

Gene model for the ortholog of *eIF4E1* in *Drosophila ananassae*

McKenzie Chamberlain¹, Ali Christie², Jeremy Girard³, Hannah M. Shaver², Lindsey J. Long², James J. Youngblom³, Chinmay P. Rele¹, Laura K Reed^{1§}

¹University of Alabama, Tuscaloosa, Alabama, United States

²Oklahoma Christian University, Edmond, Oklahoma, United States

³California State University, Stanislaus, Turlock, California, United States

[§]To whom correspondence should be addressed: lreed1@ua.edu

Abstract

Gene model for the ortholog of eukaryotic translation initiation factor 4E1 (*eIF4E1*) in the May 2011 (Agencourt dana_caf1/DanaCAF1) Genome Assembly (GenBank Accession: [GCA_000005115.1](https://www.ncbi.nlm.nih.gov/nuccore/GCA_000005115.1)) of *Drosophila ananassae*. This ortholog was characterized as part of a developing dataset to study the evolution of the Insulin/insulin-like growth factor signaling pathway (IIS) across the genus *Drosophila* using the Genomics Education Partnership gene annotation protocol for Course-based Undergraduate Research Experiences.

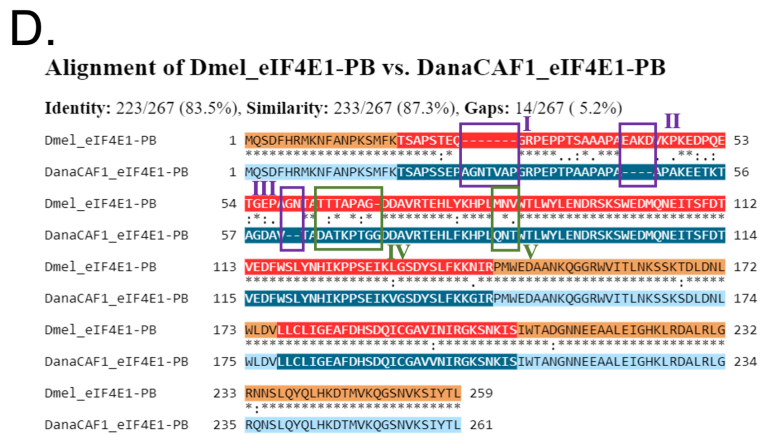
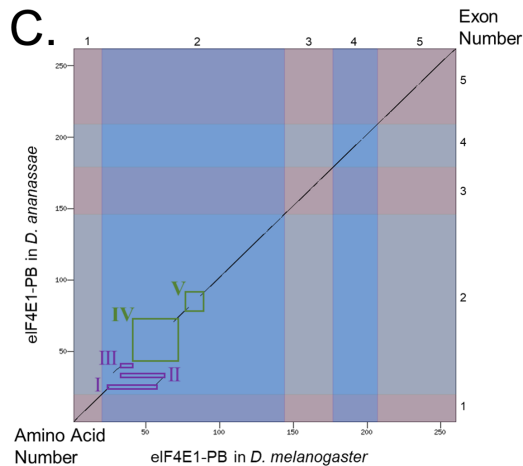
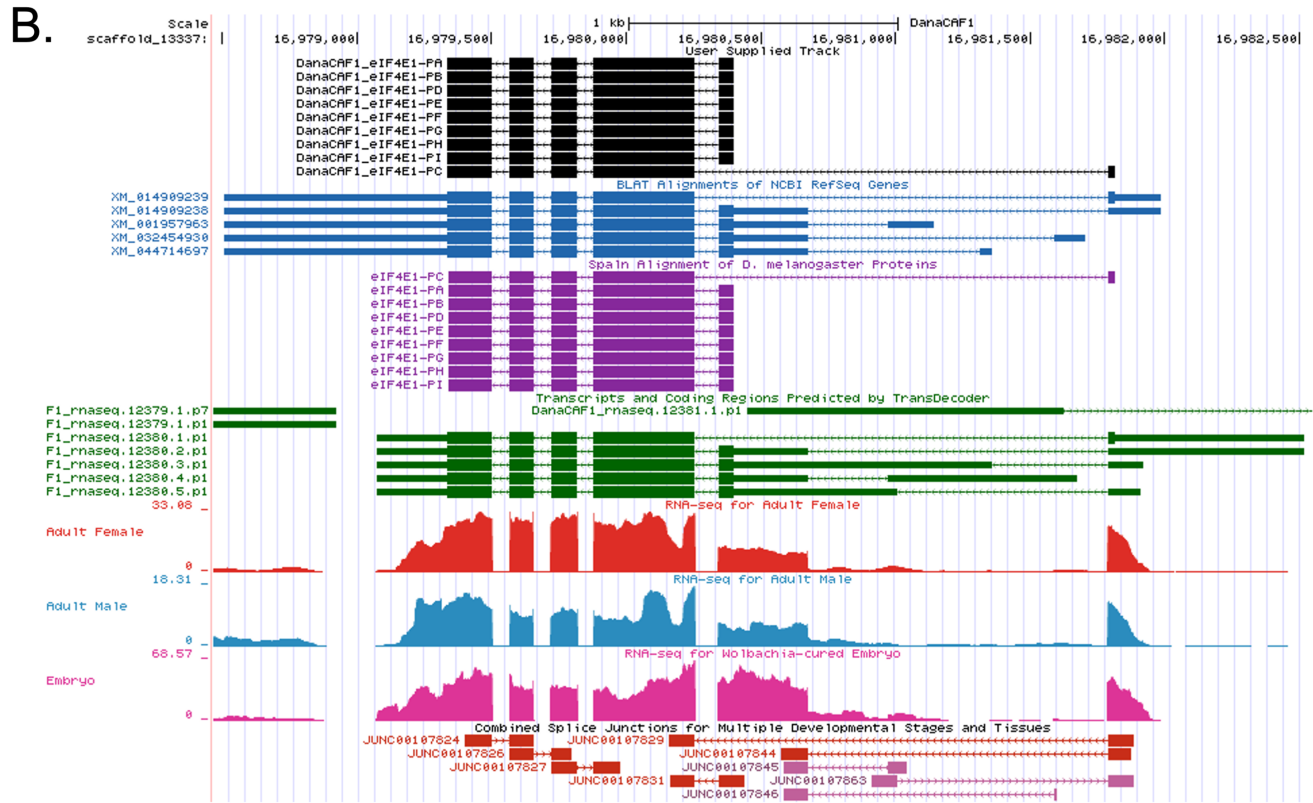
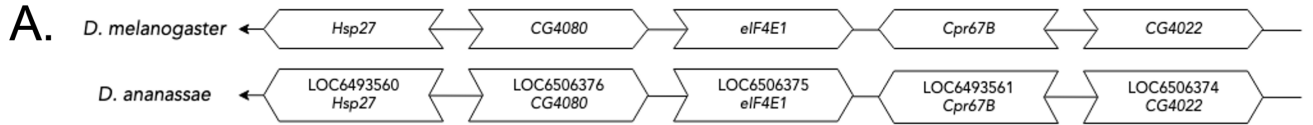


Figure 1. Genomic neighborhood and gene model for *eIF4E1* in *Drosophila ananassae*:

(A) Synteny comparison of the genomic neighborhoods for *eIF4E1* in *Drosophila melanogaster* and *D. ananassae*. Thin underlying arrows indicate the DNA strand within which the gene-*eIF4E1*-is located in *D. melanogaster* (top) and *D. ananassae* (bottom) genomes. Thin arrows pointing to the left indicate that *eIF4E1* is on the negative (-) strand in *D. ananassae* and *D. melanogaster*. The wide gene arrows pointing in the same direction as *eIF4E1* are on the same strand relative to the thin underlying arrows, while wide gene arrows pointing in the opposite direction of *eIF4E1* are on the opposite strand relative to the thin underlying arrows. White gene arrows in *D. ananassae* indicate orthology to the corresponding gene in *D. melanogaster*. Gene symbols given in the *D. ananassae* gene arrows indicate the orthologous gene in *D. melanogaster*, while the locus identifiers are specific to *D. ananassae*. **(B) Gene Model in GEP UCSC Track Data Hub (Raney et al.,**

2014). The coding-regions of *eIF4E1* in *D. ananassae* are displayed in the User Supplied Track (black); coding CDSs are depicted by thick rectangles and introns by thin lines with arrows indicating the direction of transcription. Subsequent evidence tracks include BLAT Alignments of NCBI RefSeq Genes (dark blue, alignment of Ref-Seq genes for *D. ananassae*), Spaln of *D. melanogaster* Proteins (purple, alignment of Ref-Seq proteins from *D. melanogaster*), Transcripts and Coding Regions Predicted by TransDecoder (dark green), RNA-Seq from Adult Females, Adult Males and Embryos (red, light blue, and dark pink, respectively; alignment of Illumina RNA-Seq reads from *D. ananassae*), and Splice Junctions Predicted by regtools using *D. ananassae* RNA-Seq (SRP006203; SRP007906). Splice junctions shown have a minimum read-depth of 10 with 100-499 and >1000 supporting reads in light pink and red, respectively. **(C) Dot Plot of *eIF4E1-RB* in *D. melanogaster* (x-axis) vs. the orthologous peptide in *D. ananassae* (y-axis).** Amino acid number is indicated along the left and bottom; coding-CDS number is indicated along the top and right, and CDSs are also highlighted with alternating colors. The purple boxes labeled I, II, and III contain regions where an insertion or deletion of base pairs has occurred. The green boxes labeled IV and V outline regions that have a lack of sequence similarity between *eIF4E1-RB* in *D. melanogaster* and *eIF4E1-RB* in *D. ananassae*. **(D) The protein alignment between *D. melanogaster* *eIF4E1-PB* and its putative ortholog in *D. ananassae*.** The alternating colored rectangles represent adjacent CDSs. The symbols in the match line denote the level of similarity between the aligned residues. An asterisk (*) indicates that the aligned residues are identical. A colon (:) indicates the aligned residues have highly similar chemical properties—roughly equivalent to scoring > 0.5 in the Gonnet PAM 250 matrix (Gonnet et al., 1992). A period (.) indicates that the aligned residues have weakly similar chemical properties—roughly equivalent to scoring > 0 and ≤ 0.5 in the Gonnet PAM 250 matrix. A space indicates a gap or mismatch when the aligned residues have a complete lack of similarity—roughly equivalent to scoring ≤ 0 in the Gonnet PAM 250 matrix. The purple boxes labeled I, II and III outline regions where an insertion or deletion of base pairs has occurred. The green boxes labeled IV and V outline regions where there is a lack of sequence similarity between *eIF4E1-PB* in *D. melanogaster* and *eIF4E1-PB* in *D. ananassae*.

Description

This article reports a predicted gene model generated by undergraduate work using a structured gene model annotation protocol defined by the Genomics Education Partnership (GEP; thegep.org) for Course-based Undergraduate Research Experience (CURE). The following information may be repeated in other articles submitted by participants using the same GEP CURE protocol for annotating Drosophila species orthologs of Drosophila melanogaster genes in the insulin signaling pathway.

"In this GEP CURE protocol students use web-based tools to manually annotate genes in non-model *Drosophila* species based on orthology to genes in the well-annotated model organism fruitfly *Drosophila melanogaster*. The GEP uses web-based tools to allow undergraduates to participate in course-based research by generating manual annotations of genes in non-model species (Rele et al., 2023). Computational-based gene predictions in any organism are often improved by careful manual annotation and curation, allowing for more accurate analyses of gene and genome evolution (Mudge and Harrow 2016; Tello-Ruiz et al., 2019). These models of orthologous genes across species, such as the one presented here, then provide a reliable basis for further evolutionary genomic analyses when made available to the scientific community." (Myers et al., 2024).

"The particular gene ortholog described here was characterized as part of a developing dataset to study the evolution of the Insulin/insulin-like growth factor signaling pathway (IIS) across the genus *Drosophila*. The Insulin/insulin-like growth factor signaling pathway (IIS) is a highly conserved signaling pathway in animals and is central to mediating organismal responses to nutrients (Hietakangas and Cohen 2009; Grewal 2009)." (Myers et al., 2024).

"*eukaryotic translation initiation factor 4E1* ([eIF4E1](#)) encodes eIF4F cap-binding complex essential cap-dependent translation of mRNA, and binds the 7-methyl-guanosine cap structure of mRNA in *Drosophila* (Lachance et al., 2002; Lavoie et al., 1996). The protein product of *eIF4E-3*, a paralog of [eIF4E1](#), is specifically required during spermatogenesis in *Drosophila* (Hernandez et al., 2012)." (Lose et al., 2025).

"*D. ananassae* (NCBI:txid7217) is part of the *melanogaster* species group within the subgenus *Sophophora* of the genus *Drosophila* (Sturtevant 1939; Bock and Wheeler 1972). It was first described by Doleschall (1858). *D. ananassae* is circumtropical (Markow and O'Grady 2005; <https://www.taxodros.uzh.ch>, accessed 1 Feb 2023), and often associated with human settlement (Singh 2010). It has been extensively studied as a model for its cytogenetic and genetic characteristics, and in experimental evolution (Kikkawa 1938; Singh and Yadav 2015)." (Lawson et al., 2024).

We propose a gene model for the *D. ananassae* ortholog of the *D. melanogaster* *eukaryotic translation initiation factor 4E1* ([eIF4E1](#)) gene. The genomic region of the ortholog corresponds to the uncharacterized protein [LOC6506375](#) (RefSeq

accession [LOC6506375](#)) in the Dana_CAF1 Genome Assembly of *D. ananassae* (GenBank Accession: [GCA_000005115.1](#); Drosophila 12 Genomes Consortium et al., 2007). This model is based on RNA-Seq data from *D. ananassae* ([SRP006203](#); [SRP007906](#) - Graveley et al., 2010) and [eIF4E1](#) in *D. melanogaster* using FlyBase release FB2022_04 ([GCA_000001215.4](#); Larkin et al., 2021; Gramates et al., 2022; Jenkins et al., 2022).

Synteny

The reference gene, [eIF4E1](#), occurs on chromosome 3L in *D. melanogaster* and is flanked upstream by [CG4022](#) and *Cuticular protein 67B* ([Cpr67B](#)) and downstream by [CG4080](#) and *Heat shock protein 23* ([Hsp23](#)). The *tblastn* search of *D. melanogaster* eIF4E1-PB (query) against the *D. ananassae* (GenBank Accession: [GCA_000005115.1](#)) Genome Assembly (database) placed the putative ortholog of [eIF4E1](#) within scaffold scaffold_13337 ([CH902618.1](#)) at locus [LOC6506375](#) ([XP_014764725.1](#)) — with an E-value of 8e-131 and a percent identity of 80.80%. Furthermore, the putative ortholog is flanked upstream by [LOC6506374](#) ([XP_001958001.1](#)) and [LOC6493561](#) ([XP_001958000.1](#)), which correspond to [CG4022](#) and [Cpr67B](#) in *D. melanogaster* (E-value: 6e-118 and 1e-168; identity: 88.17% and 97.31%, respectively, as determined by *blastp*) (Figure 1A, Altschul et al., 1990). The putative ortholog of [eIF4E1](#) is flanked downstream by [LOC6506376](#) ([XP_001957998.1](#)) and [LOC6493560](#) ([XP_001957997.1](#)), which correspond to [CG4080](#) and [Hsp23](#) in *D. melanogaster* (E-value: 0.0 and 2e-103; identity: 87.56% and 83.08%, respectively, as determined by *blastp*). The putative ortholog assignment for [eIF4E1](#) in *D. ananassae* is supported by the following evidence: The genes surrounding the [eIF4E1](#) ortholog are orthologous to the genes at the same locus in *D. melanogaster* and synteny is completely conserved, supported by results generated from *blastp*, so we conclude that [LOC6506375](#) is the correct ortholog of [eIF4E1](#) in *D. ananassae* (Figure 1A).

Protein Model

[eIF4E1](#) in *D. ananassae* contains two unique protein-coding isoforms: eIF4E1-PB (identical to eIF4E1-PA, eIF4E1-PD, eIF4E1-PE, eIF4E1-PF, eIF4E1-PG, eIF4E1-PH, eIF4E1-PI) and eIF4E1-PC (Figure 1B). mRNA isoforms ([eIF4E1-RB](#), [eIF4E1-RA](#), [eIF4E1-RD](#), [eIF4E1-RE](#), [eIF4E1-RF](#), [eIF4E1-RG](#), [eIF4E1-RH](#), [eIF4E1-RI](#)) contain five CDSs but differ in their UTRs. [eIF4E1-RC](#) differs from the other isoforms only in the first CDS. The remaining protein-coding isoforms are identical. Relative to the ortholog in *D. melanogaster*, the RNA CDS number and the protein isoform count are conserved. The sequence of eIF4E1-PB in *D. ananassae* has 80.80% identity (E-value: 8e-131) with the protein-coding isoform eIF4E1-PB in *D. melanogaster*, as determined by *blastp* (Figure 1C). Three indels were found within the second CDS of *D. ananassae*, outlined in boxes purple labeled I, II, and III (Figure 1C, 1D). Two regions containing a lack of sequence similarity were found between eIF4E1-PB in *D. ananassae* and *D. melanogaster*, outlined in green boxes labeled IV and V (Figure 1C, 1D). Coordinates of this curated gene model (eIF4E1-PE, eIF4E1-PF, eIF4E1-PH, eIF4E1-PA, eIF4E1-PG, eIF4E1-PI, eIF4E1-PD, eIF4E1-PB, eIF4E1-PC) are stored by NCBI at GenBank/BankIt (accessions [BK064567](#), [BK064568](#), [BK064569](#), [BK064570](#), [BK064571](#), [BK064572](#), [BK064573](#), [BK064574](#), and [BK064575](#), respectively). These data are also archived in the CaltechDATA repository (see “Extended Data” section below).

Special characteristics of the protein model

Three indels within CDS two, found in isoform [eIF4E1-RB](#), are shown in the dot plot and protein alignment outlined by the purple boxes labeled I, II, and III (Figure 1C and 1D). The first indel (I) consists of seven amino acids and is an insertion in *D. ananassae* and relative to *D. melanogaster*. The second (II) consists of four amino acids while the third (III) consists of two amino acids. Both (II and III) show deletions in *D. ananassae* relative to *D. melanogaster*.

Methods

Detailed methods including algorithms, database versions, and citations for the complete annotation process can be found in Rele et al. (2023). Briefly, students use the GEP instance of the UCSC Genome Browser v.435 (<https://gander.wustl.edu>; Kent WJ et al., 2002; Navarro Gonzalez et al., 2021) to examine the genomic neighborhood of their reference IIS gene in the *D. melanogaster* genome assembly (Aug. 2014; BDGP Release 6 + ISO1 MT/dm6). Students then retrieve the protein sequence for the *D. melanogaster* reference gene for a given isoform and run it using *tblastn* against their target *Drosophila* species genome assembly on the NCBI BLAST server (<https://blast.ncbi.nlm.nih.gov/Blast.cgi>; Altschul et al., 1990) to identify potential orthologs. To validate the potential ortholog, students compare the local genomic neighborhood of their potential ortholog with the genomic neighborhood of their reference gene in *D. melanogaster*. This local synteny analysis includes at minimum the two upstream and downstream genes relative to their putative ortholog. They also explore other sets of genomic evidence using multiple alignment tracks in the Genome Browser, including BLAT alignments of RefSeq Genes, Spaln alignment of *D. melanogaster* proteins, multiple gene prediction tracks (e.g., GeMoMa, Geneid, Augustus), and modENCODE RNA-Seq from the target species. Detailed explanation of how these lines of genomic evidenced are leveraged by students in gene model development are described in Rele et al. (2023). Genomic structure information (e.g., CDSs, intron-exon number and boundaries, number of isoforms) for the *D. melanogaster* reference gene is retrieved through the Gene Record Finder

(<https://gander.wustl.edu/~wilson/dmelgenerecord/index.html>; Rele et al., 2023). Approximate splice sites within the target gene are determined using *tblastn* using the CDSs from the *D. melanogaster* reference gene. Coordinates of CDSs are then refined by examining aligned modENCODE RNA-Seq data, and by applying paradigms of molecular biology such as identifying canonical splice site sequences and ensuring the maintenance of an open reading frame across hypothesized splice sites. Students then confirm the biological validity of their target gene model using the Gene Model Checker (<https://gander.wustl.edu/~wilson/dmelgenerecord/index.html>; Rele et al., 2023), which compares the structure and translated sequence from their hypothesized target gene model against the *D. melanogaster* reference gene model. At least two independent models for a gene are generated by students under mentorship of their faculty course instructors. Those models are then reconciled by a third independent researcher mentored by the project leaders to produce the final model. Note: comparison of 5' and 3' UTR sequence information is not included in this GEP CURE protocol.

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Extended Data

Description: A GFF, FASTA, and PEP of the model. Resource Type: Model. File: [DanaCAF1 eIF4E1.zip](#). DOI: [10.22002/shrpz-9cp23](https://doi.org/10.22002/shrpz-9cp23)

References

- Altschul SF, Gish W, Miller W, Myers EW, Lipman DJ. 1990. Basic local alignment search tool. *J Mol Biol* 215(3): 403-10. PubMed ID: [2231712](https://pubmed.ncbi.nlm.nih.gov/2231712/)
- Bock IR, Wheeler MR. (1972). The *Drosophila melanogaster* species group. *Univ. Texas Publs Stud. Genet.* 7(7213): 1-102. FBrf0024428
- Doleschall CL. (1858). Derde bijdrage tot de kennis der Dipteren fauna van nederlandsch indie. *Natuurk. Tijd. Ned.-Indie* 17: 73-128. FBrf0000091
- Drosophila* 12 Genomes Consortium, Clark AG, Eisen MB, Smith DR, Bergman CM, Oliver B, et al., MacCallum I. 2007. Evolution of genes and genomes on the *Drosophila* phylogeny. *Nature* 450(7167): 203-18. PubMed ID: [17994087](https://pubmed.ncbi.nlm.nih.gov/17994087/)
- Gonnet GH, Cohen MA, Benner SA. 1992. Exhaustive matching of the entire protein sequence database. *Science* 256(5062): 1443-5. PubMed ID: [1604319](https://pubmed.ncbi.nlm.nih.gov/1604319/)
- Gramates LS, Agapite J, Attrill H, Calvi BR, Crosby MA, dos Santos G, et al., Lovato. 2022. FlyBase: a guided tour of highlighted features. *Genetics* 220: 10.1093/genetics/iyac035. DOI: [10.1093/genetics/iyac035](https://doi.org/10.1093/genetics/iyac035)
- Grewal SS. 2009. Insulin/TOR signaling in growth and homeostasis: a view from the fly world. *Int J Biochem Cell Biol* 41(5): 1006-10. PubMed ID: [18992839](https://pubmed.ncbi.nlm.nih.gov/18992839/)
- Hernández G, Han H, Gandin V, Fabian L, Ferreira T, Zuberek J, et al., Lasko. 2012. Eukaryotic initiation factor 4E-3 is essential for meiotic chromosome segregation, cytokinesis and male fertility in *Drosophila*. *Development* 139: 3211-3220. DOI: [10.1242/dev.073122](https://doi.org/10.1242/dev.073122)
- Hietakangas V, Cohen SM. 2009. Regulation of tissue growth through nutrient sensing. *Annu Rev Genet* 43: 389-410. PubMed ID: [19694515](https://pubmed.ncbi.nlm.nih.gov/19694515/)
- Jenkins VK, Larkin A, Thurmond J, FlyBase Consortium. 2022. Using FlyBase: A Database of *Drosophila* Genes and Genetics. *Methods Mol Biol* 2540: 1-34. PubMed ID: [35980571](https://pubmed.ncbi.nlm.nih.gov/35980571/)
- Kent WJ, Sugnet CW, Furey TS, Roskin KM, Pringle TH, Zahler AM, Haussler D. 2002. The human genome browser at UCSC. *Genome Res* 12(6): 996-1006. PubMed ID: [12045153](https://pubmed.ncbi.nlm.nih.gov/12045153/)
- Kikkawa H. 1938. Studies on the genetics and cytology of *Drosophila ananassae*. *Genetica* 20: 458-516. DOI: [10.1007/BF01531779](https://doi.org/10.1007/BF01531779)
- Lachance PED, Miron M, Raught B, Sonenberg N, Lasko P. 2002. Phosphorylation of Eukaryotic Translation Initiation Factor 4E Is Critical for Growth. *Molecular and Cellular Biology* 22: 1656-1663. DOI: [10.1128/MCB.22.6.1656-1663.2002](https://doi.org/10.1128/MCB.22.6.1656-1663.2002)

- Larkin A, Marygold SJ, Antonazzo G, Attrill H, Dos Santos G, Garapati PV, et al., FlyBase Consortium. 2021. FlyBase: updates to the *Drosophila melanogaster* knowledge base. *Nucleic Acids Res* 49(D1): D899-D907. PubMed ID: [33219682](#)
- Lavoie CA, Lachance PED, Sonenberg N, Lasko P. 1996. Alternatively Spliced Transcripts from the Gene Produce Two Different Cap-binding Proteins. *Journal of Biological Chemistry* 271: 16393-16398. DOI: [10.1074/jbc.271.27.16393](#)
- Lawson ME, McAbee M, Lucas RA, Tanner S, Wittke-Thompson J, Pelletier TA, Ozsoy Z, Sterne-Marr R, Rele CP. 2024. Gene model for the ortholog of *Ilp5* in *Drosophila ananassae*. *microPublication Biology*. 10.17912/micropub.biology.000782 PubMed ID: [39717145](#)
- Lose B, Kiser CA, Laskowski LF, Girard J, Hayes J, Weast L, Minkovsky N, Justice S, Vincent JA, Youngblom JJ, Long LJ, Rele CP. 2025. Gene model for the ortholog of *eIF4E1* in *Drosophila yakuba*. *microPublication Biology*. (in press) DOI: [0.17912/micropub.biology.001020](#)
- Markow TA and O'Grady P. (2005) *Drosophila: A guide to species identification and use*. ISBN: 978-0-12-473052-6
- Mudge JM, Harrow J. 2016. The state of play in higher eukaryote gene annotation. *Nat Rev Genet* 17(12): 758-772. PubMed ID: [27773922](#)
- Myers A, Hoffmann A, Natysin M, Arsham AM, Stamm J, Thompson JS, Rele CP. 2024. Gene model for the ortholog of *Myc* in *Drosophila ananassae*. *microPublication Biology*. 10.17912/micropub.biology.000856 PubMed ID: [39677519](#)
- Navarro Gonzalez J, Zweig AS, Speir ML, Schmelter D, Rosenbloom KR, Raney BJ, et al., Kent WJ. 2021. The UCSC Genome Browser database: 2021 update. *Nucleic Acids Res* 49(D1): D1046-D1057. PubMed ID: [33221922](#)
- Raney BJ, Dreszer TR, Barber GP, Clawson H, Fujita PA, Wang T, et al., Kent WJ. 2014. Track data hubs enable visualization of user-defined genome-wide annotations on the UCSC Genome Browser. *Bioinformatics* 30(7): 1003-5. PubMed ID: [24227676](#)
- Rele CP, Sandlin KM, Leung W, Reed LK. 2023. Manual annotation of *Drosophila* genes: a Genomics Education Partnership protocol. *F1000Research* 11: 1579. DOI: [10.12688/f1000research.126839.2](#)
- Singh BN, Yadav JP. 2015. Status of research on *Drosophila ananassae* at global level. *J Genet* 94(4): 785-92. PubMed ID: [26690536](#)
- Singh BN. 2010. *Drosophila ananassae*: a good model species for genetical, behavioural and evolutionary studies. *Indian J Exp Biol* 48(4): 333-45. PubMed ID: [20726331](#)
- Sturtevant AH. 1939. On the Subdivision of the Genus *Drosophila*. *Proc Natl Acad Sci U S A* 25(3): 137-41. PubMed ID: [16577879](#)
- Tello-Ruiz MK, Marco CF, Hsu FM, Khangura RS, Qiao P, Sapkota S, et al., Micklos DA. 2019. Double triage to identify poorly annotated genes in maize: The missing link in community curation. *PLoS One* 14(10): e0224086. PubMed ID: [31658277](#)

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