFCWMQHDQCHSHFQNIFWSSLMYL SYLVLFCHFFFEAYIGKMRKTTKAE
NT seq	798 nt NT seq atgaacatgtcagtgttgactttacaagaatatgaattcgaaaagcagttcaacgagaat gaagccatccaatggatgcaggaaaactggaagaaatctttcctgttttctgctctgtat gctgcctttatattcggtggtcggcacctaatgaataaacgagcaaagtttgaactgagg aagccattagtgctctggtctctgacccttgcagtcttcagtatattcggtgctcttcga actggtgcttatatggtgtacattttgatgaccaaaggcctgaagcagtcagtttgtgac cagggtttttacaatggacctgtcagcaaattctgggcttatgcatttgtgctaagcaaa gcacccgaactaggagatacaatattcattattctgaggaagcagaagctgatcttcctg cactggtatcaccacatcactgtgctcctgtactcttggtactcctacaaagacatggtt gccgggggaggttggttcatgactatgaactatggcgtgcacgccgtgatgtactcttac tatgccttgcgggcggcaggtttccgagtctcccggaagtttgccatgttcatcaccttg tcccagatcactcagatgctgatgggctgtgtggttaactacctggtcttctgctggatg cagcatgaccagtgtcactctcactttcagaacatcttctggtcctcactcatgtacctc agctaccttgtgctcttctgccatttcttctttgaggcctacatcggcaaaatgaggaaa acaacgaaagctgaatag

So What?

- In Search of Unique Characteristics
- Ecology
- Autogeny
- Eicosanoids
- Genome mapping
- Chemical Ecology

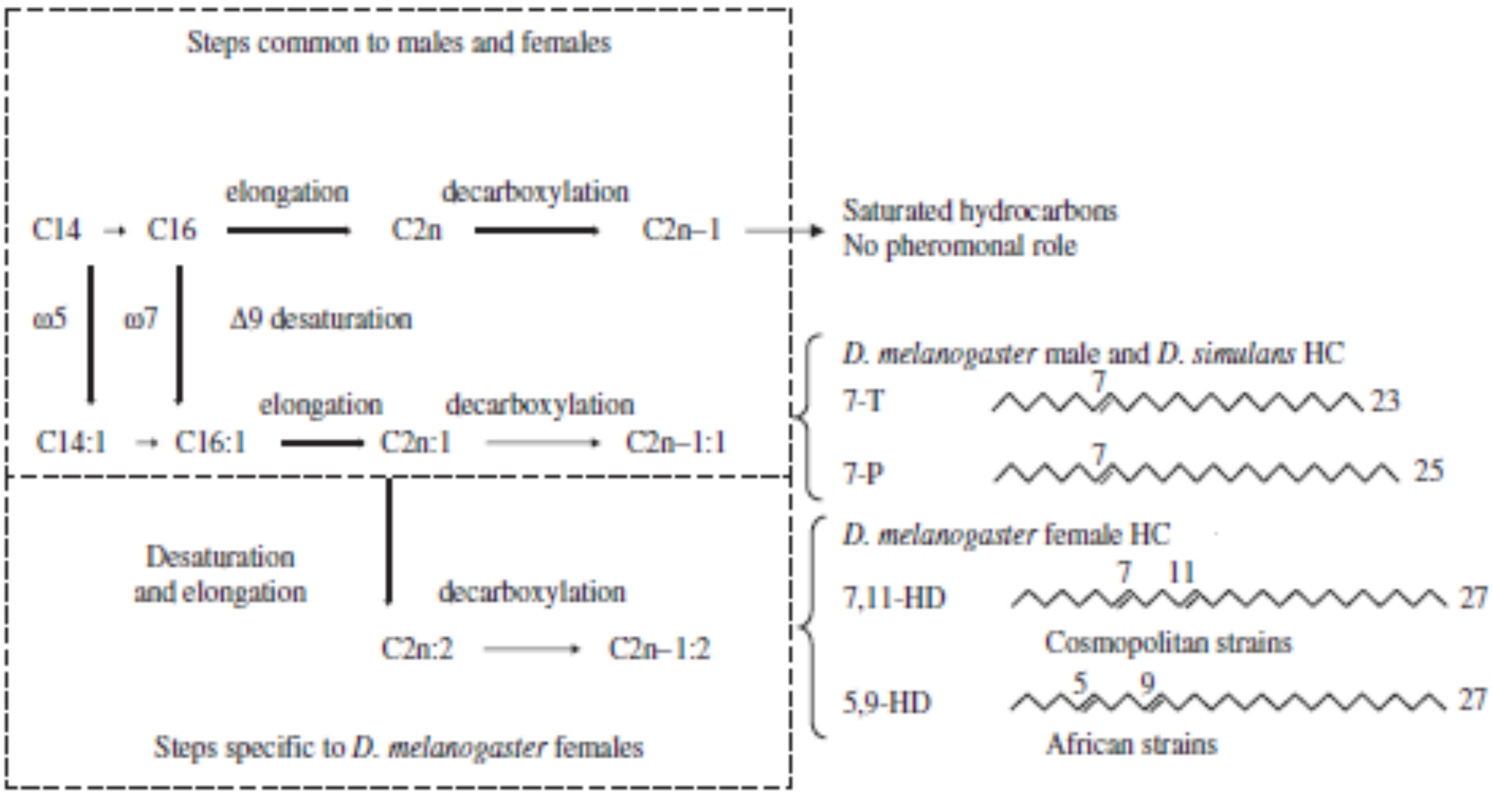


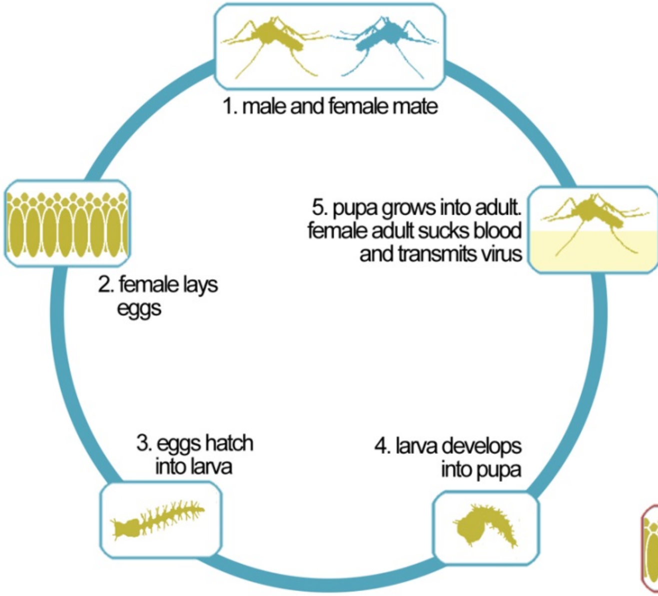
Fig. 1. Biosynthesis and main cuticular hydrocarbons (HC) in *D. simulans* and *D. melanogaster*. The desaturation of palmitic acid is performed by Desat1 and leads to ω7 fatty acids and HC insaturated in position 7. Desat2, expressed in 5,9-morph females, acts on myristic acid and leads to ω5 fatty acids. The steps specific to *D. melanogaster* females involve a female-specific desaturase (DesatF) and elongase (EloF).

Legendre A., Miaoa X-X, Da Lageb J-L, and C Wicker-Thomas. 2008. Evolution of a desaturase involved in female pheromonal cuticular hydrocarbon biosynthesis and courtship behavior in *Drosophila*. *Insect Biochemistry and Molecular Biology.* 38: 244–255.

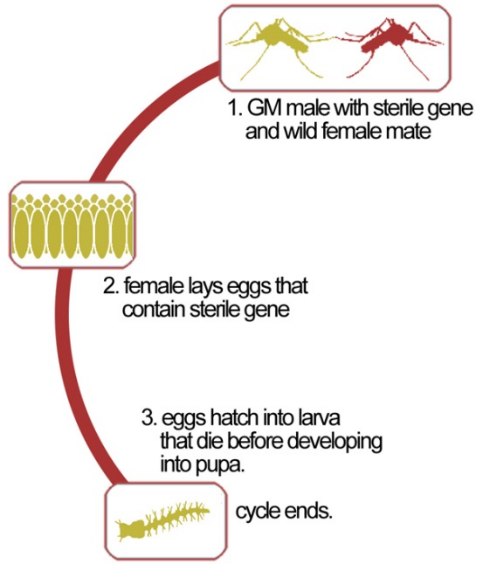
So What?

- In Search of Unique Characteristic
- Ecology
- Autogeny
- Eicosanoids
- Genome mapping
- Chemical Ecology
- Lab Rearing

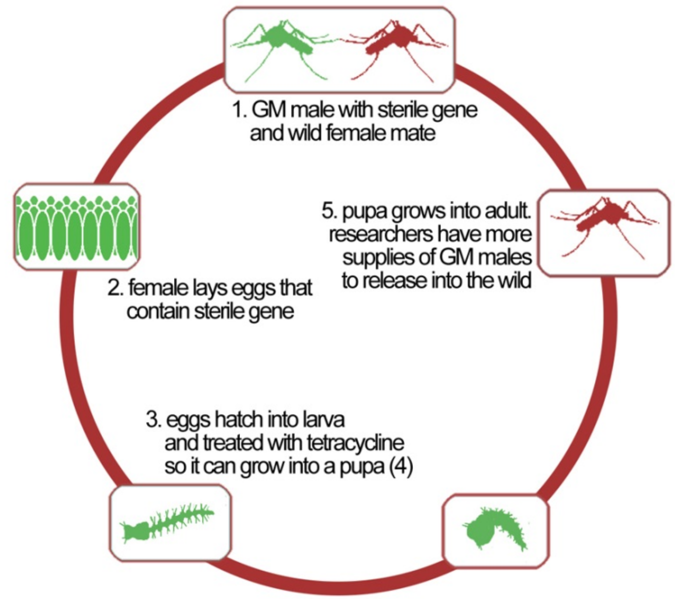
How GM mosquitoes work



Life cycle of wild male and female mosquitoes produces blood-sucking females



Introduction of GM males breaks this cycle as faulty gene causes offspring to prematurely die



More GM males are created in the lab by adding tetracylcine to larvae to allow development

https://oneinsevenpeople.wordpress.com/2011/11/08/gm-mosquitoes-buzz-off/#more-101

Questions