Indian Journal of Experimental Biology
Vol. 63, October 2025, pp. 829-835
DOI: 10.56042/ijeb.v63i10.10383

Antigenotoxic properties of extracts of representatives of the genus *Monarda* introduced in the Urals

O Antosyuk[1]*, V Kostenko[2], Y Bobkov[2] & E Bolotnik[3]

[1]Department of Biodiversity and Bioecology, Institute of Natural Sciences and Mathematics, Ural Federal University, Ekaterinburg, Russia

[2]Department of Genetics, Kazan Federal University, Kazan, Russia

[3]Herbaceous plant introduction laboratory, Botanical Garden of the Ural Branch of the Russian Academy of Sciences, Ekaterinburg, Russia

Received 12 April 2024; revised 04 October 2025

Due to the fact that many antitumor drugs have genotoxicity, the aim of the study was to evaluate the antigenotoxic properties of extracts of the genus *Monarda* representatives using the *Drosophila melanogaster* model organism as an example. High IDC (Index of DNA-Comets) characterizes 0, 1% extracts of *M. fistulosa* var. *fistulosa* and *M. fistulosa* var. *menthifolia* when used both individually and together with etoposide. Whereas the extract of *Monarda fistulosa* var. *media* shows antigenotoxic properties by reducing the IDC and showing a unidirectional hypoexpressive effect relative to the *sqh* gene. Thus, the extract of *Monarda fistulosa* var. *media* is the most suitable protector against the effects of the anticancer drug etoposide.

Keywords: Drosophila, Etoposide, Comet-assay, Mosaicism, Expression

The prevalence of oncological diseases around the world leads to a variety of approaches to their treatment. A search and testing of newly synthesized medicinal substances, as well as various additional biologically active components, is underway. As the latter, extracts, essential oils and collections of medicinal plants are studied. Among medicinal plants there are variants both as an independent medicine and as a protector for use according to a certain scheme with antitumor drugs already used in practice to damage to genetic material at different levels of organization, anticancer drugs can cause changes in gene activity, for example, cisplatin provokes the expression of endonuclease (EndoG), which in turn can act as a factor contributing to the appearance of lymphomas[1]. A decrease in the genetic activity of nalidixic acid has been described during pretreatment of *E. coli* strain cells with greater celandine juice[2]. Also, in addition to the desmutagenic effect, medicinal plants can also demonstrate bio-antimutagenic one, characterised by participation in the processes of metabolism, detoxification and repair of damaged DNA. Similar effects were found for British inula (*Inula britannica* L. family Compositae), and chamomile[3-6].

Representatives of the genus *Monarda* are characterised by various effects: antibacterial, antioxidant, anti-age, etc.[7-13]. Such properties are due to certain biologically active substances in their composition, such as flavonoids, monoterpene phenols, thymol, carvacrol[14]. An increase in the efficiency of repair systems due to the antioxidant effect contributes to a decrease in genetic activity. Anticancer drugs, in particular etoposide, which is an inhibitor of topoisomerase II, have pronounced genotoxicity both at the level of chromosomal aberrations and at the level of DNA damage[15].

Drosophila melanogaster Meig. has been used as a model in the study of fundamental mechanisms underlying such biological processes as individual development[16-17], development and functioning of the nervous system[18], and innate immune responses[19-24] Drosophila has also become a useful genetic tool for studying human diseases, such as rare Mendelian diseases[25-26], neurodegenerative disorders[27-28], and cancer[29-30]. Additionally, one of the important selection criteria is the presence of a small genome and high gene homology with vertebrates[31-32].

*Correspondence:
E-mail: antosuk-olga@mail.ru

Hypothesis: choose an extract that protects against side effects but does not alter the main cytotoxic effect of the anticancer drug etoposide. The use of a nutrient substrate with a variable composition makes it possible to test extracts of medicinal plants by per os[33]. In this connection, the aim of the study was to evaluate the antigenotoxic properties of extracts of *M. didyma, M. fistulosa* var. *fistulosa, M. fistulosa* var. *media* and *M. fistulosa* var. *menthifolia* on the example of *D. melanogaster*, using the antitumor drug etoposide.

Materials and Methods

Study subject and preparation of extracts

We used the following laboratory lines of *D. melanogaster*: Canton-S (Normal, wild type, BDSC_64349), yellow (I: 0,0), white singed 3 (I: sn 21,0, w 15,0), da-Gal4 (P{da-GAL4.w-}3), BDSC_7194 (w[*]; P{w[+mC]=sqh-EYFP-Mito}3).

The selected lines were kept on fresh nutrient medium at +24 °C and 65% humidity. Plants of 2020 were used, grown in the Botanical Garden of the Ural Branch of the Russian Academy of Sciences from collection seeds (Russia, Sverdlovsk Region, and Yekaterinburg). *Monarda* grass was harvested in the flowering phase at the end of July, 2020. Plants of these species have been under the conditions of introduction for 2 years, successfully passed the adaptation period and were not treated with growth factors during cultivation.

For the preparation of extracts, the aerial parts of the plants were used. Extraction with 70% ethanol was carried out in the ratio: dry raw material and extraction agent 1:10 (1 g/10 mL). Drugs tested during the work: etoposide (Veropharm, Russia) and extracts of four representatives of the genus *Monarda*. Experimental groups of individuals were grown on the following nutrient media: control, etoposide 0,664 mg/mL, extract solution of *M. fistulosa var. menthifolia*/*M. fistulosa var. media/M. fistulosa var. fistulosa/M. didyma* 0,1%, as well as an extract together with etoposide (concentration of the antitumor drug was determined based on the lethality rate of the individuals previously)[34].

SMART (Somatic Mutation And Recombination Test)

We crossed females from the yellow lines (yellow body colour, the yellow gene is localised on the X chromosome) and white singed 3 males (white eyes and scorched bristles on the body, the genes are also localised on the X chromosome), placing them on the test medium for no more than 72 hours (24 °C, 65% humidity). F_1 hybrid females of the wild phenotype (brown-grey body, straight bristles and red eyes) were analysed. The appearance of bristles atypical for the normal phenotype in colour and shape was recorded. The area containing such a bristle was registered in the table as a single spot y (yellow) or sn (singed) or a double spot y sn.

DNA comet assay

To assess DNA damage in the third instar larval enterocytes, an alkaline variant of the DNA comet assay was used, which allows for the determination of single-strand DNA breaks in cells[34]. The cell material was prepared by repeatedly puncturing the individuals and then homogenizing them. A fluorescence microscope was used to visualise and rank the DNA comets (Carl Zeiss Axio Imager M2, Germany).

EYFP system

We used tissue-nonspecific Gal4 - daughterless (females) no later than 6 hours after departure from the puparium and males from the spaghetti squash - EYFP - Mito line (sqh). This gene is involved in the processes of morphogenesis, proliferation, and regulation of signalling. w(*); P{w(+mC)=sqh-EYFP-Mito}3 is a Drosophila strain in which UAS regulatory sequences direct the expression of a mitochondrial import sequence under the control of the *sqh* gene, which encodes the regulatory light chain of non-muscle myosin type 2. Hybrid offspring (not older than 7 days) grown on the tested media were analysed for changes in the fluorescence intensity in the abdominal region in females and males (Fig. 1C, D). We used this driver system because it initiates the general expression of the *spaghetti squash* target gene in all tissues and organs, and allows us to evaluate the change in the main effect of the cytotoxic drug etoposide by changing the level of oxidative stress and the activity of the apoptotic and anti-apoptotic gene cascade. Photofixation was performed on a Leica DM500 B microscope. Then, the change in the green spectrum was measured using the ImageJ program.

Statistical analysis

The χ^2 criterion with Yates's correction was used to assess the frequency of mosaicism. The expression level of the sqh gene was assessed using the nonparametric Kruskal-Wallis test. The data analysis in the DNA-comet test was performed using 2-way ANOVA (Tukey's multiple comparisons test).

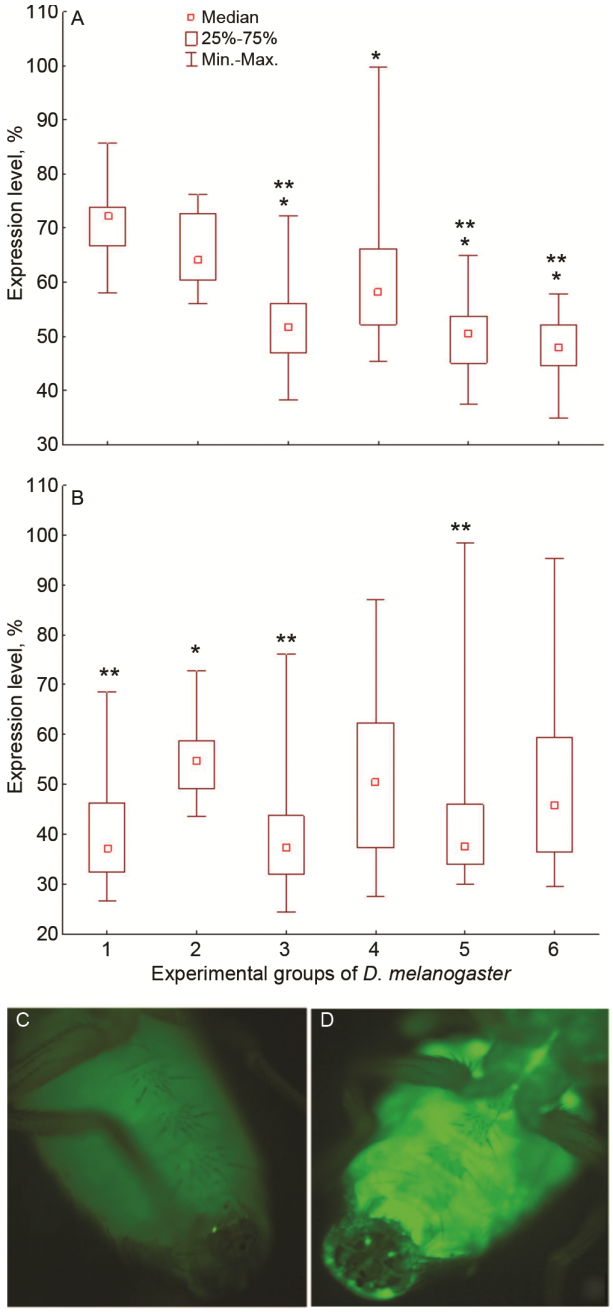

Fig. 1 — Expression level of females (A) and males (B) of experimental groups (1 – control, 2 – Etoposide 0.664 mg/mL, 3 – Extract *M. fistulosa* var. *media*, 4 – Extract *M. fistulosa* var. *fistulosa*, 5 – Extract *M. fistulosa* var. *menthifolia*, 6 – Extract *M. didyma*); An example of EYFP low (C) and highly intensive expression (D). The hybrid heterozygote flies da/sqh. The values were compared with each other using Kruskal-Wallis test. [*, $P < 0.05$ compared to the group of control flies; **, $P < 0.05$ compared to the group of flies with etoposide]

Statistica 13.0 and GraphPad Prism 8.0 software was used for statistical processing, and ImageJ was used to measure fluorescence intensity.

Results

When accounting for mosaicism in the SMART test, none of the four extracts tested showed any genotoxic manifestation. Singed type spots appeared more frequently in the experimental group grown on a nutrient medium supplemented with *M. fistulosa* var. *fistulosa* extract (0.1%), but similar fluctuations in values also remain within the control group. According to Table 1, the combined use of extracts with the antitumor drug etoposide at the tested concentrations resulted in a decrease in the frequency of mosaicism. Also, for etoposide, the appearance of aberrant phenotypes was recorded, which do not occur when combined with extracts. A similar antigenotoxic effect was previously described for the *Prunella grandiflora* extract L[35].

Using the system EYFP, we determined the multidirectional effect of the use of extracts in almost all experimental groups relative to females and males. For all experimental groups of females, hypoexpression of the *sqh* gene (decreased activity) was revealed. Abdominal luminescence did not decrease below 58.02% in the control sample, while in the experimental groups, when using *M. didyma*, the lower limit was 34. 81%. The interval of luminescence is expanded to maximum when individuals are cultivated on a nutrient medium with the introduction of *M. fistulos*a var. *fistulosa* extract and the average value is closer to the value of the etoposide group than in other groups grown on extracts, and it is in this group that the maximum upper limit of the interval was observed, namely – 99.77% (Fig. 1A). The smallest range of interval in the expression value was recorded in the group grown on a nutrient medium with the introduction of *M. fistulosa var. media* (38.26-72.29).

In turn, overexpression of the *sqh* gene was recorded in males. Above all is the lower limit of the expression in the experimental group exposed to – 43.57%. The only group of males in which hypo-expression was found, like females, were individuals grown on a nutrient medium supplemented with an extract of 0.1% *M. fistulosa* var. *media*. When exposed to other monarda extracts, the upper limit of the interval was higher (*M. fistulosa* var. *fistulosa* – 87.11, *M. fistulosa* var. *menthifolia* – 98.33, *M. didyma* – 95.21) than in the case of using the *M. fistulosa* var. *media* – 76.14% (Fig. 1B).

This is the first study to provide data regarding the effects of extracts from *M. fistulosa* var. *media,*

Table 1 — Accounting for somatic mosaicism on *Drosophila melanogaster* with yellow and singed markers

Groups	Summary	Number of individuals with mutant spots				%	χ2	*P*
		y	sn	y sn	Other mutant phenotypes			
Control	573	1	2	0	0	0.52	-	-
Etoposide (0.664 mg/mL)	833	1	12	0	9	4.59	7.55	0.006
Extract *M. fistulosa* var. *menthifolia 0.1%*	406	0	2	0	1	0.405	<0.0001	0.992
Extract *M. fistulosa* var. *fistulosa 0.1%*	205	0	2	0	0	0.9756	0.03	0.86
Extract *M. fistulosa* var. *media 0.1%*	407	0	3	0	0	0.424	<0.0001	0.995
Extract *M. didyma 1%*	381	0	4	0	1	1.0499	0.9	0.344
Extract *M. fistulosa* var. *menthifolia 0.1%* + Etoposide	272	0	2	0	0	0.7353	0.01	0.916
Extract *M. fistulosa* var. *fistulosa 0.1%*+Etoposide	514	1	4	0	2	1.474	0.7	0.404
Extract *M. fistulosa* var. *media 0.1%*+Etoposide	322	0	3	0	0	0.9317	0.08	0.771
Extract *M. didyma 0.1%*+Etoposide	422	0	6	0	0	1.4218	1.3	0.254
Extragent 0.1% (EtOH 70%)	242		3			1.2397	0.42	0.519

M. didyma, M. fistulosa var. *fistulosa, M. fistulosa* var. *menthifolia* on DNA repair *in vivo* after induction of DNA damage by etoposide influence on drosophila model.

The comet assay was used to examine the influence of *M. fistulosa var. media, M. didyma, M. fistulosa* var. *fistulosa, M. fistulosa* var. *menthifolia* extracts on DNA damage. We analysed the number of cells of flies with DNA damage and the index of DNA comets (IDC). The results of the studies are presented in Fig. 2A & 2B.

According to the data obtained, both plant extracts (*M. fistulosa* var. *fistulosa and M. fistulosa* var. *menthifolia*) adversely affect the studied parameters of DNA damage in drosophila, but *M. fistulosa* var. *fistulosa* shows a more pronounced negative effect than the other extracts. Significant differences were found compared with the etoposide group (*M. fistulosa* var. *fistulosa*) increases the number of cells with DNA damage by almost 30% [$P < 0.001$; IDC = 2.38]. Between extracts, the extract from *M. fistulosa* var. *fistulosa* turned out to be more aggressive in this case ($P < 0.05$). Cultivation of *D. melanogaster* with plant extracts from *M. fistulosa* var. *media* and *M. didyma* exhibits lower IDC values compared to the other two extracts (Fig. 2A). At the same time, supplementation of Drosophila with *M. didyma*, but not with *M. fistulosa* var. *media*, is associated with an increase in single-stranded DNA breaks in cells (Fig. 2B) to compare with the control group. Significant differences were found compared with the etoposide group (*M. fistulosa* var. *media* decreases the number of cells with DNA damage more than 32% [$P < 0.05$; IDC = 1.13], and *M. didyma* reduces the number of cells with DNA damage by about 42% [$P < 0.05$; IDC = 0.92]).

Discussion

According to the results obtained, not all representatives of the genus *Monarda* are characterised by the absence of genotoxic manifestations under the conditions of introduction. At the same time, the greatest effect was observed at the level of DNA damage, while the number of realised somatic mutations and recombinations remained at the level of the control sample. The combined use of extracts with the anticancer drug etoposide reduces the genetic activity of the latter in the SMART analysis. This effect is important for minimising secondary tumor formation after chemotherapy treatment. But despite such effects demonstrated by representatives of the Lamiaceae family, other manifestations of the genetic activity of the drug are possible[36]. The DNA comet-assay is an important component of such testing, often the antigenotoxic properties of the extract are observed precisely at the level of the degree of DNA damage[37]. According to our results, out of all the extracts, two

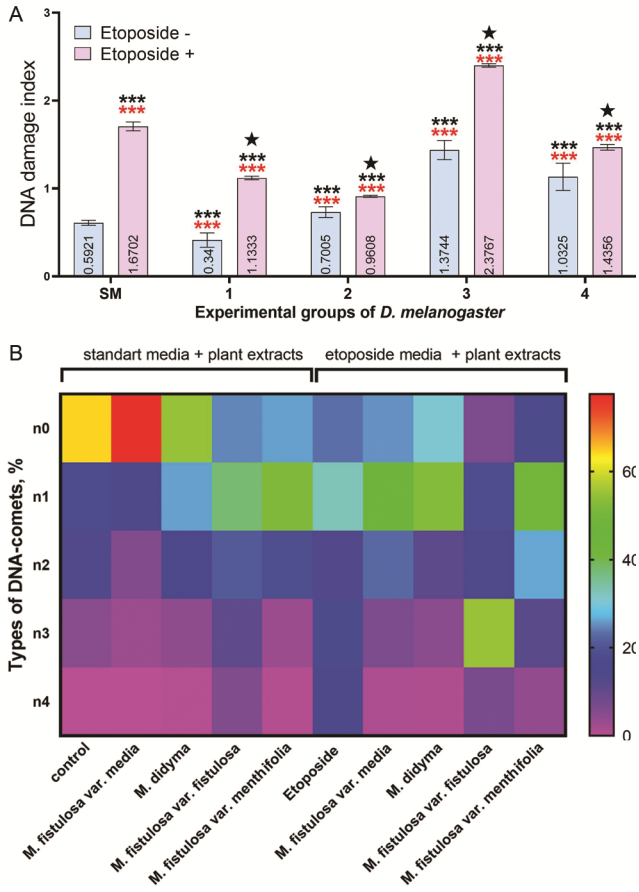

Fig. 2 — Influence of plant extracts 1 - *M. fistulosa* var. *media*, 2 - *M. didyma, 3 - M. fistulosa* var. *fistulosa, 4 - M. fistulosa* var. *menthifolia* on DNA stability of *D. melanogaster*; (A) The DNA damage index was calculated using the formula (0×n0 + 1×n1 + 2×n2 + 3×n3 + 4×n4) / Σ, where n0-n4 is the number of DNA comets of each type; Σ is the sum of the analysed DNA comets. The data was presented as columns (mean ± standard deviation). [*, $P < 0.05$ compared to the group of control flies; red *, $P < 0.05$ compared to the group of flies with etoposide]; (B) The frequency of different types of DNA comets in experimental groups

are characterised by high IDC values when used together with etoposide, namely extract of *M. fistulosa* var. *fistulosa* and *M. fistulosa* var. *menthifolia*. At the same time, the *M. fistulosa* var. *fistulosa* extract together with etoposide demonstrates the degree of DNA damage much more than the anticancer drug alone. A similar negative effect on DNA was described for carvacrol, which is one of the most abundant biochemical constituents of monards[38]. According to the data of Bolotnik *et al.* the content of flavonoids in *M. fistulosa* var. *fistulosa* in inflorescences is 3 times higher, and in leaves 1.5 times higher than in *Monarda fistulosa* var. *media*[39] and biochemical analysis of flavonoid content was carried out in three variation of *M. fistulosa*: *Monarda fistulosa* var. *fistulosa* (0.012%), *Monarda fistulosa var. media* (0.015%) and *Monarda fistulosa var. menthifolia* (0.018%). Both in samples grown in the Moscow region and in Belarus, carvacrol is the dominant component of the essential oil of *M. fistulosa* var. *fistulosa*[40].

A rather high toxic potential of the *M. fistulosa* var. *fistulosa* extract in the form of a tincture on outbred white rats was also shown, and therefore it was assigned to class III of acute toxic substances[41].

Active participation in the destabilisation of the expression of the *sqh* gene, the described toxic and genotoxic manifestations, the effect of synergy with the antitumor drug etoposide makes it inappropriate to use the extract of *M. fistulosa* var. *fistulosa* and *M. fistulosa* var. *menthifolia* at 0.1% concentration for biomedical purposes. The *sqh* gene product and myosin function in cellular processes such as cytokinesis and promote tissue morphogenesis. It is an ortholog of the human *MYL9* gene, which is associated with the development of familial hypertrophic cardiomyopathy. Mutations in the *sqh* gene lead to tau-mediated mitochondrial elongation, which causes neurotoxicity. A possible decrease in the applied concentration will lead to a less pronounced manifestation of the above effects. As for the extract of *M. didyma*, in addition to a multidirectional effect in changing the expression of the *sqh* gene, it does not demonstrate pronounced negative effects. However, the literature describes its insecticidal properties that affect the fertility and viability of *D. suzukii* individuals, which suggests its more detailed testing to minimise risks[42].

The most promising in terms of further research and the manifestation of antigenotoxic properties is the *M. fistulosa* var. *fistulosa* var. *media* extract, which is characterised by a stable hypoexpressive effect on the *sqh* gene, the lowest IDC among the tested representatives of the genus *Monarda*, and the frequency of mosaicism within the control group.

Conclusions

According to the SMART results, with the combined use of etoposide and the tested extracts of representatives of the genus *Monarda*, the frequency of somatic mosaicism is reduced to the values of the control group. Individuals grown with the combined use of etoposide and *M. fistulosa* var. *fistulosa* extract are characterised by the maximum IDC. All tested extracts exceeded the IDC of the control group, except for the extract of *M. fistulosa* var. *media*,

which is characterised by a decrease in IDC. Also, the *M. fistulosa* var. *media* extract exhibits a unidirectional change in the expression of the *sqh* gene in *D. melanogaster* individuals of both genders.

Funding statement

The research funding from Ural Federal University Program of Development within the Priority-2030 Program is gratefully acknowledged.

Acknowledgements

The authors would like to thank the staff of the Institute of Cytology and Genetics of the Russian Academy of Sciences and the Laboratory of Geroprotective and Radioprotective Technologies of the Institute of Biology, Komi Science Centre, Ural Branch, Russian Academy of Sciences for providing *Drosophila melanogaster* lines used in the work.

Conflict of interest

No conflict of interest was reported by the authors.

References

1 Park HJ, Kim JS, Lee R & Song H. Cisplatin Induces Apoptosis in Mouse Neonatal Testes Organ Culture. *Int J Mol Sci,* 23 (2022) 13360.

2 Gomaa HF, Fadl NN, Elmashad WMA, Abouelfadl DM, Mannaa FA & Abdel-Wahhab KG. Protective efficiency of *Chelidonium majus* extract against hepatoimmune and DNA changes induced by aflatoxin B1. *J Appl Pharm Sci,* 12 (2022) pp.140.

3 Eremina NV, Zhanataev AK & Durnev AD. Induced cell death as a possible pathway of antimutagenic action. *Bull. Exp. Biol. Med*, 171 (2021) pp.4.

4 Buza V, Niculae M, Hanganu D, Pall E, Burtescu RF, Olah NK, Matei-Lațiu MC, Vlasiuc I, Iozon I, Szakacs AR, Ielciu I & Ștefănuț LC. Biological Activities and Chemical Profile of *Gentiana asclepiadea* and *Inula helenium* Ethanolic Extracts. *Molecules,* 27 (2022) 3560.

5 Dilek Tepe H, Uğurlu A & Yazgan İ. Determination of Phenolic Compounds, Organic Volatile Molecules and Anticancer Properties in *Inula Viscosa* L.*Viscum Album* L. and *Raphanus Sativus* L. *Sak. Univ. J. Sci,* 25(2021) pp.647.

6 Gancedo NC, Isolani R, de Oliveira NC, Nakamura CV, de Medeiros Araújo DC, Sanches ACC, Tonin FS, Fernandez-Llimos F, Chierrito D & de Mello JCP. Chemical Constituents, Anticancer and Anti-Proliferative Potential of Limonium Species: A Systematic Review. *Pharmaceuticals,* 16 (2023) 293.

7 Chen Y, Zhao J, Liu C, Wu D & Wang X. *In-vitro* antibacterial activity and mechanism of *Monarda didyma* essential oils against Carbapenem-resistant *Klebsiella pneumoniae*. *BMC Microbiol,* 23 (2023) 263.

8 Dindo ML, Modesto M, Rossi C, Di Vito M, Burgio G, Barbanti L & Mattarelli P. *Monarda fistulosa* hydrolate as antimicrobial agent in artificial media for the in vitro rearing of the tachinid parasitoid *Exorista larvarum*. *Entomol Exp Appl,* 169 (2021) pp.79.

9 Maravić-Vlahoviček G, Kindl M, Andričević K, Obranić S & Vladimir-Knežević S. Modulatory Effects of Satureja montana L. Essential Oil on Biofilm Formation and Virulence Factors of Pseudomonas aeruginosa. *Pharmaceuticals (Basel),* 18 (2025) 1269.

10 Tit DM & Bungau SG. Antioxidant Activity of Essential Oils. *Antioxidants (Basel)*, 12(2023) 383.

11 Chen X, Shufeng S, Fei Y, Hai J, Guanjie Z, Shan T, Rui C, Dejing C & Yafeng D. Antioxidant Activities of Essential Oils and Their Major Components in Scavenging Free Radicals, Inhibiting Lipid Oxidation and Reducing Cellular Oxidative Stress. *Molecules,* 28 (2023) 4559.

12 Singh BK & Maurya A. Antioxidant Activity of Essential Oils: A Mechanistic Approach. Springer, (2024) pp59.

13 Guo Y, Qu Y, Li W, Shen H, Cui J, Liu J, Li J & Wu D. Protective effect of *Monarda didyma* L. essential oil and its main component thymol on learning and memory impairment in aging mice. *Front Pharmacol*, 13 (2022) 992269.

14 Tsibina AS & Kurkin VA. Current issues of the pharmacognostic study *Monarda fistulosa* L. herb. *Aspirantskiy vestnik Povolzhiya*, 21 (2021) pp. 132.

15 De Campos Nebel M, Palmitelli M & Pérez Maturo J. Alternative end-joining originates stable chromosome aberrations induced by etoposide during targeted inhibition of DNA-PKcs in ATM-deficient tumor cells. *Chromosome Res*, 30 (2022) pp.459.

16 Aloisi M, Deloriea J, Casey C, Pino A, Morciano P, Grifoni D & Gamberi C. Drosophila: The Centure-Long flight from the wild to the patient. *Med Sci Pulse*. 1 (2025) 1.

17 Munnik C, Xaba MP, Malindisa ST, Russell BL & Sooklal SA. *Drosophila melanogaster*: A platform for anticancer drug discovery and personalized therapies. Front Genet, 13 (2022) 949241.

18 Kimble J & Nüsslein-Volhard C. The great small organisms of developmental genetics: Caenorhabditis elegans and Drosophila melanogaster. *Dev Biol.* 485 (2022) 93.

19 Aalto AL, Luukkonen V & Meinander A. Ubiquitin signalling in Drosophila innate immune responses. *FEBS J,* 291 (2023) 4397.

20 Stączek S, Cytryńska M & Zdybicka-Barabas A. Unraveling the Role of Antimicrobial Peptides in Insects. *Int J Mol Sci*. 24(2023) 5753

21 Mpamhanga CD & Kounatidis I. The utility of Drosophila melanogaster as a fungal infection model. *Front Immunol,* 15 (2024) 1349027.

22 Cattabriga G, Giordani G , Gargiulo G & Cavaliere V. Effect of aminergic signaling on the humoral innate immunity response of Drosophila. *Front Physiol,* 14 (2023) 1249205.

23 Cammarata-Mouchtouris A, Acker A, Goto A, Chen D, Matt N & Leclerc V. Dynamic Regulation of NF-κB Response in Innate Immunity: The Case of the IMD Pathway in Drosophila. *Biomedicines*, 10 (2022) 2304.

24 Söderhäll I, Fasterius E, Ekblom C & Söderhäll K. Characterization of hemocytes and hematopoietic cells of a freshwater crayfish based on single-cell transcriptome analysis. *iScience*. 25 (2022) 104850

25 Sutton DC, Andrews JC, Dolezal DM, Park YJ, Li H, Eberl DF, Yamamoto S & Groves AK. Comparative exploration of mammalian deafness gene homologues in the Drosophila

auditory organ shows genetic correlation between insect and vertebrate hearing. *PLoS One,* 19 (2024) e0297846.

26 Agrawal N, Lawler K, Davidson CM, Keogh JM, Legg R, Barroso I, Farooqi IS & Brand AH. Predicting novel candidate human obesity genes and their site of action by systematic functional screening in Drosophila. PLoS Biol, 19 (2021) e3001255.

27 Marzullo M, Coni S, De Simone A, Canettieri G & Ciapponi L. Modeling Myotonic Dystrophy Type 2 Using Drosophila melanogaster*. Int J Mol Sci*, 24 (2023) 14182.

28 Coni S, Falconio FA, Marzullo M, Munafò M, Zuliani B, Mosti F, Fatica A, Ianniello Z, Bordone R, Macone A, Agostinelli E, Perna A, Matkovic T, Sigrist S, Silvestri G, Canettieri G & Ciapponi L. Translational control of polyamine metabolism by CNBP is required for Drosophila locomotor function. *Elife*, 10 (2021) e69269.

29 Sharpe JL, Morgan J, Nisbet N, Campbell K & Casali A. Modelling Cancer Metastasis in Drosophila melanogaster. *Cells*, 12 (2023) 677.

30 Wong KKL & Verheyen EM. Metabolic reprogramming in cancer: mechanistic insights from Drosophila. *Dis Model Mech,* 14 (2021) pp. 1.

31 Weasner BM & Kumar JP. The timing of cell fate decisions is crucial for initiating pattern formation in the Drosophila eye. *Development,* 149 (2022) dev199634.

32 DeSantis DF, Neal SJ, Zhou Q & Pignoni F. Peripodial adherens junctions regulate Ajuba-Yorkie signaling to preserve fly eye morphology. *Biol Open*, 12 (2023) bio059579.

33 Luna EM, Freitas TS, Campina FF, Costa MS, Rocha JE, Cruz RP, Sena Júnior DL, Silveira ZS, Macedo NS, Pinheiro JCA, Pereira-Júnior FN, Lisboa MAN, Cruz GV, Calixto Júnior JT, Teixeira AMR & Coutinho HDM. Evaluation of phytochemical composition, toxicity in *Drosophila melanogaster* and effects on antibiotics modulation of *Plathymenia reticulata* Benth extract. *Toxicol Rep*, 8 (2021), pp.732.

34 Magombe N, Kostenko VV, Antosyuk ON & Bolotnik EV. Testing the antigenotoxicity and anticytotoxicity properties of *Prunella Grandiflora* L. extract using the example of *Drosophila Mela-nogaster*. *Chimica Techno Acta*, 9 (2022) 202292S14.

35 Antosyuk ON, Bolotnik EV & Postovalova AS. Protective effect of the *Prunella grandiflora* L. extract in relation to the toxic effect of etoposide through the example of *Drosophila melanogaster*. *Bull. Sib. Med,* 20(2) (2021), pp. 7.

36 Hudhud L, Chisholm DR, Whiting A, Steib A, Pohóczky K, Kecskés A, Szőke É & Helyes Z. Synthetic Diphenylacetylene-Based Retinoids Induce DNA Damage in Chinese Hamster Ovary Cells without Altering Viability. *Molecules.* 27 (2022) 977.

37 Kostekci OC & Zemheri-Narvus F. Protective effects of *Aloe Vera* extract administration against trifluralin in *Drosophila melanogaster* with various parameters. *Braz. Arch. Biol. Technol.*, 66 (2023).

38 Nesterkina M, Bilokon S, Alieksieieva T, Kravchenko I & Hirsch AKH. Genotoxic and mutational potential of monocyclic terpenoids (carvacrol, carvone and thymol) in Drosophila melanogaster. *Toxicol Rep.* 10 (2023) 327.

39 Grineva DI, Gafarova DD & Bolotnik EV. The content of flavonoids in the raw materials of *Monarda fistulosa var. media* (Willd.) A. Gray and *Monarda fistulosa* L. species introduced in a Botanical Garden URO RAN. In: I International (76 All-Russian) Scientific and Practical Conference "Topical issues of modern medical science and healthcare", 2021 April 8-9, *Ekaterinburg, Russia,* 1313.

40 Kovalenko NA, Leontiev VN, Supichenko GN, Ahramovich TI, Feskova EV & Shutova AG. Anti-microbial properties of essential oils of the Genus *Monarda* plants cultivated in Belarus*. Chemistry of plant raw materials,* 2 (2021) pp.137.

41 Ghosh M, Schepetkin IA, Özek G, Özek T, Khlebnikov AI, Damron DS & Quinn MT. Essential Oils from Monarda fistulosa: Chemical Composition and Activation of Transient Receptor Potential A1 (TRPA1) Channels. *Molecules.* 25 (2020) 4873.

42 Finetti L, Civolani S, Mirandola D, Benetti L, Francati S, Albanese F, Menicucci F, Michelozzi M, Bellardi MG, Dindo ML & Bernacchia G. *Monarda didyma* Hydrolate Affects the Survival and the Behaviour of *Drosophila suzukii*. *Insects,* 13 (2022) 280.