



AMERICAN JOURNAL OF PHARMTECH RESEARCH

Journal home page: <http://www.ajptr.com/>

CDK7 Targeting In Cancer- A Review On Current Trends.

Ghodgaonkar S^{1*}, Juvatkar Pritam²

1. Vighnagarata Trust's Shivajirao S Jondhle College of Pharmacy, Asangaon-421601

2. AIMS college of Pharmacy, AIMS foundation, Vadvali, Dombivali (East) – 421 204

ABSTRACT

Cholecystokinin has been found to be a potential target for the treatment of various conditions including pancreatic cancer, pancreatitis, and gastrointestinal disorders. CDK7 (cyclin-dependent kinase 7) is an enzyme that is a key regulator of the cell cycle and gene transcription. It functions as a component of the Cdk-activated kinase (CAK) and transcription factor IIH (TFIIH) complexes. CDK7 phosphorylates other CDKs to promote cell cycle progression and phosphorylates RNA polymerase II to initiate gene transcription. CDK7 is often overexpressed in cancer due to its role in regulating cell proliferation. Hence CDK7 inhibitors have been researched in clinical trials as they are responsible for cell cycle arrest, apoptosis, and antiproliferative activities. This review particularly focuses on various synthetic and naturally occurring CDK7 inhibitors and their role in preventing various cancers including breast cancer, leukemia, hepatoma or cancer of liver and so on.

Keywords: CDK7, CDK7 inhibitors, cancer

*Corresponding Author Name: Ghodgaonkar S

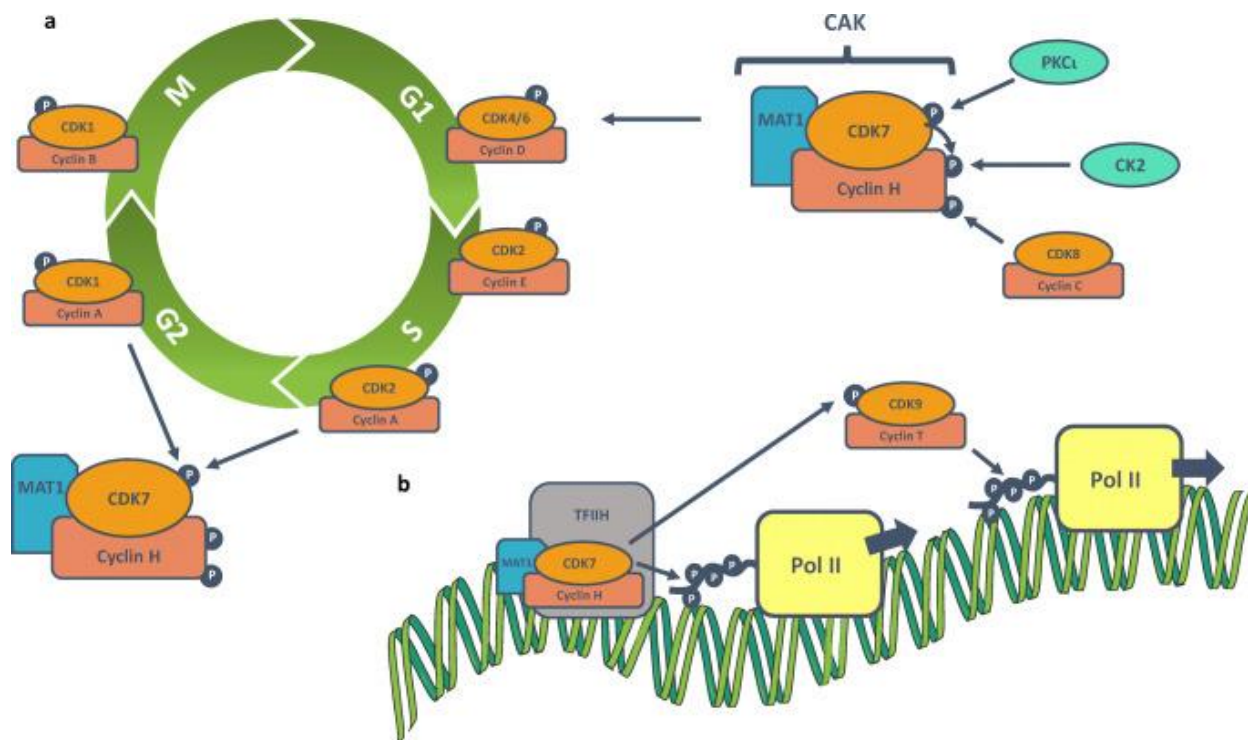
Received 12 September 2026, Accepted 29 September 2026

Please cite this article as: Ghodgaonkar S *et al.*, CDK7 Targeting In Cancer- A Review On Current Trends. American Journal of PharmTech Research 2026.

INTRODUCTION

Cyclin-dependent kinase 7 (CDK7) plays a major role in regulating planning of cell cycle and gene transcriptional activity. CDK7 is a serine/threonine kinase consisting of 346 amino acids. CDK7 is known to have a molecular weight of 39 kDa. Structurally, CDK7 shows a traditional kinase fold composing the N-terminal cyclin H-binding lobe comprising 13 to 96 amino acids, mainly consisting of several β pleated sheets and one α helix and a C-terminal MAT1 binding lobe comprising 97 to 311 amino acids, predominantly composed of α helices¹. In human cells, CDK7 activation is a two-step process. The S164 and T170 phosphorylation is a primary process for activation. T170 phosphorylation is the second step for activation of CDK7. Thus, dual T-loop phosphorylation can regulate Cdk7 through multiple mechanisms, with pS164 supporting tripartite complex formation and possibly influencing processivity, while pT170 enhances activity towards key transcriptional substrates. In contrast to other CDKs, CDK7 requires two proteins for its activation, Cyclin H and the RING-finger protein MAT1. The heterotrimeric complex formed by these proteins activates the cell-cycle CDKs 1, 2, 4, and 6 via T-loop phosphorylation. In humans this complex is referred to as the CAK complex. Compared with the other CDKs, however, for the formation of the trimeric CAK complex phosphorylation of the threonine in the activation loop is not necessary to activate the kinase².

CDK7 is overexpressed in breast cancer and selective inhibition of CDK7 encourages apoptosis and inhibits cell cycle progression³. Inhibition of transcriptional kinase of CDK7 prevents resistance in HER-2 positive breast cancer patients⁴. In Pancreatic ductal adenocarcinoma (PDAC) deletion of CDK7 prevented cell proliferation encouraged apoptosis and inhibited cell cycle progression in human cell lines⁵. An inhibitor of CDK7 inhibits the growth of several cancer types including triple-negative breast cancer, non-small cell lung carcinoma and MYCN-driven neuroblastoma, This suggests that CDK7 is a promising target to inhibit cell proliferation, apoptosis and cell cycle suppression⁶. It has been found that a novel CDK7-specific inhibitor, THZ1 inhibits cell proliferation⁷. Studies indicate that CDK7 is over expressed in epithelial ovarian cancer, gastric cancer and breast cancer. CDK7 is directly involved in the cell cycle process. CDK7. Inhibitors have a very strong antitumor effect especially in gastric cancer and breast cancer⁸.



General representation of the regulation of CAK and the role of CDK7 in regulating the cell cycle (a) and transcription (b). CAK = CDK activating kinase, CDK = cyclin-dependent kinase, CK2 = cyclin protein kinase CK2, G1 = gap phase 1, G2 = gap phase 2, M = mitosis, P = phosphate, PKC ϵ = protein kinase C iota, Pol II = RNA polymerase II, S = synthesis, TFIID = transcription factor II H

C-16661 exhibited excellent CDK7 inhibitory particularly in colorectal carcinoma cells of the mouse⁹ Zhang. H. et.al., synthesized and evaluated potent thieno [3,2-d] pyrimidine derivatives as CDK7 inhibitors. Compound 20 was found to be very potent CDK7 inhibitor¹⁰. Zhang.H, et.al., synthesized and evaluated novel 2,4-Diaminopyrimidine Derivatives as Potent CDK7 Inhibitors. It was found that Compound 22 effectively inhibited the phosphorylation of RNA polymerase II and CDK2. This led to G1/S phase cell cycle arrest and cell death in MV4-11 cells. It appears to be a potent lead compound for the development of a CDK7 inhibitor for cancer therapy.¹¹ Carbone. D, et.al., synthesized and evaluated novel Pyrazolo [1,5-a]-1,3,5-Triazine Derivatives as CDK7 Inhibitors. These compounds particularly exhibited activity against three immortalized cell lines (SUIT 2.28, PATU-T, PANC-1) of Pancreatic Ductal Adenocarcinoma Models (PDAC). Out of the 33 derivatives 8 derivatives showed excellent activity¹². Eskandrani. R et.al., synthesized new anilino pyrimidine derivatives that targeted transcriptional CDKs 7, 8, and 9. Compound 5f, 3-((4-(4-Fluorophenyl) pyrimidin-2-yl) amino) benzene sulfonamide displayed remarkable CDK& inhibitory activity ($IC_{50} = 0.716 \mu M$)¹³. Bhatia.MS, et.al., synthesized novel spiropyranopyrazole derivatives as CDK7 inhibitors. They discovered that compounds 2c and 3c exhibited CDK7

inhibitory activity¹⁴. Sava.GP *et.al.*, have found that CDK7i inhibitors including CDK7i, ICEC0942 (CT7001), SY-1365, SY-5609 and LY3405105 have progressed towards phase I/II trials¹⁵. Chen.R , *et.al.*, synthesized novel and potent N -pyridinylpyrimidin-2-amines derivatives. They discovered that compound 9q inhibited the kinase activity of cellular CDKs 7 and 9, stopped the cell cycle at sub-G1 phase and caused apoptosis¹⁶. Kovalová, *et.al.*, synthesized novel trisubstituted pyrazolo[4,3-d] pyrimidine derivative, LGR6768, that targets CDK7 in the nanomolar range and is a selective the CDK family inhibitor¹⁷. Wilson.SC, *et.al.*, designed, synthesized novel 6-pyridylmethylaminopurines moieties. It was found that compound 2-[(1S,2R)-1-Ethyl-2-hydroxypropylamino]-9-isopropyl-6-[(pyridin-3-ylmethyl)-amino]purine (α SbR-21) targets CDK2/cyclin E with $IC_{50} = 30$ nM, CDK7-cyclin H with $IC_{50} = 1.3$ μ M, and CDK9-cyclin T with $IC_{50} = 0.11$ μ M; it (CCT68127) arrests growth of HCT116 colon cancer cells in vitro with $GI_{50} = 0.7$ μ M; and shows antitumor activity when dosed p.o. at 50 mg/kg to mice bearing HCT116 solid human tumour xenografts¹⁸. Olson.CM, *et.al.*, developed a potent CDK7 inhibitor called YKL-5-124. It was found that YKL-5-124 selectively inhibits CDK7 leading to arrested cell cycle. I also exhibited a little effect on RNA polymerase II phosphorylation status¹⁹. Aga Y *et.al.*, developed a novel selective CDK7 inhibitor, UD-017, and discovered that in vivo, UD-017 inhibited tumor growth in an HCT-116 xenograft mouse model by 33%, 64%, and 88% at doses of 25, 50, and 100 mg/kg, respectively, with clear dose-dependency whereas in-vitro it UD-017 significantly inhibited CDK7 activity ($IC_{50} = 16$ nM) with high selectivity in an in vitro kinase assay testing a panel of over 300 proteins and lipid kinases²⁰. Hongfu Lu, *et.al.*, developed a compound 13, Compound 13 displays excellent in vitro activity, good ADME properties, and significant in vivo antitumor activity in xenograft models as a monotherapy. The compound 13 with lower basicity exhibited improved Caco-2 permeability, low blood/plasma ratio, and low intestinal distribution in rats, thus mitigating gastrointestinal and hematotoxic side effects²¹.

Natural CDK& inhibitors

Bhurta.D, and Bharate.S found that pongol (SBN-88), a naturally acting furan flavonoid inhibits CDK7/H as well as CDK9/T1 with IC_{50} values of 0.93 and 0.83 μ M²². Khandelwal. P, *et.al.*, discovered that tectonaquinone B, 2-methylquinizarin along with tecomaquinone I, lapachol , 2-isopropenyl naphtho[2,3-b]-furan-4,9-quinone, dehydro- α -lapachone, α -lapachone, and β -lapachone isolated from petroleum ether extract of heartwood of *Tecomella undulate* had high binding affinities for CDK7 as was proved by molecular docking²³. Singh.R, *et.al.*, docked natural pyrrolone-fused benzosuberene (PBS) compounds and based on the docking results ligands -3, 5, 14, and 16 were screened among 17 different compounds and it was found that Ligands-3, 14

selectively inhibit CDK7²⁴. Zhang. XH, et.al., while discovering the mechanism of action of myricetin, a natural flavonoid found out that myricetin inhibited the overexpression of CDK7 kinase protein, as well as CDK7-mediated Thr161 phosphorylated (active) Cdc2. This was particularly found in human hepatoma HepG2 cells, where myricetin prohibited cell proliferation and induced G2/M phase arrest²⁵. Variolin B (VAR-B) is a natural product isolated from the sponge *Kirkpatrickia variolosa*. It is found in Antarctica. Simone. M, et. al., evaluated the activity of variolin and found that it inhibited the activity of CDK7. CDK7 is overexpressed in cancer cells²⁶. Khalil.HS, et.al., researched that the roscovitine, a synthetic analogue of rosmarine from *Raphanus sativus* (radish) exhibited anti anti CDK7 activity. Roscovitine (generic name Seliciclib) has been evaluated in a number of Phase I and II clinical trials and have displayed very good activity in patients²⁷. Al-Rawashde.FA, et.al., evaluated that thymoquinone (TQ) obtained from *Nigella sativa* seeds was exposed to the cells of chronic myeloid leukemia (CML) for 48 hours led to the downregulated cyclin A2, cyclin D1, cyclin E1, cyclin B1, CDK1, CDK2, CDK4, CDK6, and CDK7 and upregulated p53, p16, p18, p21, and p27 expressions were increased by TQ incubation for 72 h²⁸. Yuying Li, et. al., found out that three flavonoids homogenous compounds from tartary buckwheat seeds and bran, namely quercetin, isoquercetin, and rutin downregulated Cyclin D1, Cdk2, and Cdk7 levels and upregulated expression of p53 and p21²⁹. Chiang.SK, et.al., performed paraptosis or non-apoptosis programmed cell death on xenograft mouse models with paraptosis inducing agents CPYPP, cyclosporin A, and curcumin, and found that they inhibit cyclin-dependent kinase (CDK) 7/9 drive paraptotic progression in a mutually-dependent manner with heat shock proteins (HSPs). The xenograft mouse models of MDA-MB-231 breast cancer and docetaxel-resistant OECM-1 head and neck cancer cells further confirmed the induction of paraptosis against tumor growth³⁰. Oroxylin A is primarily obtained from the roots of the medicinal plants *Oroxylum indicum* and *Scutellaria baicalensis*. Yang.Y, et.al., found that Oroxylin A is a promising apoptosis inducer of human hepatoma HepG2 cells. Further it was found that Oroxylin A caused cell cycle arrest of BGC-823 human gastric carcinoma cells. Along with cell cycle arrest it was found that Oroxylin A inhibited expression of Cdk7³¹.

Nukaya. M, et.al., researched that when an oncogene DNAJB1-PRKACA was introduced in Fibrolamellar carcinoma (FLC), using CRISPR/Cas9 there was an aberrant cell cycle progression and an evidence was found that there was inhibition of CDK7³². Resveratrol (3,5,4'-trihydroxystilbene), is a phytoalexin found in grapes. Liang. YC, et.al., gave a possible mechanism for anti-cancer activity of resveratrol. It was found that that resveratrol have low levels of CDK7 kinase-Thr(161)-phosphorylated p34(CDC2)³³. Li. Y, et.al., investigated that quercetin extracted

from buckwheat increased expression of p53 and p21, decreased levels of CDK causing apoptosis production of reactive oxygen species and further arrest of G2/M phase in human hepatoma HepG2 cells³⁴. Manzo.SG, et.al., found that Triptolide, a Chinese medicine obtained from medicinal herb *Tripterygium wilfordii* Hook. f. causes degradation of RNAPII mediated by CDK7³⁵. Campos.PE, et.al., discovered that Osirisyne 5,6 obtained from methylene chloride methanol (1:1) extract obtained from marine sponge *Haliclona* sp. collected in Mayotte. Of all the compounds Osirisyne B (5) was the most active compound with IC₅₀ on, CDK7 kinase of μM , 9.13 μM ³⁶. Hassane. CS, et.al., found that polybrominated diphenyl ethers (PBDEs) of the extract of the marine sponge *Lendenfeldia chondrodes* (Thorectidae) displayed kinase activities particularly compound number 6 was found to have a very potent activity against CDK7³⁷. Bhurta.D and Bharate.S discovered that many natural compounds including rutin, bergenin, morin, quercetin, baicalein, boeravinone B, pongol, isopongaglabol, fisetin, and lanceolatin has CDK7 inhibitory activity and made a library of these compounds. The flavonoids rutin, morin, quercetin, baicalein, and fisetin were particularly active against CDK7/H³⁸. König. A, et.al., found that flavopiridol inhibits CDK7³⁹. Zocchi.L, et.al., discovered that flavopiridol exhibits its cytotoxic effects through inhibition of CDK9 and CDK7, hence inhibiting global RNA transcription⁴⁰.

CONCLUSION

It can be concluded that CDK7 is a promising target for future cancer treatment. It would inhibit cell proliferation encourage apoptosis and causes cell death thereby reducing the tumour size. Some of the derivatives have reached Phase I/Phase II stages in clinical trials indicating that CDK7 inhibitors can be considered as serious candidates for the treatment of different cancers especially breast cancer and lung cancers. Both natural and synthetic CDK7 inhibitors have been found to be very effective in inhibiting various cancer cell lines. Hence CDK7 inhibitors can be considered as a potential target to inhibit malignant tumour growth by targeting overexpressing CDK7 selectively.

REFERENCES

1. Gong.Y, Li.H, CDK7 in breast cancer: mechanisms of action and therapeutic potential, *Cell Communication and Signaling*, 2024, 22 (226), <https://doi.org/10.1186/s12964-024-01577-y>.
2. Peissert.S,et.al., Structural basis for CDK7 activation by MAT1 and Cyclin H, *Proc Natl Acad Sci U S A.*, 2020, 117(43):26739–26748. doi: 10.1073/pnas.2010885117.

3. Cristina Guarducci, et.al., Selective CDK7 Inhibition Suppresses Cell Cycle Progression and MYC Signaling While Enhancing Apoptosis in Therapy-resistant Estrogen Receptor–positive Breast Cancer, *Clin Cancer Res* ,2024, 30 (9), 1889–1905.
4. Sun. B, et.al., Inhibition of the transcriptional kinase CDK7 overcomes therapeutic resistance in HER2-positive breast cancers, *Oncogene*,2020,39, 50–63. <https://doi.org/10.1038/s41388-019-0953-9>.
5. Zeng. S, et.al., CDK7 inhibition augments response to multidrug chemotherapy in pancreatic cancer, *Journal of Experimental & Clinical Cancer Research*, 2022, 41, 241, 1-18, <https://doi.org/10.1186/s13046-022-02443-w>.
6. Yao. Y, et.al., CDK7 controls E2F- and MYC-driven proliferative and metabolic vulnerabilities in multiple myeloma, *Blood*,2023, 141 (23): 2841–2852.
7. Cao K, Shilatifard A, inhibit globally, act locally: CDK7 inhibitors in cancer therapy., *Cancer Cell.*, 2014, 26(2):158-159. DOI: 10.1016/j.ccr.2014.07.020. PMID: 25117707.
8. Bao.XJ, et.al., Clinical data analysis of CDKS expression and prognosis in breast cancer, *WCRJ*, 2023, 10: e2475,1-15.
9. Park H, et.al., Abstract LB168: A selective, potent, and orally bioavailable CDK7 inhibitor demonstrates superior anti-cancer activity in colorectal cancer models, *Cancer Res.*, 2024. 84, (7_Supplement): LB168. <https://doi.org/10.1158/1538-7445.AM2024-LB168>.
10. Zhang. H. et.al., Design, synthesis and evaluation of thieno[3,2-d]pyrimidine derivatives as novel potent CDK7 inhibitors, *Bioorganic Chemistry*,2024, 148, 107456.
11. Zhang. H, et.al., Design, Synthesis, and Biological Evaluation of 2,4-Diaminopyrimidine Derivatives as Potent CDK7 Inhibitors, *ACS Med Chem Lett.*, 2024, 15(8):1213–1220.
12. Carbone. D, et.al., Novel Pyrazolo [1,5-a]-1,3,5-Triazine Derivatives as CDK7 Inhibitors: Synthesis and Biological Insights in Pancreatic Ductal Adenocarcinoma Models, *ChemMedChem*, 2025, e202500448. doi: 10.1002/cmdc.202500448
13. Eskandrani. R et.al., Targeting Transcriptional CDKs 7, 8, and 9 with Anilinopyrimidine Derivatives as Anticancer Agents: Design, Synthesis, Biological Evaluation and In Silico Studies, . *Molecules* 2023, 28, 2-24.
14. Bhatia.MS, et.al., Exploration of anticancer potential of spiropyranopyrazole derivatives as CDK7inhibitors, *Journal of Pharmaceutical Research*, 2016, 15 (3), 73-78.

15. Sava GP *et.al*, CDK7 inhibitors as anticancer drugs, *Cancer and Metastasis Reviews*, 2020, 39:805–823.
16. Chen.R , *et.al.*, Discovery of Novel and Potent Inhibitors of Cyclin-Dependent Kinases 7 and 9: Design, Synthesis, Structure-Activity Relationship Analysis and Biological Evaluation,. Available at SSRN: <https://ssrn.com/abstract=4210989> or <http://dx.doi.org/10.2139/ssrn.4210989>.
17. Kovalová, , *et.al.*, Characterization of new highly selective pyrazolo[4,3-d]pyrimidine inhibitor of CDK7, *Biomedicine & Pharmacotherapy*, 2023, 161, 114492,ISSN 0753-3322, <https://doi.org/10.1016/j.biopha.2023.114492>.
18. Wilson.SC, *et.al.*, Design, synthesis and biological evaluation of 6-pyridylmethylaminopurines as CDK inhibitors, *Bioorganic & Medicinal Chemistry*, 2011, 19 (2), 6949-6965.
19. Olson.CM, *et.al.*, Development of a Selective CDK7 Covalent Inhibitor reveals predominant cell-cycle phenotype, *Cell Chemical Biology*, 2019, 26, 792–803.
20. Aga Y *et.al.*, Novel Oral Derivative UD-017, a Highly Selective CDK7
21. Inhibitor, Exhibits Anticancer Activity by Inducing Cell Cycle Arrest and Apoptosis in Human Colorectal Cancer, *Hiroshima J. Med. Sci*, 2020, 69(1), 23-31.
22. Hongfu Lu, *et.al.*, Discovery of a Novel Macrocyclic Noncovalent CDK7 Inhibitor for Cancer Therapy, *Journal of Medicinal Chemistry*, 2024, 67(22), 20580-20594.
23. Bhurta.D, and Bharate.S, Discovery of Pongol, the Furanoflavonoid, as an Inhibitor of CDK7/Cyclin H/MAT1 and Its Preliminary Structure–Activity Relationship, *ACS Omega*, 2022, 8(1), 1291-1300.
24. Khandelwal. P, *et.al.*, Study of potent CDK7 inhibitor secondary metabolites from *Tecomella undulate*, *Natural Product Research*, 2022. 36(22), 5793–5797, <https://doi.org/10.1080/14786419.2021.2016748>.
25. Singh R, *et.al.*, Natural analogues inhibiting selective Cyclin-dependent kinase protein isoforms: A computational prospective, *Journal of Biomolecular Structure and Dynamics*, 2019, 38(17), DOI: <https://doi.org/10.1080/07391102.2019.1696709>.
26. Zhang. XH, *et.al.*, Myricetin induces G2/M phase arrest in HepG2 cells by.inhibiting the activity of the cyclin B/Cdc2 complex, *Molecular Medicine Reports* ,2011,4, 273-277.

27. Simone.M,et.al., Variolin B and its derivate deoxy-variolin B: New marine natural compounds with cyclin-dependent kinase inhibitor activity, *European Journal of Cancer* 2005,41, 2366–2377.
28. Khalil.HS, et.al., Discovery and development of Seliciclib. How systems biology approaches can lead to better drug performance, *Journal of Biotechnology*,2015,202,40-49.
29. Al-Rawashde. FA, et.al., Targeting Cyclin Dependent Kinases by Thymoquinone against Chronic Myeloid Leukemia: Molecular Docking and Gene Expression Analysis, *Journal of Medicinal and Chemical Sciences*, 2024, 7(11), 1449-1466.
30. Yuying Li, et.al., Flavonoids from tartary buckwheat induce G2/M cell cycle arrest and apoptosis
31. in human hepatoma HepG2 cells, *Acta Biochim Biophys Sin*, 2014, 46, 460–470.
32. Chiang.SK, et.al., CDK7/CDK9 mediates transcriptional activation to prime paraptosis in cancer cells, *Cell Biosci.*, 2024, 14(1), 1-22. doi: 10.1186/s13578-024-01260-2.
33. Yang.Y, et. al., Oroxylin A induces G2/M phase cell-cycle arrest viainhibiting Cdk7-mediated expression of Cdc2/p34 in human gastric carcinoma BGC-823 cells, *JPP* 2008, 60, 1459–1463.
34. Nukaya. M, et.al., CDK7 is a Novel Therapeutic Vulnerability in Fibrolamellar Carcinoma, *bioRxiv*, doi: <https://doi.org/10.1101/2023.04.22.537934>.
35. . Liang.YC, et.al., Resveratrol-induced G2 arrest through the inhibition of CDK7 and p34CDC2 kinases in colon carcinoma HT29 cells, *Biochem Pharmacol*, 65(7):1053-60.
36. Li.Y, et.al., Flavonoids from tartary buckwheat induce G2/M cell cycle arrest and apoptosis in human hepatoma HepG2 cells, *Acta Biochimica et Biophysica Sinica*, 2014, 46(6), 460-470.
37. Manzo.SG, et.al., Natural product triptolide mediates cancer cell death by triggering CDK7-dependent degradation of RNA polymerase II, *Cancer Res.* 2012, 72(20):5363-73. doi: 10.1158/0008-5472.CAN-12-1006.
38. Campos.PE, et.al., Osirisynes G-I, New Long-Chain Highly Oxygenated Polyacetylenes from the Mayotte Marine Sponge *Haliclona* sp., *Mar. Drugs* 2020, 18(350) , 1-19 doi:10.3390/md18070350.
39. Hassane.CS, et.al., doi: 10.1080/14786419.2023.2204431. Epub 2023 Apr 22. Polybrominated diphenyl ethers isolated from the marine sponge *Lendenfeldia*

- chondrodes collected in Mayotte, *Nat Prod Res.*, 2024, 38(17):2973-2982. doi: 10.1080/14786419.2023.2204431. Epub 2023 Apr 22. PMID: 37086477.
40. Bhurta D and Bharate S, Discovery of Pongol, the Furano flavonoid, as an Inhibitor of CDK7/Cyclin H/MAT1 and Its Preliminary Structure–Activity Relationship, *ACS Omega*, 2022, 8(1), 1291-1300.
41. König. A, et.al., The Novel Cyclin-Dependent Kinase Inhibitor Flavopiridol Downregulates Bcl-2 and Induces Growth Arrest and Apoptosis in Chronic B-Cell Leukemia Lines, *Blood*, 18(11), 1997, 4307-4312.
42. Zocchi L, et.al., The cyclin-dependent kinase inhibitor flavopiridol (alvocidib) inhibits metastasis of human osteosarcoma cells, *Oncotarget*, 2018, 9(34), 23505-23518, doi: 10.18632/oncotarget.25239.

