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Efficient synthesis of various acycloalkenyl derivatives of pyrimidine using cross-metathesis and Pd(0) methodologies

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Abstract—Novel acyclonucleosides (**9a–d**, **10a–d**, **18a**,**b** and **19a**,**b**) have been prepared using Pd(0) and cross-metathesis methodologies. The allylic *N*-alkylation under Tsuji–Trost conditions was used to introduce the nucleobase, while the Suzuki–Miyaura reaction afforded C-5 substituted uracil analogues. The cross-metathesis performed with a ruthenium catalyst was used to provide new acycloalkenyl nucleosides. The antiviral activities of all final compounds have been evaluated.

1. Introduction

Interest in acyclic nucleosides began in the mid-1970s when acyclovir was first reported as a potent anti-herpes drug.[1] The unprecedented selectivity of acyclovir as an antiviral drug and the subsequent clarification of its behavior towards virally coded enzymes provided massive impetus for further synthesis of such compounds and for the investigation of their biochemical fate. Many variations, both of the acyclic glycone and of the heterocyclic base, have been described.[2,3] Acyclonucleosides are commonly synthesized by reaction of nucleic bases with α-chloromethyl ethers in the presence of strong bases[4] or by reaction of persilylated nucleic bases with an activated aglycone catalyzed by various Lewis acid[5] (Vorbrüggen conditions).[6] Others' approaches have employed an acid catalyzed transglycosylation,[7] an oxidative cleavage of the pentose moiety of cyclic nucleosides.[8] Acycloalkenyl nucleosides can be produced through the alkylation of 1,4-dichloro-2-butyne with the heterocycle followed by an acetylene–allene isomerization,[9] or from a protected glyceraldehydes using a Wittig–Horner–Emmons reaction; nevertheless, in the later case, only the *Z*-α,β-unsaturated ester was obtained exclusively without any trace of the *E*-isomer.[10]

Efforts aimed at synthesizing and isolating new actives nucleosides now require the development and elaboration of new strategy yielding facile and rapid access to a large variety of compounds. To our knowledge, no attempt has been made to use a combination of olefin cross-metathesis[11] and palladium-assisted routes[12] to make acyclonucleosides; our aim was thus to fill this gap. As part of our drug discovery program, we have previously reported[13] a preliminary account of methodologies leading to acycloalkenyl nucleosides. In this paper, we report an extension of this strategy as a powerful route for the synthesis and the diversification of new acycloalkenyl pyrimidine nucleosides including trisubstituted alkene and allylic phosphonate (Fig. 1).

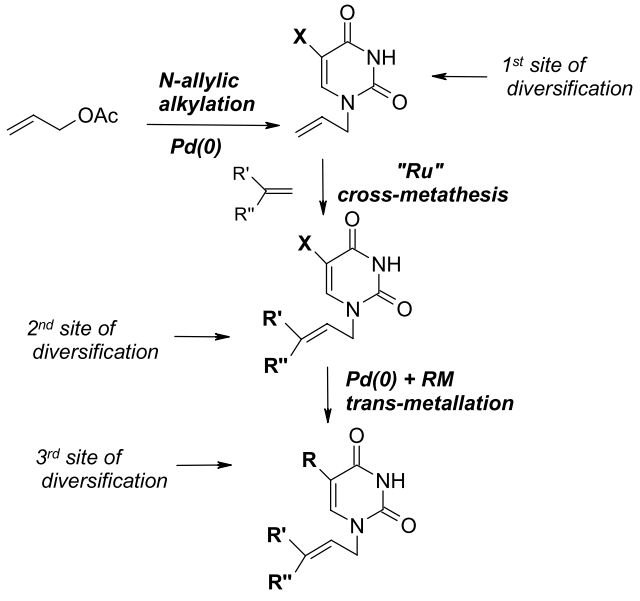

Figure 1.

Keywords: Cross-metathesis; Acyclonucleosides; Suzuki–Miyaura; Pd(0).
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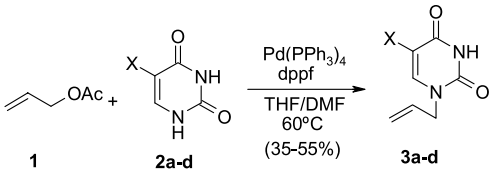
2. Results and discussion

2.1. Allylic *n*-alkylation by Tsuji–Trost reaction

The first step of this synthetic approach consists in the regioselective synthesis of *N*-allyl derivatives of nucleobases using Pd(0)-catalyzed reaction of commercially available allylic acetate with various pyrimidines under Tsuji–Trost conditions (Scheme 1).



Entry	Nucleobase	X	Product	Yield (%)
1	**2a**	H	**3a**	45[a]
2	**2b**	CH_3	**3b**	55
3	**2c**	I	**3c**	35
4	**2d**	F	**3d**	52[b]

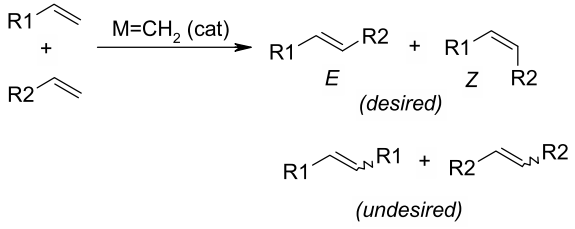
[a]total yield: formation of a 4/1 mixture of monoallylated and diallylated compounds separable by chromatography. [b]total yield: formation of a 5/2 mixture of monoallylated and diallylated compounds separable by chromatography.

Scheme 1.

Thus, treatment of uracil derivatives **2a–d** with allyl acetate **1** in the presence of freshly prepared $Pd(PPh_3)_4$ and dppf [(1,1′-bis(diphenyl-phosphinoferocene)] in a mixture of THF/DMF, led to the desired N-1 allylic pyrimidine derivatives **3a–d** in moderate yield. It is interesting to note that in the case of uracil (entry 1) and 5-fluorouracil (entry 4), the Tsuji–Trost allylic alkylation led to a 4/1 and 5/2 mixture of N-1 monoallylated (**3a** or **3d**, respectively) and N1,N3-diallylated analogues. The formation of bis-alkylated product has been reported[14] previously as has the influence of the solvent on the regioselectivity of the Pd(0)-catalyzed allylation of uracils.[15]

2.2. Cross-metathesis

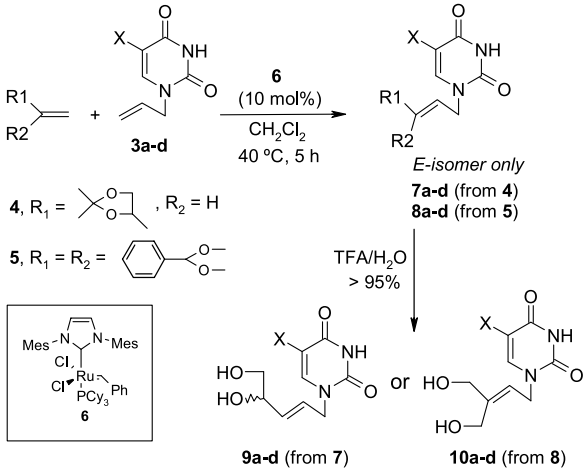
In contrast to the vast number of successful ring-closing metathesis reactions, only a few examples of selective cross-metathesis in the presence of functional groups have been reported.[16] In fact, the metal carbene catalyzed intermolecular coupling between two different olefins potentially yields four new alkenes as depicted in Scheme 2. Thus, the allylthymine cross-metathesis efficiency depends



Scheme 2.

on the selectivity observed in the coupling. Optimization of the desired alkene as well as the stereocontrol of the formed double bond is a crucial issue to access its usefulness for the synthesis of unsaturated acyclonucleosides.

In order to achieve diversification within the acyclic nucleoside family, we have explored and optimized the cross-metathesis reaction of two terminal olefins, 2,2-dimethyl-4-vinyl-[1,3]dioxolane[17] (**4**) and 5-methylene-2-phenyl-[1,3]dioxane[18] (**5**), with allyluracils (**3a–d**). Under optimized conditions moderate to good yields of the desired products were achieved (Scheme 3).



Entry	Olefin	X	Product	Yield (%)
1	**4**	H	**7a**	78
2	//	CH_3	**7b**	50
3	//	I	**7c**	56
4	//	F	**7d**	62
5	**5**	H	**8a**	53
6	//	CH_3	**8b**	64
7	//	I	**8c**	57
8	//	F	**8d**	70

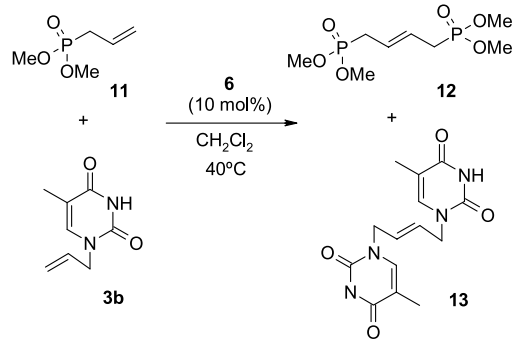
Scheme 3.

It is interesting to note that: (1) no self-metathesis products were observed; (2) those metathetical coupling reactions all proceed with a high or exclusive degree of *trans* selectivity. The ^1H NMR clearly showed that only the *E*-isomer was produced as the major compound with no detectable corresponding *Z*-isomer. Even though its origin is not clear at present, the stereoselectivity of this reaction seems to be substrate dependant; (3) the synthesis of trisubstituted carbon–carbon double bonds such as in **8a–d**, which still remains an ongoing challenge, proceeded smoothly with the ruthenium–carbene species bearing one imidazol-2-ylidene ligand **6**.[19] This catalyst displays a great tolerance towards an array of polar groups.

The acidic deprotection (TFA/H_20, 2/1, v/v) of **7a–d** and **8a–d** afforded in quantitative yields the acycloalkenyl nucleosides **9a–d** and **10a–d**, respectively.

Based on the well-known potent and broad spectrum of

antiviral acyclic phosphonate nucleosides (ANP),[3a,b,20] we then turned our attention to the introduction of a phosphonate moiety using the cross-metathesis methodology. Vinyl or allyl phosphonates have been already reported to be viable cross-metathesis partners in metathesis reaction catalyzed by second generation catalyst.[21] Thus, the allylthymine **3b** was used as substrate in a cross-metathesis reaction with the commercially available allyl phosphonic acid dimethyl ester (**11**) under various conditions (Scheme 4). When a first-generation ruthenium catalyst (up to 1 equiv) was employed (entry 1), no reaction occurred; the starting material was always recovered after allowing the reaction to proceed as long as a few days. When the second generation catalyst **6** was used, the starting material **3b** was rapidly consumed generating a complex mixture of products, which could not be separated by silica gel column chromatography. Any attempt in modifying the solvent or increasing the amount of allylic phosphonate **11** (entries 2–4) always led to the same results. The ^{1}H NMR data suggests that two compounds (**12**,**13**) issuing from the self-metathesis of **11** and **3b**, respectively are present in the complex mixture.



Entry	equiv.	Catalyst (10%)	Solvent	Results
1	5	Grubbs 1	CH_2Cl_2	S.M.
2	5	Nolan (**6**)	CH_2Cl_2	homodimers
3	5	//	Toluene	homodimers
4	10	//	CH_2Cl_2	homodimers

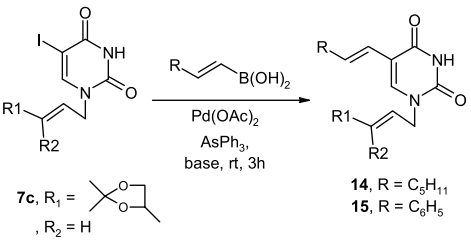
Scheme 4.

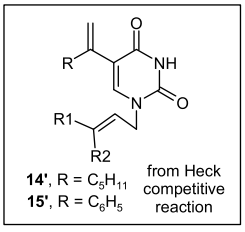
To explain the lack of formation of the desired cross coupling compound, we hypothesized first that the allylic phosphonate **11** may be more reactive than the allylic thymine **3b** in the cross-metathesis reaction; the phosphonate dimer **12** could be initially formed allowing thus the allylic thymine to react only with itself affording the bipyrimidinic derivative **13**. Another hypothesis is based on the reversible nature of the cross-metathesis reaction which ensures the preferential formation of the most thermodynamically stable product, for example, the homodimers in the present case. These results are in agreement with the recently reported general empirical model for olefin reactivity in the cross-metathesis reaction.[22] In fact, categorizing olefins by their relative ability to undergo homodimerization via cross-metathesis, the allyl phosphonate is able to rapidly produce the homodimers.

3. Suzuki–Miyaura coupling

3.1. With alkenyl boronic derivatives

To bring further structural modifications and diversity to the synthesized acycloalkenyl nucleosides, we turned our attention to the coupling of various organoboron compounds with iodinated acycloalkenyl pyrimidine **7c** under Suzuki–Miyaura conditions.[23,24] This reaction is suitable in numerous synthetic pathways to pharmaceutical agents, as boron derivatives are non-toxic, easily prepared and stable. Thus the 5-iodinated derivative **7c** was reacted in THF, at rt, with two boronic acid compounds in the presence of $Pd(OAc)_2$, $AsPh_3$ and K_2CO_3 (Scheme 5).





Entry	Compound	R	Base	Ratio Suzuki : Heck	Yield (%)
1	**14**		K_2CO_3	6 : 3	45
2	//	//	KOH	8 : 2	52
3	**15**		K_2CO_3	5 : 4	55
4	//	//	KOH	7 : 3	60

Scheme 5.

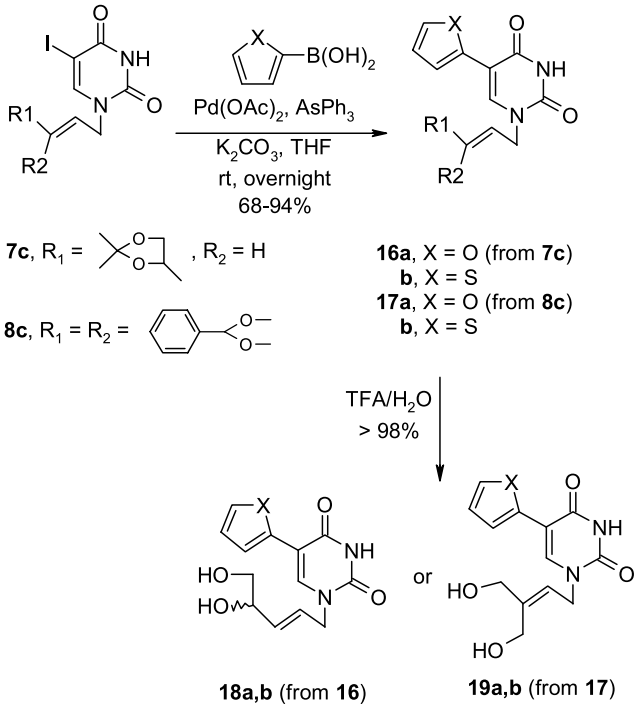
During the Pd(0) transmetallation coupling between **7c** with pentylboronic acid, we observed the formation of two non-separable compounds, one (**14**) resulting from the expected Suzuki–Miyaura reaction and the second (**14′**) from an unexpected Heck reaction. This competition between both reactions has been already reported in the literature[25] for non-aromatic boronic acid. Owing to the low nucleophilicity of an alkenylboronic acid compared with aryl derivatives, the transmetallation step on the Pd(0) catalyst slowly proceeded and a Heck type side reaction took place competitively. In order to accelerate the transmetallation step and suppress the formation of the isomer **14′**, a stronger base such as KOH was used instead of K_2CO_3. This resulted in an increase of the amount of the expected compound **14**; nevertheless, the presence of the byproduct **14′** led us to consider other derivatives. Similar results were obtained with the vinylbenzeneboronic acid affording an inseperable mixture of **15** and **15′**. We thus

turned our attention to the more reactive heterocyclic boronic acids.

3.2. With heterocyclic boronic acid

Herdewijn et al.[26] have described the synthesis and marked antiviral activities of uridine derivatives bearing a thiophene ring at the C-5 position of the nucleobase. Therefore the Suzuki–Miyaura coupling reaction between iodinated derivatives **7c** and **8c**, with the commercially available thiophene (X=S) - or furan (X=O) boronic acids, in the presence of $Pd(OAc)_2$, $AsPh_3$ and K_2CO_3, at rt in THF overnight afforded the desired compounds **16a**,**b** and **17a**,**b**, respectively, in good yields (Scheme 6). These compounds have been obtained by Stille reaction, in similar yields, using appropriate tin derivatives in the presence of $Pd_2(dba)_3$ (20 mol%) and $AsPh_3$ (40 mol%).

The acidic deprotection (TFA/H_20, 2/1, v/v) of nucleosides **16** and **17** afforded in quantitative yields the acycloalkenyl nucleosides **18** and **19**, respectively.



Scheme 6.

4. Biological results

The synthesized compounds **9a–d**, **10a–d**, **18a**,**b** and **19a**,**b**, along with the known antiviral compounds (acyclovir for HSV and AZT for HIV), were tested for their anti-HIV and anti-HSV activity in vitro, and the results are shown in Table 1.

Among these nucleosides analogues, only compounds **10d**, **18a** and **18b** were found to exhibit moderate anti-HIV activity, with an EC_{50} of 72.9, 10.1 and 3.9 μM, respectively. Compounds **18a** and **18b** exhibited also moderate anti-HSV activity with and EC_{50} of 12.2 and 8.8 μM, respectively. Nevertheless, those compounds and especially **18b** showed toxicity against PBM, CEM or VERO cells. The antiviral[27] and cytotoxicity[28] assays were done as previously described.

5. Conclusion

An efficient route to various acycloalkenyl nucleosides (**9a–d**, **10a–d**, **18a**,**b** and **19a**,**b**) has been developed using a combination of Pd(0) and cross-metathesis methodologies. The allylic N-alkylation under Tsuji–Trost conditions was used to introduce the nucleobase, meanwhile the Suzuki–Miyaura reaction afforded C-5 substituted uracil analogues. The cross-metathesis, with a ruthenium catalyst, was used to access new acycloalkenyl nucleosides. The antiviral activities of all final compounds have been determined.

Table 1. Evaluation of synthesized acyclic nucleosides antiviral activity against human immunodeficiency virus (HIV), herpes simplex virus (HSV-1) and cytotoxicity against PBM, CEM and VERO cells in vitro, expressed in μM

Compound	Anti-HIV-1 activity in PBMCs	HSV-1 plaque Reduction assay	Toxicity (IC_{50}) in:		
	EC_{50}	EC_{50}	PBM	CEM	VERO
AZT[a]	0.016	>10	>100	14.0	29.0
Acyclovir[a]	>100	0.11	>100	>100	>100
9a	(100	(100	(100	(100	(100
9b	(100	(100	(100	(100	(100
9c	(100	(100	(100	(100	(100
9d	ND[b]	ND	ND	ND	ND
10a	(100	(100	(100	(100	(100
10b	(100	(100	(100	(100	(100
10c	(100	(100	(100	(100	(100
10d	72.9	(100	64.9	49.3	(100
18a	10.1	12.2	20.5	16.8	27.6
18b	3.9	8.8	13.4	6.6	4.9
19a	(100	(100	(100	(100	(100
19b	(100	(100	70.9	65.1	(100

[a] Reference compounds.
[b] ND: not determined.

6. Experimental

6.1. General methods

Commercially available chemicals were reagent grade and used as received. THF was distilled from sodium/benzophenone and CH_2Cl_2 from CaH_2 immediately prior use. The reactions were monitored by thin-layer chromatography (TLC), analysis using silica gel plates (kieselgel 60 F_{254}, E. Merck). Compounds were visualized by UV irradiation and/or spraying with 20% H_2SO_4 in EtOH, followed by charring at 150 °C. Column chromatography was performed on Silica Gel 60 M (0.040–0.063 mm, E. Merck). NMR spectra were recorded with a Brucker AVANCE DPX 250 Fourier transform 250 spectrometer, with Me_4Si as the internal standard, unless otherwise stated. Chemical shifts are given in ppm (δ). High Resolution Mass spectra were performed by the Centre regional de Mesures Physiques de l'Ouest (University of Rennes, France).

6.2. General procedure for Tsuji–Trost reaction

To a solution of pyrimidine (**2**) (8.40 mmol) in DMF/THF (100 mL, 1/1) was added NaH (202 mg, 8.40 mmol, 60% dispersion in oil). After heating this suspension at 60 °C for 45 min, allyl acetate **1** (0.45 mL, 4.20 mmol), dppf (232 mg, 0.42 mmol) and freshly prepared $Pd(PPh_3)_4$ (485 mg, 0.42 mmol) were successively added. The reaction was heated to 40 °C until complete conversion was reached. The mixture was allowed to return to room temperature, diluted with EtOAc (25 mL) and washed with an aqueous saturated solution of NH_4Cl. The organic layer was dried over anhydrous $MgSO_4$, filtered then concentrated in vacuo and the residue was finally purified by column flash chromatography to afford (**3**).

6.2.1. 1-Allyl-2,4(1*H*,3*H*)-pyrimidinedione (3a).[15] Eluant PE/EtOAc 5/5; white solid; mp 102 °C; ^{1}H NMR ($CDCl_3$) δ 4.30 (d, 2H, J=5.7 Hz), 5.22 (dd, 2H, J=9.4, 16.3 Hz), 5.68 (d, 1H, J=7.8 Hz), 5.72–5.93 (m, 1H), 7.10 (d, 1H, J=7.8 Hz), 9.84 (br s, NH); ^{13}C NMR ($CDCl_3$) δ 50.1 (CH_2), 102.5 (CH), 119.5 (CH_2), 131.5 (CH), 143.9 (CH), 151.0, 164.2; MS: m/z 153 $[M+H]^+$; 175 $[M+Na]^+$; UV (MeOH) λ_{max} 265 nm.

6.2.2. 1-Allyl-5-methyl-2,4(1*H*,3*H*)-pyrimidinedione (3b).[29] Eluant PE/EtOAc 3/7; yield 55%; white solid; mp 122 °C; ^{1}H NMR ($CDCl_3$) δ 1.89 (s, 3H), 4.31 (d, 2H, J=5.8 Hz), 5.18–5.33 (m, 2H), 5.77–5.92 (m, 1H), 6.96 (s, 1H), 9.74 (br s, NH); ^{13}C NMR ($CDCl_3$) δ 14.1 (CH_3), 51.6 (CH_2), 112.8, 120.9 (CH_2), 133.6 (CH), 141.5 (CH), 152.8, 166.3; MS: m/z 167 $[M+H]^+$; UV (MeOH) λ_{max} 269 nm.

6.2.3. 1-Allyl-5-iodo-2,4(1*H*,3*H*)-pyrimidinedione (3c). Eluant PE/EtOAc 4/6; yield 35%; white solid; mp 204 °C; ^{1}H NMR (DMSO-d_6) δ 4.26–4.30 (m, 2H), 5.10–5.5.21 (m, 2H), 5.79–5.94 (m, 1H), 8.12 (s, 1H), 11.64 (br s, NH); ^{13}C NMR (DMSO-d_6) δ 49.4 (CH_2), 68.3, 117.7 (CH_2), 132.9 (CH), 149.6 (CH), 150.4, 161.1; HRMS ESI Obsd, m/z 300.9451; calcd for $C_7H_7N_2O_4INa$, m/z 300.9450 $[M+Na]^+$; UV (MeOH) λ_{max} 290 nm.

6.2.4. 1-Allyl-5-fluoro-2,4(1*H*,3*H*)-pyrimidinedione (3d).[30] Eluant PE/EtOAc 3/7; white solid; mp 101 °C; ^{1}H NMR ($CDCl_3$) δ 4.35 (d, 2H, J=5.9 Hz), 5.35 (dd, 2H, J=10.9, 16.1 Hz), 5.78–5.96 (m, 1H), 7.27 (d, 1H, J=5.4 Hz), 9.65 (sl, NH); ^{13}C NMR (DMSO) δ 50.9 (CH_2), 120.9 (CH_2), 128.5 (CH), 131.5 (CH), 141.1 (C–F), 150.3, 158.1; MS: m/z 171 $[M+H]^+$; UV (MeOH) λ_{max} 270 nm.

6.3. General procedure for cross-metathesis reaction

To a solution of allyl derivative (0.66 mmol) in freshly distilled CH_2Cl_2 (12.5 mL) were successively added the protected diol **4** or **5** (3.32 mmol) and ruthenium catalyst **6** (56 mg, 0.06 mmol). The reaction mixture was stirred at 40 °C during 5 h. After evaporation of volatiles the crude residue was purified by flash chromatography.

6.3.1. 1-[(*E*)-3-(2,2-dimethyl-1,3-dioxolan-4-yl)-2-propenyl]-2,4(1*H*,3*H*)-pyrimidinedione (7a). Eluant PE/EtOAc 2/8; yield 78%; pale yellow gum; ^{1}H NMR ($CDCl_3$) δ 1.37 (s, 3H), 1.41 (s, 3H), 3.58 (dd, 1H, J=8.0 Hz), 4.10 (dd, 1H, J=6.4, 8.0 Hz), 4.25–4.47 (m, 2H), 4.48–4.57 (m, 1 H), 5.63–5.78 (m, 2H), 5.83 (dt, 1H, J=5.3, 15.7 Hz), 7.13 (d, 1H, J=7.8 Hz), 9.45 (s, NH); ^{13}C NMR ($CDCl_3$) δ 25.9 (CH_3), 26.8 (CH_3), 49.0 (CH_2), 69.3 (CH_2), 76.8 (CH), 102.8 (CH), 109.8, 126.9 (CH), 133.2 (CH), 143.8 (CH), 150.8 (CO), 163.8 (CO); HRMS EI Obsd, m/z 237.0892; calcd for $C_{11}H_{13}N_2O_4$, m/z 237.08753 $[M-CH_3]^+$; UV (MeOH) λ_{max} 265 nm.

6.3.2. 1-[(*E*)-3-(2,2-dimethyl-1,3-dioxolan-4-yl)-2-propenyl]-5-methyl-2,4(1*H*,3*H*)-pyrimidinedione (7b). Eluant PE/EtOAc 2/8; yield 50%; pale yellow gum; ^{1}H NMR ($CDCl_3$) δ 1.37 (s, 3H), 1.42 (s, 3H), 1.90 (s, 3H), 3.58 (dd, 1H, J=8.0 Hz), 4.10 (dd, 1H, J=6.4, 8.0 Hz), 4.22–4.41 (m, 2H), 4.47–4.57 (m, 1H), 5.69 (dd, 1H, J=6.6, 15.2 Hz), 5.82 (dt, 1H, J=7.0, 15.2 Hz) 6.94 (s, 1H), 9.32 (s, NH); ^{13}C NMR ($CDCl_3$) δ 12.4 (CH_3), 25.9 (CH_3), 26.7 (CH_3), 48.8 (CH_2), 69.4 (CH_2), 76.0 (CH), 109.8, 111.3, 127.3 (CH), 132.7 (CH), 139.7 (CH), 150.9, 164.4; HRMS EI Obsd, m/z 266.1269; calcd for $C_{13}H_{18}N_2O_4$, m/z 266.12666 $[M]^{+\cdot}$; UV (MeOH) λ_{max} 270 nm.

6.3.3. 1-[(*E*)-3-(2,2-dimethyl-1,3-dioxolan-4-yl)-2-propenyl]-5-iodo-2,4(1*H*,3*H*)-pyrimidinedione (7c). Eluant PE/EtOAc 5/5; yield 56%; pale yellow gum; ^{1}H NMR ($CDCl_3$) δ 1.39 (s, 3H), 1.43 (s, 3H), 3.61 (dd, 1H, J=7.3, 8.1 Hz), 4.12 (dd; 1H, J=6.3, 8.1 Hz), 4.31–4.44 (m, 2H), 4.51–4.59 (m, 1H), 5.71–5.90 (m; 2H), 7.57 (s, 1H), 9.03 (bs, NH); ^{13}C NMR ($CDCl_3$) δ 25.9, 26.8, 49.5, 68.4, 69.3, 75.8, 109.9, 126.3, 133.9, 148.2, 150.4, 160.4; HRMS EI Obsd, m/z 378.087; calcd for $C_{12}H_{15}N_2O_4I$, m/z 300.9450 $[M]^{+\cdot}$; UV (MeOH) λ_{max} 288 nm.

6.3.4. 1-[(*E*)-3-(2,2-dimethyl-1,3-dioxolan-4-yl)-2-propenyl]-5-fluoro-2,4(1*H*,3*H*)-pyrimidinedione (7d). Eluant PE/EtOAc 4/6; yield 62%; pale yellow gum; ^{1}H NMR ($CDCl_3$) δ 1.39 (s, 3H), 1.43 (s, 3H), 3.60 (dd, 1H, J=7.3, 8.1 Hz), 4.12 (dd; 1H, J=6.3, 8.1 Hz), 4.33–4.42 (m, 2H), 4.51–4.61 (m, 1H), 5.72–5.90 (m, 2H), 7.23 (d, 1H, J=5.4 Hz,), 9.60 (s, NH); ^{13}C NMR ($CDCl_3$) δ 25.8 (CH_3), 26.7 (CH_3), 49.3 (CH_2), 69.3 (CH_2), 75.8 (CH), 109.9, 126.0 (CH), 127.8 (CH), 134.1 (CH), 140.1 (C–F), 149.5, 157.3;

HRMS ESI Obsd, *m/z* 293.1604; calcd for $C_{12}H_{15}FN_2O_4Na$, *m/z* 293.1608 $[M+Na]^+$; UV (MeOH) λ_{max} 270 nm.

6.3.5. 1-[2-(2-Phenyl-1,3-dioxan-5-yliden)ethyl]-2,4(1*H*, 3*H*)-pyrimidinedione (8a). Eluant PE/EtOAc 2/8; yield 53%; pale yellow gum; ^{1}H NMR (DMSO-d_6) δ 4.28–4.55 (m, 5H), 4.96–5.05 (m, 1H), 5.43–5.51 (m, 1H), 5.58 (d, 1H, $J=7.3$ Hz), 5.69 (s, 1H), 7.28–7.49 (m, 5H), 7.63 (d, 1H, $J=7.3$ Hz), 11.29 (s, NH); ^{13}C NMR (DMSO-d_6) δ 43.6 (CH_2), 65.3 (CH_2), 70.6 (CH_2), 100.5 (CH), 101.2 (CH), 119.6 (CH), 126.1 (CH $\times$2), 128.1 (CH $\times$2), 128.7 (CH), 133.9, 138.3, 145.2 (CH), 150.8, 163.7; HRMS ESI Obsd, *m/z* 323.1007; calcd for $C_{16}H_{16}N_2O_4Na$, *m/z* 323.1008 $[M+Na]^+$; UV (MeOH) λ_{max} 265 nm.

6.3.6. 5-Methyl-1-[2-(2-phenyl-1,3-dioxan-5-yliden)-ethyl]-2,4(1*H*,3*H*)-pyrimidinedione (8b). Eluant PE/EtOAc 2/8; yield 64%; pale yellow gum; ^{1}H NMR (DMSO-d_6) δ 1.76 (s, 3H), 4.26–4.60 (m, 5H), 4.92–5.05 (m, 1H), 5.41–5.52 (m, 1H), 5.69 (s, 1H), 7.29–7.61 (m, 6H), 11.28 (s, NH); ^{13}C NMR (DMSO-d_6) δ 11.9 (CH_3), 43.4 (CH_2), 65.3 (CH_2), 70.7 (CH_2), 100.4 (CH), 108.8, 119.7 (CH), 126.1 (CH $\times$2), 128.0 (CH $\times$2), 128.7 (CH), 133.7, 138.3, 140.9 (CH), 150.7, 164.2; HRMS ESI Obsd, *m/z* 337.3415; calcd for $C_{17}H_{18}N_2O_4Na$, *m/z* 337.3417 $[M+Na]^+$; UV (MeOH) λ_{max} 270 nm.

6.3.7. 5-Iodo-1-[2-(2-phenyl-1,3-dioxan-5-yliden) ethyl]-2,4(1*H*,3*H*)-pyrimidinedione (8c). Eluant PE/EtOAc 4/6; yield 57%; pale yellow gum; ^{1}H NMR ($CDCl_3$) δ 4.17–4.26 (m, 1H), 4.42–4.55 (m, 4H), 4.93–4.99 (m, 1H), 5.45 (t, 1H, $J=6.7$ Hz), 5.68 (s, 1H), 7.36–7.40 (m, 3H), 7.47–7.51 (m, 2H), 7.61 (s, 1H), 8.91 (s, 1H); ^{13}C NMR ($CDCl_3$) δ 44.8 (CH_2), 66.1 (CH_2), 68.8, 71.9 (CH_2), 102.0 (CH), 118.6 (CH), 126.4 (CH $\times$2), 128.7 (CH $\times$2), 129.5 (CH), 136.7, 137.9, 148.3 (CH), 150.6, 160.5; HRMS ESI Obsd, *m/z* 448.9980; calcd for $C_{16}H_{15}N_2O_4INa$, *m/z* 448.9974 $[M+Na]^+$; UV (MeOH) λ_{max} 290 nm.

6.3.8. 5-Fluoro-1-[2-(2-phenyl-1,3-dioxan-5-yliden)-ethyl]-2,4(1*H*,3*H*)-pyrimidinedione (8d). Eluant PE/EtOAc 5/5; yield 70%; pale yellow gum; ^{1}H NMR (DMSO-d_6) δ 4.23–4.55 (m, 5H), 4.95–5.00 (m, 1H), 5.48 (t, 1H, $J=6.6$ Hz), 5.69 (s, 1H), 7.34–7.41 (m, 5H), 8.08 (d, 1H, $J=6.6$ Hz), 11.81 (s, NH); ^{13}C NMR (DMSO-d_6) δ 43.9 (CH_2), 65.3 (CH_2), 70.6 (CH_2), 100.5 (CH), 119.2 (CH), 126.1 (CH $\times$2), 128.1 (CH $\times$2), 129.4 (CH), 129.7 (CH, $J=132.3$ Hz), 134.1, 138.3, 139.7 (C–F), 149.4, 157.5; HRMS ESI Obsd, *m/z* 341.3052; calcd for $C_{16}H_{15}FN_2O_4Na$, *m/z* 341.3048 $[M+Na]^+$; UV (MeOH) λ_{max} 269 nm.

6.4. General procedure for Suzuki reaction

Under dry nitrogen, to a solution of iodo derivatives (0.132 mmol) in THF (1 mL), boronic acid derivatives (0.529 mmol), $Pd(OAc)_2$ (0.053 mmol), Ph_3As (0.026 mmol) and K_2CO_3 (1.188 mmol) were added. The reaction was stirred at room temperature until complete conversion was reached. After evaporation of volatiles the crude residue was purified by column flash chromatography.

6.4.1. 1-[(*E*)-3-(2,2-dimethyl-1,3-dioxolan-4-yl)-2-propenyl]-5-(2-furyl)-2,4(1*H*,3*H*)-pyrimidinedione (16a). Eluant PE/EtOAc 5/5; yield 94%; pale yellow gum; ^{1}H NMR ($CDCl_3$) δ 1.37 (s, 3H), 1.42 (s, 3H), 3.60 (dd, 1H, $J=$ 8.1 Hz), 4.11 (dd, 1H, $J=6.3$, 8.1 Hz), 4.42 (d, 2H, $J=$ 5.3 Hz), 4.49–4.57 (m, 1H), 5.76 (dd, 1H, $J=6.6$, 15.7 Hz), 5.89 (dt, 1H, $J=5.65$ Hz, $J=15.7$ Hz), 6.43 (dd, 1H, $J=$ 1.8, 3.5 Hz), 7.04 (d, 1H, $J=3.5$ Hz), 7.33 (d, 1H, $J=$ 1.8 Hz), 7.61 (s, 1H), 10.01 (s, NH); ^{13}C NMR ($CDCl_3$) δ 25.9 (CH_3), 26.7 (CH_3), 49.5 (CH_2), 69.3 (CH_2), 75.9 (CH), 107.4, 109.5, 109.8 (CH), 111.9 (CH), 126.8 (CH), 133.1 (CH), 137.5 (CH), 141.2 (CH), 145.6, 150.0, 160.7; HRMS ESI Obsd, *m/z* 341.1106; calcd for $C_{16}H_{18}N_2O_5Na$, *m/z* 341.1113 $[M+Na]^+$; UV (MeOH) λ_{max} 284 nm.

6.4.2. 1-[(*E*)-3-(2,2-dimethyl-1,3-dioxolan-4-yl)-2-propenyl]-5-(2-thienyl)-2,4(1*H*,3*H*)-pyrimidinedione (16b). Eluant PE/EtOAc 5/5; yield 68%; pale yellow gum; ^{1}H NMR ($CDCl_3$) δ 1.38 (s, 3H), 1.43 (s, 3H), 3.61 (dd, 1H, $J=$ 8.0 Hz), 4.12 (dd, 1H, $J=6.3$, 8.0 Hz), 4.38–4.48 (m, 2H), 4.53–4.60 (m, 1H), 5.78 (dd, 1H, $J=6.6$, 15.7 Hz), 5.90 (dt, 1H, $J=5.6$ Hz, $J=15.7$ Hz), 7.00–7.05 (m, 1H), 7.25–7.29 (m, 1H), 7.37–7.40 (m, 1H), 7.48 (s, 1H), 9.98 (s, NH); ^{13}C NMR ($CDCl_3$) δ 25.8 (CH_3), 26.7 (CH_3), 49.4 (CH_2), 69.3 (CH_2), 75.8 (CH), 109.8, 110.4, 124.5 (CH), 125.6 (CH), 126.7, 127.1, 133.2 (CH), 138.7 (CH), 150.1, 161.7; HRMS ESI Obsd, *m/z* 357.0889; calcd for $C_{16}H_{18}N_2O_4NaS$, *m/z* 357.0885 $[M+Na]^+$; UV (MeOH) λ_{max} 260, 324 nm.

6.4.3. 5-(2-Furyl)-1-[2-(2-phenyl-1,3-dioxan-5-yliden)-ethyl]-2,4(1*H*,3*H*)-pyrimidinedione (17a). Eluant PE/EtOAc 5/5; yield 75%; pale yellow gum; ^{1}H NMR ($CDCl_3$) δ 4.18–4.33 (m, 1H), 4.42–4.68 (m, 4H), 4.93–5.07 (m, 1H), 5.51 (t, 1H, $J=6.4$ Hz), 5.68 (s, 1H), 6.45–6.47 (m, 1H), 7.08–7.10 (m, 1H), 7.28–7.42 (m, 4H), 7.47–7.55 (m, 2H), 7.65 (s, 1H), 10.05 (s, NH); ^{13}C NMR ($CDCl_3$) δ 44.6 (CH_2), 65.8 (CH_2), 71.6 (CH_2), 101.5 (CH), 107.5, 109.6 (CH), 111.9 (CH), 118.7 (CH), 126.2 (CH $\times$ 2), 128.4 (CH $\times$2), 129.1 (CH), 135.7, 137.3 (CH), 137.8, 141.3 (CH), 145.6, 150.1, 160.7; HRMS ESI Obsd, *m/z* 389.3741; calcd for $C_{20}H_{18}N_2O_5Na$, *m/z* 389.3748 $[M+Na]^+$; UV (MeOH) λ_{max} 284 nm.

6.4.4. 1-[2-(2-Phenyl-1,3-dioxan-5-yliden)ethyl]-5-(2-thienyl)-2,4(1*H*,3*H*)-pyrimidinedione (17b). Eluant PE/EtOAc 5/5; yield 76%; pale yellow gum; ^{1}H NMR (DMSO-d_6) δ 4.35–4.56 (m, 5H), 5.00–5.09 (m, 1H), 5.48–5.61 (m, 1H), 5.71 (s, 1H), 6.99–7.12 (m, 1H), 7.28–7.52 (m, 8H), 8.30 (s, 1H), 11.69 (s, NH); ^{13}C NMR (DMSO-d_6) δ 44.2 (CH_2), 65.3 (CH_2), 70.6 (CH_2), 100.4 (CH), 107.9, 119.6 (CH), 122.6 (CH), 125.6 (CH), 126.1 (CH $\times$2), 126.4 (CH), 128.1 (CH $\times$2), 128.7 (CH), 133.8, 133.9, 138.3, 140.7 (CH), 149.8, 161.7; HRMS ESI Obsd, *m/z* 405.0880; calcd for $C_{20}H_{18}N_2O_4NaS$, *m/z* 405.0885 $[M+Na]^+$; UV (MeOH) λ_{max} 260, 324 nm.

6.5. General procedure for deprotection

Acetal derivatives (0.22 mmol) were stirred at room temperature during 3 h in mixture of TFA/H_2O (10 mL/5 mL). After evaporation of volatiles, crude residue are purified by flash chromatography.

6.5.1. 1-[(*E*)-4,5-dihydroxy-2-pentenyl]-2,4 (1*H*,3*H*)-pyrimidinedione (9a). Eluant CH_2Cl_2/MeOH 8/2; yield

98%; pale yellow gum; ^{1}H NMR (DMSO-d_6) δ 3.20–3.26 (m, 2H), 3.82–3.97 (m, 1H), 4.27–4.31 (m, 2H), 4.57 (t, OH, J=5.6 Hz), 4.79 (d, OH, J=4.8 Hz), 5.51–5.65 (m, 3H), 7.43 (d, 1H, J=7.6 Hz), 11.17 (s, NH); ^{13}C NMR (DMSO-d_6) δ 38.8 (CH_2), 65.9 (CH_2), 71.4 (CH), 99.8 (CH), 123.8 (CH), 134.1 (CH), 140.8 (CH), 151.2, 162.8; HRMS ESI Obsd, *m/z* 235.0697; calcd for $C_9H_{12}N_2O_4Na$, *m/z* 235.0695 $[M+Na]^+$; UV (MeOH) λ_{max} 265 nm.

6.5.2. 1-[(*E*)-4,5-dihydroxy-2-pentenyl]-5-methyl-2,4-(1*H*,3*H*)-pyrimidinedione (9b). Eluant CH_2Cl_2/MeOH 8/2; yield 96%; pale yellow gum; ^{1}H NMR (DMSO-d_6) δ 1.74 (s, 3H), 3.22–3.32 (m, 2H), 3.89–4.01 (m, 1H), 4.18–4.25 (m, 2H), 4.60 (t, OH, J=5.8 Hz), 4.85 (d, OH, J=5.0 Hz), 5.57–5.65 (m, 2H), 7.44 (s, 1H), 11.23 (s, NH); ^{13}C NMR (DMSO-d_6) δ 12.0 (CH_3), 48.1 (CH_2), 65.8 (CH_2), 71.3 (CH), 108.7, 124.2 (CH), 135.2 (CH), 141.0 (CH), 150.7, 164.3; HRMS ESI Obsd, *m/z* 249.0851; calcd for $C_{10}H_{14}N_2O_4Na$, *m/z* 249.0851 $[M+Na]^+$; UV (MeOH) λ_{max} 270 nm.

6.5.3. 1-[(*E*)-4,5-dihydroxy-2-pentenyl]-5-iodo-2,4(1*H*,3*H*)-pyrimidinedione (9c). Eluant CH_2Cl_2/MeOH 8/2; yield 97%; pale yellow gum; ^{1}H NMR (DMSO-d_6) δ 3.21–3.35 (m, 2H), 3.91–4.03 (m, 1H), 4.22–4.36 (m, 2H), 5.61–5.79 (m, 2H), 8.12 (s, 1H), 11.64 (s, NH); ^{13}C NMR (DMSO-d_6) δ 48.9 (CH_2), 65.7 (CH_2), 68.4, 71.4 (CH), 124.2 (CH), 135.8 (CH), 149.8 (CH), 150.6, 161.3; HRMS ESI Obsd, *m/z* 361.1015; calcd for $C_9H_{11}IN_2O_4Na$, *m/z* 361.1011 $[M+Na]^+$; UV (MeOH) λ_{max} 290 nm.

6.5.4. 1-[(*E*)-4,5-dihydroxy-2-pentenyl]-5-fluoro-2,4(1*H*,3*H*)-pyrimidinedione (9d). Eluant CH_2Cl_2/MeOH 8/2; yield 97%; pale yellow gum; ^{1}H NMR (DMSO-d_6) δ 3.14–3.32 (m, 2H), 3.94–3.99 (m, 1H), 4.18–4.35 (m, 2H), 4.61 (t, OH, J=5.6 Hz), 4.85 (d, OH, J=4.8 Hz), 5.62–5.78 (m, 2H), 7.99 (d, 1H, J=6.6 Hz), 11.77 (brs, NH); ^{13}C NMR (DMSO-d_6) δ 48.6 (CH_2), 65.7 (CH_2), 71.3 (CH), 123.6 (CH), 129.5 (CH), 135.7 (CH), 139.6 (C–F), 149.4, 157.2; HRMS ESI Obsd, *m/z* 253.1957; calcd for $C_9H_{11}FN_2O_4Na$, *m/z* 253.1953 $[M+Na]^+$; UV (MeOH) λ_{max} 270 nm.

6.5.5. 1-[4-Hydroxy-3-(hydroxymethyl)-2-butenyl]-2,4(1*H*,3*H*)-pyrimidinedione (10a). Eluant CH_2Cl_2/MeOH 9/1; yield 98%; pale yellow gum; ^{1}H NMR (DMSO-d_6) δ 3.94 (d, 2H, J=5.0 Hz), 4.03 (d, 2H,, J=5.3 Hz), 4.38 (d, 2H,, J=7.0 Hz), 4.75 (t, OH, J=5.0 Hz), 4.82 (t, OH, J=5.3 Hz), 5.44 (t, 1H, J=7.0 Hz), 5.55 (d, 1H, J=7.2 Hz), 7.59 (d, 1H, J=7.2 Hz), 11.24 (s, NH); ^{13}C NMR (DMSO-d_6) δ 44.2 (CH_2), 56.9 (CH_2), 62.4 (CH_2), 101.1 (CH), 118.7 (CH), 144.7, 145.3 (CH), 150.9, 163.7; HRMS ESI Obsd, *m/z* 235.0690; calcd for $C_9H_{12}N_2O_4Na$, *m/z* 235.0695 $[M+Na]^+$; UV (MeOH) λ_{max} 265 nm.

6.5.6. 1-[4-Hydroxy-3-(hydroxymethyl)-2-butenyl]-5-methyl-2,4(1*H*,3*H*)-pyrimidinedione (10b). Eluant CH_2Cl_2/MeOH 9/1; yield 97%; pale yellow gum; ^{1}H NMR (DMSO-d_6) δ 1.74 (s, 3H), 3.94 (d, 2H, J=5.0 Hz), 4.03 (d, 2H,, J=5.3 Hz), 4.35 (d, 2H,, J=7.0 Hz), 4.72 (t, OH, J=5.0 Hz), 4.80 (t, OH, J=5.3 Hz), 5.43 (t, 1H, J=7.0 Hz), 7.47 (s, 1H), 11.22 (s, NH); ^{13}C NMR (DMSO-d_6) δ 11.9 (CH_3), 43.9 (CH_2), 56.9 (CH_2), 62.4 (CH_2), 108.7, 118.9 (CH), 141.0, 144.4 (CH), 150.9, 164.3; HRMS ESI Obsd, *m/z* 249.0850; calcd for $C_{10}H_{14}N_2O_4Na$, *m/z* 249.0851 $[M+Na]^+$; UV (MeOH) λ_{max} 270 nm.

6.5.7. 1-[4-Hydroxy-3-(hydroxymethyl)-2-butenyl]-5-iodo-2,4(1*H*,3*H*)-pyrimidinedione (10c). Eluant CH_2Cl_2/MeOH 9/1; yield 92%; pale yellow gum; ^{1}H NMR (DMSO-d_6) δ 3.94 (d, 2H, J=5.0 Hz), 4.02 (d, 2H, J=5.0 Hz), 4.40 (d, 2H, J=6.9 Hz), 4.76 (t, OH, J=5.0 Hz), 4.83 (t, OH, J=5.0 Hz), 5.44 (t, 1H, J=6.9 Hz), 8.13 (s, 1H), 11.60 (s, NH); ^{13}C NMR (DMSO-d_6) δ 44.6 (CH_2), 56.9 (CH_2), 62.4 (CH_2), 68.3, 118.7 (CH), 144.9, 149.6 (CH), 150.7, 161.1; HRMS ESI Obsd, *m/z* 360.9666; calcd for $C_9H_{11}N_2O_4INa$, *m/z* 360.9661 $[M+Na]^+$; UV (MeOH) λ_{max} 290 nm.

6.5.8. 5-Fluoro-1-[4-hydroxy-3-(hydroxymethyl)-2-butenyl]-2,4(1*H*,3*H*)-pyrimidinedione (10d). Eluant CH_2Cl_2/MeOH 9/1; yield 95%; pale yellow gum; ^{1}H NMR (DMSO-d_6) δ 3.94 (d, 2H, J=5.0 Hz), 4.02 (d, 2H, J=5.0 Hz), 4.34 (d, 2H, J=7.2 Hz), 4.75–4.85 (m, OH ×2), 5.45 (t, 1H, J=7.2 Hz), 8.01 (d, 1H, J=6.9 Hz), 11.78 (s, NH); ^{13}C NMR (DMSO-d_6) δ 44.5 (CH_2), 56.9 (CH_2), 62.4 (CH_2), 118.4 (CH), 129.7 (CH), 139.2 (C–F), 145.1, 149.6, 157.4; HRMS ESI Obsd, *m/z* 253.1952; calcd for $C_9H_{11}FN_2O_4Na$, *m/z* 253.1955 $[M+Na]^+$; UV (MeOH) λ_{max} 270 nm.

6.5.9. 1-[(*E*)-4,5-dihydroxy-2-pentenyl]-5-(2-furyl)-2,4(1*H*,3*H*)-pyrimidinedione (18a). Eluant CH_2Cl_2/MeOH 9/1; yield 93%; pale yellow gum; ^{1}H NMR (DMSO-d_6) δ 3.18–3.32 (m, 2H), 3.88–4.03 (m, 1H), 4.37–4.41 (m, 2H), 4.60 (t, OH, J=5.6 Hz), 4.87 (d, OH, J=5.0 Hz), 5.66–5.81 (m, 2H), 6.52 (dd, 1H, J=1.0, 3.4 Hz), 6.85 (d, 1H, J=3.4 Hz), 7.65 (d, 1H, J=1.0 Hz), 8.00 (s, 1H), 11.62 (s, NH); ^{13}C NMR (DMSO-d_6) δ 48.7 (CH_2), 65.8 (CH_2), 71.3 (CH), 105.1, 107.8 (CH), 111.7 (CH), 124.0 (CH), 135.5 (CH), 139.4 (CH), 141.4 (CH), 146.4, 149.7, 160.6; HRMS ESI Obsd, *m/z* 301.0806; calcd for $C_{13}H_{14}N_2O_5Na$, *m/z* 301.0800 $[M+Na]^+$; UV (MeOH) λ_{max} 284 nm.

6.5.10. 1-[(*E*)-4,5-dihydroxy-2-pentenyl]-5-(2-thienyl)-2,4(1*H*,3*H*)-pyrimidinedione (18b). Eluant CH_2Cl_2/MeOH 9/1; yield 90%; pale yellow gum; ^{1}H NMR (DMSO-d_6) δ 3.19–3.32 (m, 2H), 3.88–4.02 (m, 1H), 4.31–4.48 (m, 2H), 4.60 (t, OH, J=5.7 Hz), 4.86 (d, OH, J=5.0 Hz), 5.68–5.85 (m, 2H), 7.06 (dd, 1H, J=4.2 Hz), 7.44 (d, 2H, J=4.2 Hz), 8.21 (s, 1H), 11.65 (s, NH); ^{13}C NMR (DMSO-d_6) δ 48.8 (CH_2), 65.7 (CH_2), 71.3 (CH), 107.9, 122.6 (CH), 124.0 (CH), 125.5 (CH), 126.4 (CH), 133.9, 135.6 (CH), 140.7 (CH), 149.7, 161.8; HRMS ESI Obsd, *m/z* 317.0572; calcd for $C_{13}H_{14}N_2O_4NaS$, *m/z* 317.0572 $[M+Na]^+$; UV (MeOH) λ_{max} 260, 324 nm.

6.5.11. 5-(2-Furyl)-1-[4-hydroxy-3-(hydroxymethyl)-2-butenyl]-2,4(1*H*,3*H*)-pyrimidinedione (19a). Eluant CH_2Cl_2/MeOH 9/1; yield 96%; pale yellow gum; ^{1}H NMR (DMSO-d_6) δ 3.95 (d, 2H,, J=4.4 Hz), 4.05 (d, 2H, J=5.1 Hz), 4.51 (d, 2H, J=6.6 Hz), 4.78–4.84 (m, OH × 2), 5.47 (t, 1H, J=6.6 Hz), 6.21–6.22 (m, 1H), 6.79–6.81 (m, 1H), 7.34–7.36 (m, 1H), 7.90 (s, 1H), 11.59 (s, NH); ^{13}C NMR (DMSO-d_6) δ 44.7 (CH_2), 57.0 (CH_2), 62.4 (CH_2), 105.0, 108.8 (CH), 109.5 (CH), 118.9 (CH), 139.2 (CH), 144.7 (CH), 145.9, 149.8, 152.4, 160.5; HRMS ESI Obsd, *m/z* 301.2647; calcd for $C_{13}H_{14}N_2O_5Na$, *m/z* 301.2642 $[M+Na]^+$; UV (MeOH) λ_{max} 284 nm.

6.5.12. 1-[4-Hydroxy-3-(hydroxymethyl)-2-butenyl]-5-(2-thienyl)-2,4(1*H*,3*H*)-pyrimidinedione (19b). Eluant CH_2Cl_2/MeOH 9/1; yield 93%; pale yellow gum; ^{1}H NMR (DMSO-d_6) δ 3.96 (d, 2H, $J=5.0$ Hz), 4.07 (d, 2H, $J=5.3$ Hz), 4.50 (d, 2H, $J=7.0$ Hz), 4.77–4.83 (m, OH $\times$ 2), 5.53 (t, 1H, $J=7.0$ Hz), 7.05 (dd, 1H, $J=3.8$, 5.0 Hz), 7.43 (t, 2H, $J=5.0$ Hz), 8.25 (s, 1H), 11.65 (s, NH); ^{13}C NMR (DMSO-d_6) δ 44.8 (CH_2), 56.9 (CH_2), 62.4 (CH_2), 107.8, 118.9 (CH), 122.5 (CH), 125.5 (CH), 126.4 (CH), 133.9, 140.8 (CH), 144.8, 149.8, 161.7; HRMS ESI Obsd, *m/z* 317.0574; calcd for $C_{13}H_{14}N_2O_4NaS$, *m/z* 317.0572 $[M+Na]^+$; UV (MeOH) λ_{max} 260, 324 nm.

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