CRYSTALLINE FGFR4 INHIBITOR COMPOUND AND USES THEREOF

CROSS-REFERENCE TO RELATED APPLICATIONS

This application claims priority to United States Provisional Patent Application No. 62/147,313, filed on April 14, 2015. That application is incorporated by reference herein.

BACKGROUND

Fibroblast growth factors (FGF) are a family of more than 20 structurally related proteins with a variety of biological activities. Their main receptors, the fibroblast growth factor receptors (FGFR1, FGFR2, FGFR3 and FGFR4), are a family of receptor tyrosine kinases that bind FGF and are involved in processes of cell proliferation and differentiation. Deregulation of FGFR signaling networks is implicated in a number of pathophysiological conditions, including many types of human cancers.

"Fibroblast Growth Factor Receptor 4" or "FGFR4" is known to regulate proliferation and antiapoptosis and is expressed or highly expressed in many cancers. *See, e.g.*, Dieci et al. 2013, Cancer Discovery, 0F1-0F16. Studies have shown that expression of FGFR4 is predictive of a more aggressive phenotype of the cancer, and knockdown or reduction of FGFR4 expression serves to reduce proliferation and promote apoptosis. *See, e.g.*, Wesche et al. 2011, Biochem J 437:199-213.

For example, FGFR4 expression or overexpression is associated with cancer aggressiveness in gastric cancer (Ye et al. 2011, Cancer, 5304-5313), prostate cancer (Xu et al. 2011, BMC Cancer, 11;84), sarcoma such as rhabdomyosarcoma (Taylor VI et al. 2009, J Clin Invest, 119(11):3395-3407), skin cancer such as melanoma (Streit et al. 2006, British J Cancer, 94:1879-1886), liver cancer such as cholangiocarcinoma (Sia et al. 2013, Gastroenterology 144:829-840) and hepatocellular carcinoma (French et al. 2012, PLoS ONE 7(5): e367313; Miura et al. 2012, BMC Cancer 12:56; Chiang et al. 2008, Cancer Res 68(16):6779-6788; Sawey et al. 2011, Cancer Cell 19:347-358), pancreatic cancer such as pancreatic intraepithelial neoplasia and pancreatic ductal adenocarcinoma (Motoda et al. 2011, Int'l J Oncol 38:133-143), lung cancer such as non-small-cell lung cancer (Fawdar et al. 2013, PNAS 110(30):12426-12431), colorectal cancer (Pelaez-Garcia et al. 2013, PLoS ONE 8(5): e63695; Barderas et al. 2012, J Proteomics 75:4647-4655), and ovarian cancer (Zaid et al. 2013, Clin Cancer Res

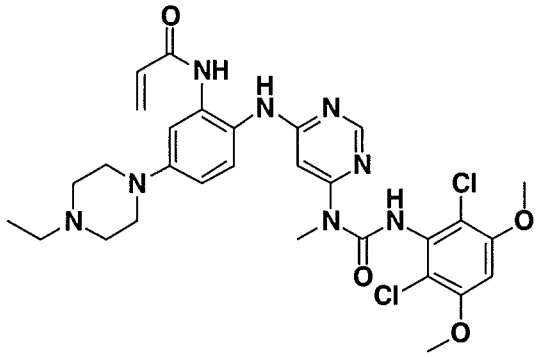
19:809-820).

Clinical development of several FGFR inhibitors have confirmed their utility as antitumor agents. Dieci et al. 2013, Cancer Discovery, 0F1-0F16. However, new agents are needed that are useful to target FGFR, and FGFR4, in particular.

Furthermore, in the manufacture of pharmaceutical products, the compound should be in a form that can be conveniently manipulated and processed. In this regard, chemical stability and physical stability of the active compound are important considerations. Preferably, the compound and pharmaceutical compositions containing it are capable of being effectively stored over long periods of time without exhibiting significant change in physico-chemical characteristics.

SUMMARY

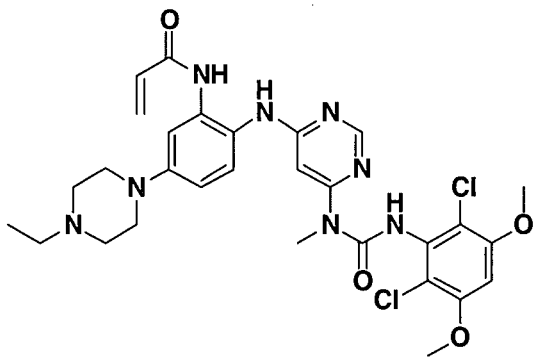
Embodiments of the invention may provide a crystalline form of the compound:



N-(2-((6-(3-(2,6-dichloro-3,5-dimethoxyphenyl)-1-methylureido)pyrimidin-4-yl)amino)-5-(4-ethylpiperazin-1-yl)phenyl)acrylamide

In some embodiments, for example, a crystalline form may be a free base form, a hydrochloride salt form, a monohydrochloride salt form, a dihydrochloride salt form, or an ethanesulfonate salt form.

Embodiments may provide a crystalline free base form of *N*-(2-((6-(3-(2,6-dichloro-3,5-dimethoxyphenyl)-1-methylureido)pyrimidin-4-yl)amino)-5-(4-ethylpiperazin-1-yl)phenyl)acrylamide (Compound 108):



N-(2-((6-(3-(2,6-dichloro-3,5-dimethoxyphenyl)-1-methylureido)pyrimidin-4-yl)amino)-5-(4-ethylpiperazin-1-yl)phenyl)acrylamide

(Compound 108).

In some embodiments, the crystalline free base form compound gives peaks in a powder X-ray diffraction (PXRD) spectra at least one, two, three, four, five or six of the following value ranges of 2θ°: 7.8-8.2; 10.1-10.5; 14.6-15.0; 16.3-16.7; 16.9-17.3; and 21.6-22.0. For example, the compound may exhibit at least one, two, three, four, five or six values of 2θ° (± 0.2 °) selected from the group consisting of: 8.0, 10.3, 14.8, 16.5 17.1 and 21.8. In some embodiments, the crystalline free base compound is characterized by a PXRD pattern substantially as indicated in Figure 5 (FIG. 5). In some embodiments the crystalline free base form of the compound gives peaks in powder X-ray diffraction spectra at the following ranges of 2θ° (±0.2): at least 10.3, 8.0 and 9.5; at least 10.3, 8.0, 9.5, 14.8, 16.5, and 17.1; or at least 10.3, 8.0, 9.5, 14.8, 16.5, 17.1, 19.3, 21.8, 23.7, and 24.5.

In some embodiments, the crystalline free base form is characterized by a differential scanning calorimetry (DSC) curve substantially the same as shown in Figure 7 (FIG. 7).

In some embodiments, the crystalline free base form compound is characterized by a ^{13}C NMR substantially as shown in Figure 10 (FIG. 10).

Some embodiments may provide a compound that is a crystalline *N*-(2-((6-(3-(2,6-dichloro-3,5-dimethoxyphenyl)-1-methylureido)pyrimidin-4-yl)amino)-5-(4-ethylpiperazin-1-yl)phenyl)acrylamide monohydrochloride salt. In some embodiments the crystalline *N*-(2-((6-(3-(2,6-dichloro-3,5-dimethoxyphenyl)-1-methylureido)pyrimidin-4-yl)amino)-5-(4-ethylpiperazin-1-yl)phenyl)acrylamide monohydrochloride salt gives peaks in powder X-ray diffraction spectra at the following ranges of 2θ° (±0.2): at least 26.6, 19.9, and 11.3; at least 26.6, 19.9, 11.3, 9.0, 23.5, and 25.4; or at least 26.6, 19.9, 11.3, 9.0, 23.5, 25.4, 27.6, 23.0, 18.1, and 29.0. In some embodiments, the crystalline *N*-(2-((6-(3-(2,6-dichloro-3,5-dimethoxyphenyl)-1-methylureido)pyrimidin-4-yl)amino)-5-(4-ethylpiperazin-1-yl)phenyl)acrylamide

monohydrochloride salt is characterized by a PXRD spectrum substantially as shown in Figure 13 (FIG. 13).

In some embodiments, the crystalline *N*-(2-((6-(3-(2,6-dichloro-3,5-dimethoxyphenyl)-1-methylureido)pyrimidin-4-yl)amino)-5-(4-ethylpiperazin-1-yl)phenyl)acrylamide monohydrochloride salt is characterized by a ^{13}C NMR substantially as shown in Figure 11 (FIG. 11).

Some embodiments may provide a compound that is a crystalline form of *N*-(2-((6-(3-(2,6-dichloro-3,5-dimethoxyphenyl)-1-methylureido)pyrimidin-4-yl)amino)-5-(4-ethylpiperazin-1-yl)phenyl)acrylamide dihydrochloride salt. In some embodiments the crystalline *N*-(2-((6-(3-(2,6-dichloro-3,5-dimethoxyphenyl)-1-methylureido)pyrimidin-4-yl)amino)-5-(4-ethylpiperazin-1-yl)phenyl)acrylamide dihydrochloride salt gives peaks in powder X-ray diffraction spectra at the following ranges of 2θ° (±0.2): at least 26.6, 22.8, and 21.3; at least 26.6, 22.8, 21.3, 8.0, 26.2, and 13.5; or at least 26.6, 22.8, 21.3, 8.0, 26.2, 13.5, 12.4, 16.1, 28.0, and 18.7. In some embodiments, the crystalline *N*-(2-((6-(3-(2,6-dichloro-3,5-dimethoxyphenyl)-1-methylureido)pyrimidin-4-yl)amino)-5-(4-ethylpiperazin-1-yl)phenyl)acrylamide dihydrochloride salt is characterized by a PXRD spectrum substantially as shown in Figure 16 (FIG. 16).

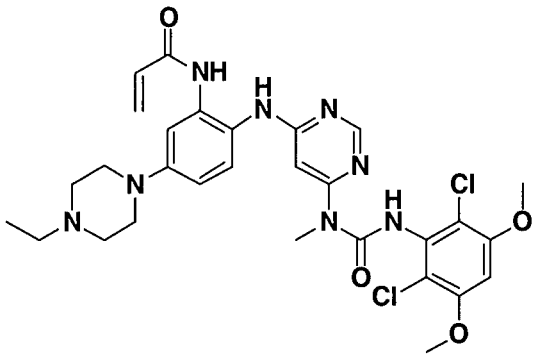
In some embodiments, the crystalline *N*-(2-((6-(3-(2,6-dichloro-3,5-dimethoxyphenyl)-1-methylureido)pyrimidin-4-yl)amino)-5-(4-ethylpiperazin-1-yl)phenyl)acrylamide dihydrochloride salt is characterized by a ^{13}C NMR substantially as shown in Figure 14 (FIG. 14).

Embodiments may provide a compound that is a crystalline form of *N*-(2-((6-(3-(2,6-dichloro-3,5-dimethoxyphenyl)-1-methylureido)pyrimidin-4-yl)amino)-5-(4-ethylpiperazin-1-yl)phenyl)acrylamide ethanesulfonate salt. In some embodiments the crystalline *N*-(2-((6-(3-(2,6-dichloro-3,5-dimethoxyphenyl)-1-methylureido)pyrimidin-4-yl)amino)-5-(4-ethylpiperazin-1-yl)phenyl)acrylamide ethanesulfonate salt gives peaks in powder X-ray diffraction spectra at the following ranges of 2θ° (±0.2): at least 19.2, 15.1, and 23.3; at least 19.2, 15.1, 23.3, 20.3, 11.2, and 21.8; or at least 19.2, 15.1, 23.3, 20.3, 11.2, 21.8, 9.4, 22.4, 23.6, and 24.0. In some embodiments, the crystalline *N*-(2-((6-(3-(2,6-dichloro-3,5-dimethoxyphenyl)-1-methylureido)pyrimidin-4-yl)amino)-5-(4-ethylpiperazin-1-yl)phenyl)acrylamide ethanesulfonate salt is characterized by a PXRD spectrum substantially as shown in Figure 19 (FIG. 19).

In some embodiments, the crystalline *N*-(2-((6-(3-(2,6-dichloro-3,5-dimethoxyphenyl)-1-methylureido)pyrimidin-4-yl)amino)-5-(4-ethylpiperazin-1-yl)phenyl)acrylamide ethanesulfonate salt is characterized by a ^{13}C NMR substantially as shown in Figure 17 (FIG. 17).

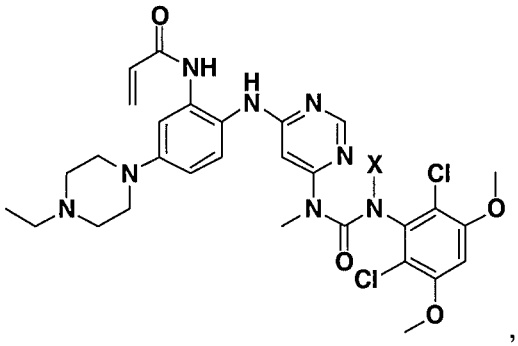
A further purpose is a pharmaceutical composition comprising a crystalline form compound as described herein and a pharmaceutically acceptable carrier. In some embodiments, the composition is formulated for oral or parenteral administration.

A further purpose is a method of making a crystalline free base form of the compound :



N-(2-((6-(3-(2,6-dichloro-3,5-dimethoxyphenyl)-1-methylureido)pyrimidin-4-yl)amino)-5-(4-ethylpiperazin-1-yl)phenyl)acrylamide

Such methods may include one or more of the steps of: a) providing a composition comprising a compound:



, wherein X is (2-(trimethylsilyl)ethoxy)methyl, in a solvent;

b) adding an acid to said composition at such rate as to maintain a temperature of the composition at ≤ 50 °C (e.g., ≤ 30, 20, or 15 °C);

c) allowing the composition formed in step b) to warm (e.g., to room temperature); and then

d) adding the composition to saturated ammonium hydroxide solution (e.g., cold, such as 0-5 °C) at such a rate as to maintain a temperature of the composition at ≤ 25 °C; and then

e) extracting the composition with a mixture of immiscible solvents (e.g., dichloromethane/methanol) to form an organic phase; and

f) adding a suitable solvent to the organic phase,

to thereby form said crystalline free base form of the compound.

A further purpose is a method of treating hepatocellular carcinoma in a subject in need thereof comprising administering to said subject a treatment effective amount of a crystalline form compound as described herein. In some embodiments, hepatocellular carcinoma has altered FGFR4 and/or FGF19 status (*e.g.*, increased expression of FGFR4 and/or FGF19).

A further purpose is a method of treating hepatocellular carcinoma in a subject in need thereof, comprising: detecting an altered FGFR4 and/or FGF19 status (*e.g.*, increased expression of FGFR4 and/or FGF19) in a biological sample containing cells of said hepatocellular carcinoma, and if said hepatocellular carcinoma has said altered FGFR4 and/or FGF19 status, administering a crystalline form compound as described herein to said subject in a treatment-effective amount.

A further purpose is the use of a crystalline form compound as described herein in a method of treatment of hepatocellular carcinoma.

A further purpose is the use of a crystalline form compound as described herein in the preparation of a medicament for the treatment of hepatocellular carcinoma.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 presents the results of *in vivo* efficacy testing in hepatocellular carcinoma model using HUH7 cells. Compound 108 (25 mg/kg or 37.5 mg/kg) or Vehicle control was administered via intraperitoneal injection, and tumor volume was measured twice weekly over the course of 15 days.

FIG. 2 presents the results of *in vivo* efficacy testing in hepatocellular carcinoma model using HEP3B cells. Compound 108 (12.5 mg/kg, 25 mg/kg or 37.5 mg/kg) or Vehicle control was administered via intraperitoneal injection, and tumor volume was measured twice weekly over the course of 15 days.

FIG. 3 presents the results of *in vivo* efficacy testing in hepatocellular carcinoma model using JHH7 cells. Compound 108 (12.5 mg/kg, 25 mg/kg or 37.5 mg/kg) or Vehicle control was administered via intraperitoneal injection, and tumor volume was measured twice weekly over the course of 15 days.

FIG. 4 presents the results of comparative *in vivo* efficacy testing in hepatocellular

carcinoma model using HEP3B cells. Compound 108 (25 mg/kg, 37.5 mg/kg or 50 mg/kg) was administered twice daily via intraperitoneal injection, or BGJ398 (30 mg/kg or 60 mg/kg) was administered orally twice daily.

FIG. 5 presents a PXRD spectrum obtained from crystalline free base form of Compound 108.

FIG. 6 presents an overlay of crystalline free base form of Compound 108 PXRD spectra from three lots.

FIG. 7 presents a DSC curve for crystalline free base form of Compound 108.

FIG. 8 presents an overlay of DSC curves for three lots of crystalline free base form of Compound 108.

FIGS. 9A-9D present ^{1}H-NMR spectrum consistent with the structure of Compound 108.

FIG. 10 presents a ^{13}C-NMR spectrum of crystalline free base form of Compound 108.

FIG. 11 presents ^{13}C-NMR spectrum of crystalline *N*-(2-((6-(3-(2,6-dichloro-3,5-dimethoxyphenyl)-1-methylureido)pyrimidin-4-yl)amino)-5-(4-ethylpiperazin-1-yl)phenyl)acrylamide monohydrochloride (i.e. the crystalline monohydrochloride salt form of Compound 108) obtained in Example 10 herein.

FIG. 12 presents a ^{1}H-NMR spectrum of *N*-(2-((6-(3-(2,6-dichloro-3,5-dimethoxyphenyl)-1-methylureido)pyrimidin-4-yl)amino)-5-(4-ethylpiperazin-1-yl)phenyl)acrylamide monohydrochloride obtained in Example 10 herein.

FIG. 13 presents a PXRD spectrum obtained from the crystalline *N*-(2-((6-(3-(2,6-dichloro-3,5-dimethoxyphenyl)-1-methylureido)pyrimidin-4-yl)amino)-5-(4-ethylpiperazin-1-yl)phenyl)acrylamide monohydrochloride obtained in Example 10 herein.

FIG. 14 presents a ^{13}C-NMR spectrum of crystalline *N*-(2-((6-(3-(2,6-dichloro-3,5-dimethoxyphenyl)-1-methylureido)pyrimidin-4-yl)amino)-5-(4-ethylpiperazin-1-yl)phenyl)acrylamide dihydrochloride (i.e. the crystalline dihydrochloride salt form of Compound 108) obtained in Example 13 herein.

FIG. 15 presents a ^{1}H-NMR spectrum of *N*-(2-((6-(3-(2,6-dichloro-3,5-dimethoxyphenyl)-1-methylureido)pyrimidin-4-yl)amino)-5-(4-ethylpiperazin-1-yl)phenyl)acrylamide dihydrochloride obtained in Example 13 herein.

FIG. 16 presents a PXRD spectrum obtained from the crystalline *N*-(2-((6-(3-(2,6-dichloro-3,5-dimethoxyphenyl)-1-methylureido)pyrimidin-4-yl)amino)-5-(4-ethylpiperazin-1-yl)phenyl)acrylamide dihydrochloride obtained in Example 13 herein.

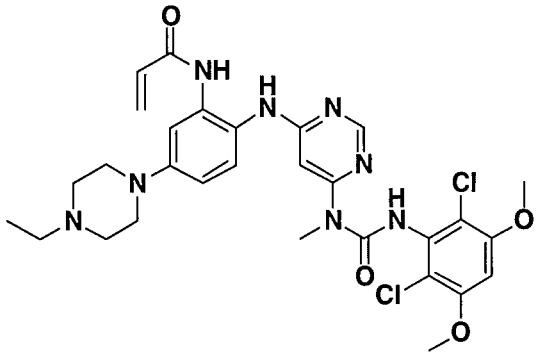
FIG. 17 presents a ^{13}C-NMR spectrum of crystalline *N*-(2-((6-(3-(2,6-dichloro-3,5-dimethoxyphenyl)-1-methylureido)pyrimidin-4-yl)amino)-5-(4-ethylpiperazin-1-yl)phenyl)acrylamide ethanesulfonate (i.e. the crystalline ethanesulfonate salt form of Compound 108) obtained in Example 16 herein.

FIG. 18 presents a ^{1}H-NMR spectrum of *N*-(2-((6-(3-(2,6-dichloro-3,5-dimethoxyphenyl)-1-methylureido)pyrimidin-4-yl)amino)-5-(4-ethylpiperazin-1-yl)phenyl)acrylamide ethanesulfonate obtained in Example 16 herein.

FIG. 19 presents a PXRD spectrum obtained from the crystalline *N*-(2-((6-(3-(2,6-dichloro-3,5-dimethoxyphenyl)-1-methylureido)pyrimidin-4-yl)amino)-5-(4-ethylpiperazin-1-yl)phenyl)acrylamide ethanesulfonate obtained in Example 16 herein.

DETAILED DESCRIPTION OF EMBODIMENTS

Provided herein are crystalline forms of the compound :



N-(2-((6-(3-(2,6-dichloro-3,5-dimethoxyphenyl)-1-methylureido)pyrimidin-4-yl)amino)-5-(4-ethylpiperazin-1-yl)phenyl)acrylamide , which is useful as a selective FGFR4 inhibitor.

In some embodiments, the crystalline compound is the free base form of *N*-(2-((6-(3-(2,6-dichloro-3,5-dimethoxyphenyl)-1-methylureido)pyrimidin-4-yl)amino)-5-(4-ethylpiperazin-1-yl)phenyl)acrylamide. An embodiment of the crystalline free base form gives peaks in a powder X-ray diffraction (PXRD) spectra at one, two, three, four, five, six or more of the following value ranges of 2θ°: 7.8-8.2; 10.1-10.5; 14.6-15.0; 16.3-16.7; 16.9-17.3; and 21.6-22.0. For example the crystalline free base form compound may exhibit at least one, two, three, four, five or six values selected from the group consisting of 2θ° (± 0.2 °): 8.0, 10.3, 14.8, 16.5 17.1 and 21.8. In some embodiments, the crystalline free base compound is characterized by a PXRD pattern substantially as shown in FIG. 5. In some embodiments the crystalline free base form of the compound gives peaks in powder X-ray diffraction spectra at the following ranges of 2θ°

(±0.2): at least 10.3, 8.0 and 9.5; at least 10.3, 8.0, 9.5, 14.8, 16.5, and 17.1; or at least 10.3, 8.0, 9.5, 14.8, 16.5, 17.1, 19.3, 21.8, 23.7, and 24.5.

In some embodiments, the crystalline free base form is characterized by a differential scanning calorimetry (DSC) curve substantially the same as shown in Figure 7.

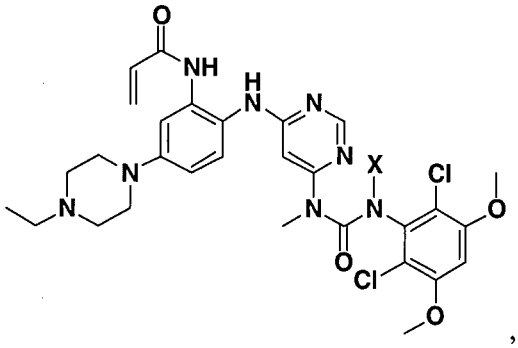
Some embodiments may provide a compound that is a crystalline *N*-(2-((6-(3-(2,6-dichloro-3,5-dimethoxyphenyl)-1-methylureido)pyrimidin-4-yl)amino)-5-(4-ethylpiperazin-1-yl)phenyl)acrylamide monohydrochloride salt. In some embodiments the crystalline *N*-(2-((6-(3-(2,6-dichloro-3,5-dimethoxyphenyl)-1-methylureido)pyrimidin-4-yl)amino)-5-(4-ethylpiperazin-1-yl)phenyl)acrylamide monohydrochloride salt gives peaks in powder X-ray diffraction spectra at the following ranges of 2θ° (±0.2): at least 26.6, 19.9, and 11.3; at least 26.6, 19.9, 11.3, 9.0, 23.5, and 25.4; or at least 26.6, 19.9, 11.3, 9.0, 23.5, 25.4, 27.6, 23.0, 18.1, and 29.0. Such an embodiment may have a PXRD spectrum as shown in FIG. 13.

Some embodiments may provide a compound that is a crystalline form of *N*-(2-((6-(3-(2,6-dichloro-3,5-dimethoxyphenyl)-1-methylureido)pyrimidin-4-yl)amino)-5-(4-ethylpiperazin-1-yl)phenyl)acrylamide dihydrochloride salt. In some embodiments the crystalline *N*-(2-((6-(3-(2,6-dichloro-3,5-dimethoxyphenyl)-1-methylureido)pyrimidin-4-yl)amino)-5-(4-ethylpiperazin-1-yl)phenyl)acrylamide dihydrochloride salt gives peaks in powder X-ray diffraction spectra at the following ranges of 2θ° (±0.2): at least 26.6, 22.8, and 21.3; at least 26.6, 22.8, 21.3, 8.0, 26.2, and 13.5; or at least 26.6, 22.8, 21.3, 8.0, 26.2, 13.5, 12.4, 16.1, 28.0, and 18.7. Such an embodiment may have a PXRD spectrum as shown in FIG. 16.

Embodiments may provide a compound that is a crystalline form of *N*-(2-((6-(3-(2,6-dichloro-3,5-dimethoxyphenyl)-1-methylureido)pyrimidin-4-yl)amino)-5-(4-ethylpiperazin-1-yl)phenyl)acrylamide ethanesulfonate salt. In some embodiments the crystalline *N*-(2-((6-(3-(2,6-dichloro-3,5-dimethoxyphenyl)-1-methylureido)pyrimidin-4-yl)amino)-5-(4-ethylpiperazin-1-yl)phenyl)acrylamide ethanesulfonate salt gives peaks in powder X-ray diffraction spectra at the following ranges of 2θ° (±0.2): at least 19.2, 15.1, and 23.3; at least 19.2, 15.1, 23.3, 20.3, 11.2, and 21.8; or at least 19.2, 15.1, 23.3, 20.3, 11.2, 21.8, 9.4, 22.4, 23.6, and 24.0. Such an embodiment may have a PXRD spectrum as shown in FIG. 19.

As used herein, "substantially as shown." "substantially the same," or "substantially as indicated" with reference to data such as a spectrum means that the skilled person, when comparing such spectra obtained using the same methods of collection of the data, for example, such as shown in Figure 6, would conclude that the spectra are similar enough to be indicative of the same crystalline free base form of the compound as taught herein.

Also provided are methods of synthesizing and crystallizing compounds as taught herein. For a crystalline free base form, methods may include one or more of the steps of: a) providing a composition comprising a compound:



, wherein X is (2-(trimethylsilyl)ethoxy)methyl, in a solvent;

b) adding an acid to said composition at such rate as to maintain a temperature of the composition $\leq$ 50 °C (e.g., $\leq$ 30, 20, or 15 °C);

c) allowing the composition formed in step b) to warm (e.g., to room temperature); and then

d) adding the composition to saturated ammonium hydroxide solution (e.g., cold, such as 0-5 °C) at such a rate as to maintain a temperature of the composition $\leq$ 25 °C; and then

e) extracting the composition with a mixture of immiscible solvents (e.g., dichloromethane/methanol) to form an organic phase; and

f) adding a suitable solvent to the organic phase,

to thereby form said crystalline free base form of the compound.

A crystalline compound as reported herein may be combined with a pharmaceutically acceptable carrier to provide pharmaceutical formulations thereof. The particular choice of carrier and formulation will depend upon the particular route of administration for which the composition is intended. In some embodiments, the carrier is selected so as to maintain the crystalline form of the compound prior to administration.

"Pharmaceutically acceptable carrier" as used herein refers to a nontoxic carrier, adjuvant, or vehicle that does not destroy the pharmacological activity of the compound with which it is formulated. In some embodiments, the pharmaceutically acceptable carrier is selected so as to maintain the crystalline free base form of the compound. Pharmaceutically acceptable carriers, adjuvants or vehicles may include, but are not limited to, sorbic acid, potassium sorbate, partial glyceride mixtures of saturated vegetable fatty acids, water, salts or electrolytes, disodium hydrogen phosphate, potassium hydrogen phosphate, sodium chloride, zinc salts, colloidal silica,

magnesium trisilicate, polyvinyl pyrrolidone, cellulose-based substances, polyethylene glycol, sodium carboxymethylcellulose, polyacrylates, waxes, polyethylene glycol and wool fat.

The compositions of the present invention may be suitable for parenteral, oral, inhalation spray, topical, rectal, nasal, buccal, vaginal or implanted reservoir administration, etc. In some embodiments, the formulation comprise ingredients that are from natural or non-natural sources. In some embodiments, the formulation or carrier may be provided in a sterile form. Non-limiting examples of a sterile carrier include endotoxin-free water or pyrogen-free water.

The term "parenteral" as used herein includes subcutaneous, intravenous, intramuscular, intra-articular, intra-synovial, intrasternal, intrathecal, intrahepatic, intralesional and intracranial injection or infusion techniques. In particular embodiments, the compounds are administered intravenously, orally, subcutaneously, or via intramuscular administration. Sterile injectable forms of the compositions of this invention may be aqueous or oleaginous suspension. These suspensions may be formulated according to techniques known in the art using suitable dispersing or wetting agents and suspending agents. The sterile injectable preparation may also be a sterile injectable solution or suspension in a nontoxic parenterally acceptable diluent or solvent. Among the acceptable vehicles and solvents that may be employed are water, Ringer's solution and isotonic sodium chloride solution. In addition, sterile, fixed oils are conventionally employed as a solvent or suspending medium.

For this purpose, any bland fixed oil may be employed including synthetic mono- or di-glycerides. Fatty acids and their glyceride derivatives are useful in the preparation of injectables, as are natural pharmaceutically acceptable oils, such as olive oil or castor oil, especially in their polyoxyethylated versions. These oil solutions or suspensions may also contain a long-chain alcohol diluent or dispersant, such as carboxymethyl cellulose or similar dispersing agents that are commonly used in the formulation of pharmaceutically acceptable dosage forms including emulsions and suspensions. Other commonly used surfactants, such as Tweens, Spans and other emulsifying agents that are commonly used in the manufacture of pharmaceutically acceptable solid, liquid, or other dosage forms may also be used for the purposes of formulation.

For oral administration, a compound or salt may be provided in an acceptable oral dosage form, including, but not limited to, capsules, tablets, aqueous suspensions or solutions. In the case of tablets for oral use, carriers commonly used include lactose and corn starch. Lubricating agents, such as magnesium stearate, may also be added. For oral administration in a capsule form, useful diluents include lactose and dried cornstarch. When aqueous suspensions are required for oral use, the active ingredient may be combined with emulsifying and suspending

agents. If desired, certain sweetening, flavoring or coloring agents may also be added. In addition preservatives may also be added. Suitable examples of pharmaceutically acceptable preservatives include, but are not limited to, various antibacterial and antifungal agents such as solvents, for example ethanol, propylene glycol, benzyl alcohol, chlorobutanol, quaternary ammonium salts, and parabens (such as methyl paraben, ethyl paraben, propyl paraben, etc.).

Subjects and methods of use

The crystalline form of the compound as taught herein may be used to treat hepatocellular carcinoma.

"Treatment," "treat," and "treating" refer to reversing, alleviating, delaying the onset of, inhibiting the progress of, or otherwise ameliorating a disease or disorder as described herein. In some embodiments, treatment may be administered after one or more symptoms have developed. In other embodiments, treatment may be administered in the absence of symptoms. For example, treatment may be administered to a susceptible individual prior to the onset of symptoms (*e.g.*, in light of a history of symptoms and/or in light of genetic or other susceptibility factors). Treatment may also be continued after symptoms have resolved, for example to prevent or delay their recurrence.

"Patient" or "subject", as used herein, means an animal subject, preferably a mammalian subject, and particularly human subjects (including both male and female subjects, and including neonatal, infant, juvenile, adolescent, adult and geriatric subjects). Subjects may also include other mammalian subjects (*e.g.*, dog, cat, horse, cow, sheep, goat, monkey, bird, etc.), for laboratory or veterinary purposes.

In some embodiments, treatment is provided to a subject having hepatocellular carcinoma with altered FGFR4 and /or FGF19 (fibroblast growth factor 19) status.

In some embodiments, treatment may include or be performed in conjunction with analyzing (*e.g.*, measuring or assaying for) FGFR4 and/or FGF19 status in a biological sample containing cells of said hepatocellular carcinoma, and if said hepatocellular carcinoma exhibits an FGFR4 and/or FGF19 alteration, treating a subject with a treatment effective amount of an active agent as described herein.

"Altered status" as used herein with reference to FGFR4 and/or FGF19 includes an increased expression thereof (*e.g.*, increased levels of the mRNA or increased levels of the protein), increased copy number in the genome, and/or increased activity of the encoded protein as a result of mutation, etc., as compared to a corresponding non-cancerous tissue. In some

embodiments, altered status of FGFR4 and/or FGF19 includes gene and/or encoded protein mutations that result in an increase in activity or are otherwise associated with a more aggressive form of hepatocellular carcinoma.

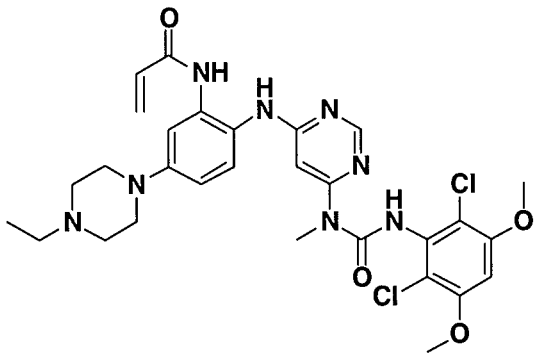
"Expression" of FGFR4 and/or FGF19 means that a gene encoding the same is transcribed, and preferably, translated. Typically, expression of a coding region will result in production of the encoded polypeptide.

The FGFR4 and FGF19 proteins are known, and their altered status and/or expression may be measured using techniques standard in the art, *e.g.*, genomic analysis of mutations or copy number aberrations such as by nucleic acid amplification, sequencing analysis, and/or hybridization-based techniques, RNA expression analysis such as northern blot or qRT-PCR, western blot or other immunoblot or immunoassay, fluorescent activated cell sorting (FACS), etc.

In order that the invention described herein may be more fully understood, the following examples are set forth. It should be understood that these examples are for illustrative purposes only and are not to be construed as limiting.

EXAMPLES

EXAMPLE 1: Procedures for the synthesis of:



N-(2-((6-(3-(2,6-dichloro-3,5-dimethoxyphenyl)-1-methylureido)pyrimidin-4-yl)amino)-5-(4-ethylpiperazin-1-yl)phenyl)acrylamide

(Compound 108)

General:

Microwave heating was done using a Biotage Emrys Liberator or Initiator microwave. Column chromatography was carried out using an Isco Rf200d. Solvent removal was carried out using either a Büchi rotary evaporator or a Genevac centrifugal evaporator. Preparative LC/MS

was conducted using a Waters autopurifier and 19 x 100mm XTerra 5 micron MS C18 column under acidic mobile phase conditions. NMR spectra were recorded using a Varian 400MHz spectrometer. Analytical mass spectra (MS) results were obtained using a Waters Acquity UPLC equipped with a single quadrapole MS detector (Waters SQD).

Preparative HPLC Conditions for Purification

Chromatography Conditions:

Instrument: Waters 2767-SQD Mass trigger Prep System
Column : Waters Xbridge C18 150mm*19mm*5μm
Detector: VWD SQD
Flow Rate : 15 mL/min
Gradient Time:

Time(min)	B%
0	5
7.5	70
8	95
11	95

Representative Mobile Phase:

1)
Mobile Phase: A: 0.1%TFA in water
Mobile Phase: B: ACN

2)
Mobile Phase: A: 0.1%NH_4HCO_3 in water
Mobile Phase: B: ACN

3)
Mobile Phase: A: 0.1%NH_4OAc in water
Mobile Phase: B: ACN

4)
Mobile Phase: A: 0.1%NH_4OH in water
Mobile Phase: B: ACN

Definitions: The following abbreviations have the indicated meanings:

ACN: Acetonitrile

Boc_2O: Di-tert-butyl dicarbonate

Brettphos: 2-(Dicyclohexylphosphino)-3,6-dimethoxy-2',4',6'-triisopropyl-1,1'-biphenyl

tBuONa: Sodium tert-butoxide

CH_3I: Iodomethane

Cs_2CO_3: Cesium carbonate

DCC: N,N'-dicyclohexylcarbodiimide

DCM: Dichloromethane

DIEA: N,N-diisopropylethylamine

DIPEA: N,N-diisopropylethylamine

DMAP: 4-(Dimethylamino)pyridine

DME: Dimethyl ether

DMF: Dimethylformamide

DMSO: Dimethyl sulfoxide

EGTA: Ethylene glycol tetraacetic acid

ESI-MS: Electrospray ionization – mass spectrometry

EtOH: Ethanol

HATU: 1-[Bis(dimethylamino)methylene]-1H-1,2,3-trizolo[4,5-b]pyridinium 3-oxid hexafluorophosphate

H_2SO_4: Sulfuric acid

iPrOH: Isopropanol

K_2CO_3: Potassium carbonate

KHMDS: Potassium bis(trimethylsilyl)amide

KOH: Potassium hydroxide

LCMS: Liquid chromatography – mass spectrometry

MeOH: Methanol

MsCl: Methansulfonyl chloride

$NaBH_3CN$: Sodium cyanoborohydride

$NaBH(OAc)_3$: Sodium triacetoxyborohydride

NH_4Cl: Ammonium chloride

NH_4HCO_3: Ammonium bicarbonate

NaI: Sodium iodide

$NaNO_3$: Sodium nitrate

NaOAc: Sodium acetate

MTBE: Methyl *tert*-butyl ether

nBuOH: n-Butanol

prep-HPLC: Preparative high-performance liquid chromatography

prep-TLC: Preparative thin layer chromatography

TBAF: Tetrabutylammonium fluoride

TBDMS-CL: tert-Butyldimethylsilyl chloride

TBSCl: tert-Butyldimethylsilyl chloride

TBSOTf: tert-Butyldimethylsilyl trifluoromethanesulfonate

TEA: Triethylamine

TESCl: Chlorotriethylsilane

TFA: Trifluoroacetic acid

THF: Tetrahydrofuran

$Ti(O^iPr)_4$: Titanium isopropoxide

TLC: Thin-layer chromatography

PPTS: Pyridinium p-toluenesulfonate

PE: Petroleum ether

PEG: Poly(ethylene glycol)

PtO_2: platinum dioxide

EtOAc: Ethyl acetate

Pd/C: Palladium (0) on carbon

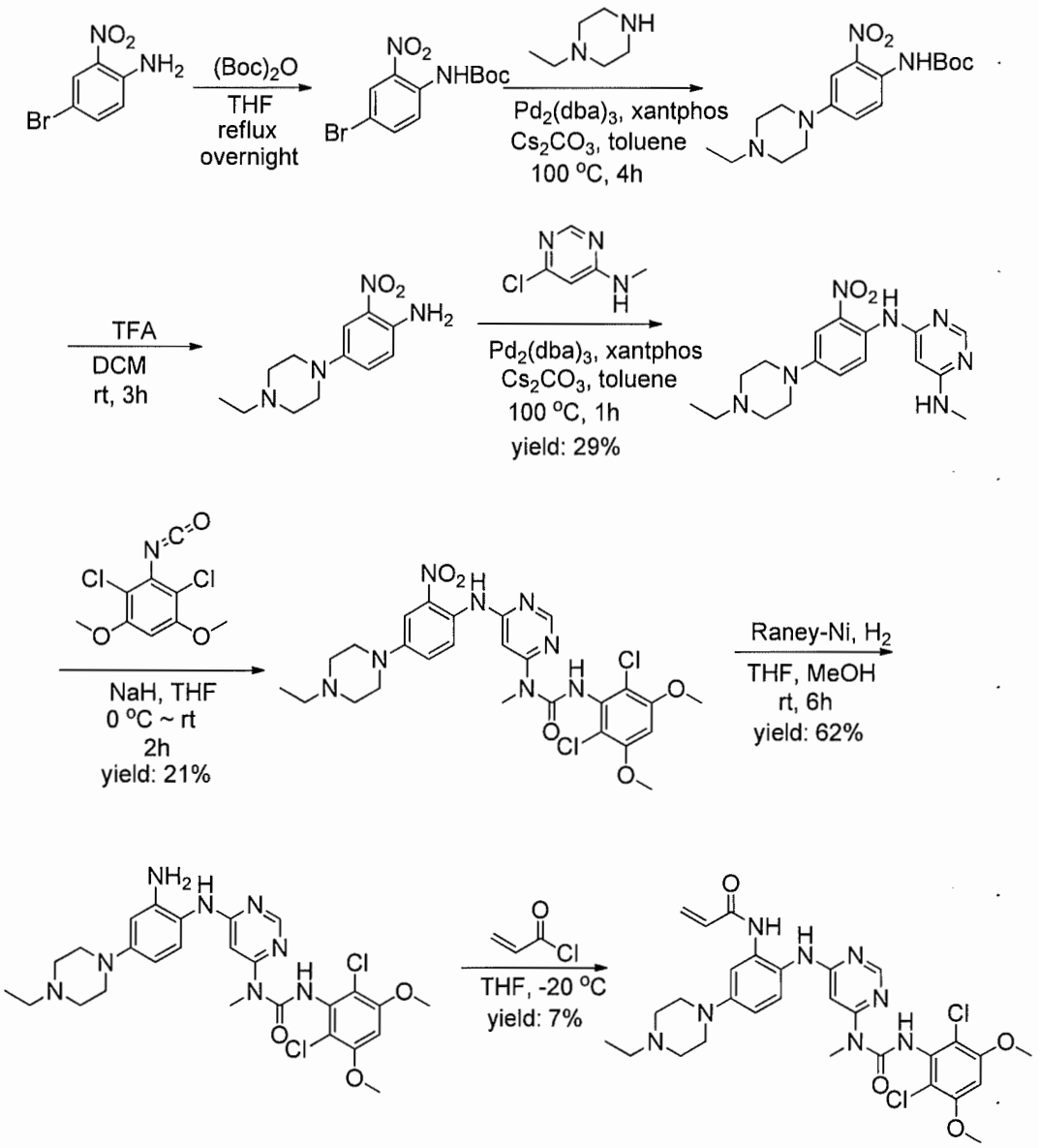
$Pd_2(dba)_3$: Tris(dibenzylideneacetone) dipalladium(0)

$Pd(dppf)_2Cl_2$: [1,1'-Bis(diphenylphosphino)ferrocene]dichloropalladium(II)

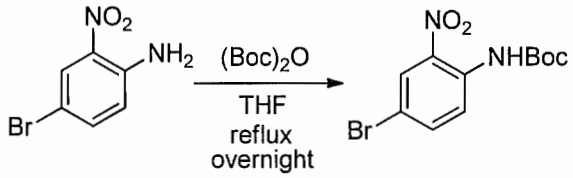
Ruphos: 2-Dicyclohexylphosphino-2',6'-diisopropoxybiphenyl

Xantphos: 4,5-Bis(diphenylphosphino)-9,9-dimethylxanthene

As used in the specification and claims, the singular forms "a," "an," and "the" include plural references unless the content dictates otherwise. Thus, for example, reference to "an HCl salt" makes reference to monohydrochloride salts, dihydrochloride salts, 1.5 hydrochloride salts, and other stoichiometric and nonstoichiometric hydrochloride salts.

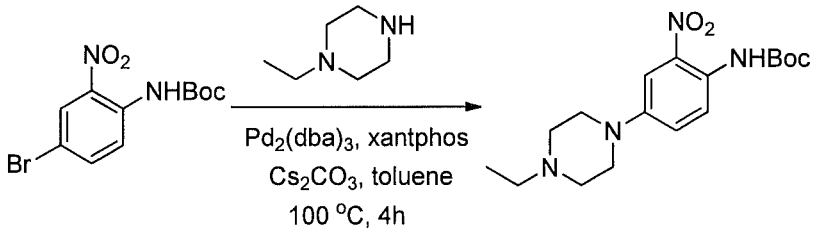


_N_-[2-{6-[3-(2,6-dichloro-3,5-dimethoxy-phenyl)-1-methyl-ureido]-pyrimidin-4-ylamino}-5-(4-ethyl-piperazin-1-yl)-phenyl]-acrylamidemethane



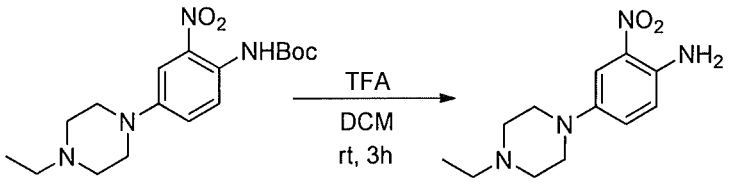
a. tert-Butyl 4-bromo-2-nitrophenylcarbamate

A mixture of 4-bromo-2-nitroaniline (4 g, 18.4 mmol), $(Boc)_2O$ (4.4 g, 20.24 mmol) in THF (50 mL) was heated under reflux overnight. The mixture was concentrated and the residue was purified by flash chromatography on silica eluting with PE:EtOAc = 20:1 to obtain the title compound (5.4 g, yield: 93%). MS (ESI): 317, 319 $[M+H]^+$.



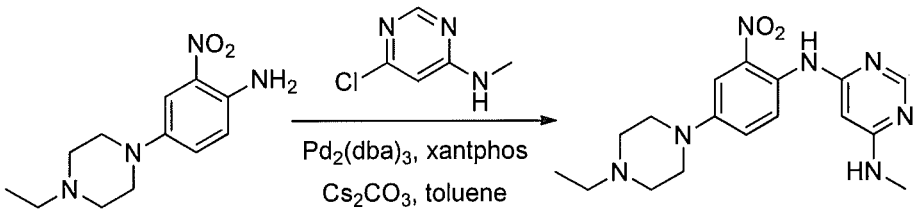
b. tert-Butyl 4-(4-ethylpiperazin-1-yl)-2-nitrophenylcarbamate

A degassed mixture of tert-butyl 4-bromo-2-nitrophenylcarbamate (5.4 g, 17 mmol), 1-ethylpiperazine (2.91 g, 25.5 mmol), $Pd_2(dba)_3$ (2.1 g, 3.4 mmol), xantphos (3.92 g, 6.8 mmol) and Cs_2CO_3 (11.1 g, 34 mmol) in toluene (85 mL) was heated at 100 °C for 4 hours. The reaction was concentrated, and the residue was purified by flash chromatography on silica eluting with MeOH: DCM = 1:50~1:20 to obtain the title compound (3.3 g, yield: 55%). MS (ESI): 351 $[M+H]^+$.



c. 4-(4-Ethylpiperazin-1-yl)-2-nitroaniline

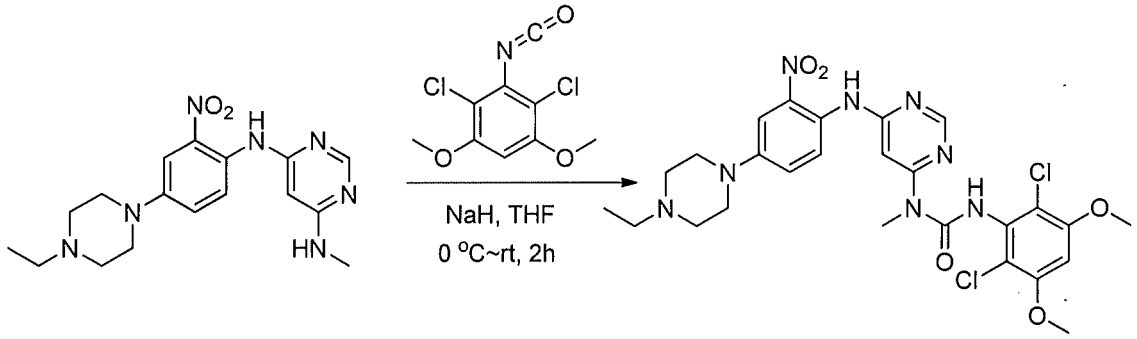
To a solution of tert-butyl 4-(4-ethylpiperazin-1-yl)-2-nitrophenylcarbamate (3.3 g, 9.43 mmol) in DCM (50 mL) was added TFA (20 mL) at 0 °C, the resulting mixture was stirred for 3 hours at rt. After removal of all volatiles in *vacuo*, the residue was re-dissolved in DCM, neutralized with saturated aqueous K_2CO_3 and extracted with DCM. The combined extracts were concentrated to obtain the title compound (2.1 g, yield: 90%), which was used directly in the next step. ^1H NMR (400 MHz, DMSO-d6) δ 1.02 (t, 3H), 2.36 (q, 2H), 2.47-2.49 (m, 4H) 2.97-3.00 (m, 4H), 6.97 (d, 1H), 7.20 (s, 2H), 7.25 (s, 1H), 7.34 (dd, 1H); MS (ESI): 251 $[M+H]^+$.



d. N^4-(4-(4-ethylpiperazin-1-yl)-2-nitrophenyl)-N^6-methylpyrimidine-4,6-diamine

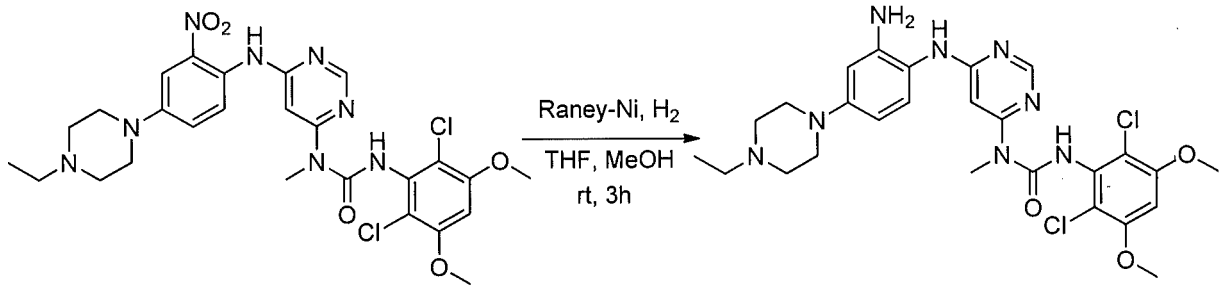
A degassed mixture of 4-(4-ethylpiperazin-1-yl)-2-nitroaniline (2.1 g, 8.4 mmol), 6-chloro-*N*-

methylpyrimidin-4-amine (Procedure 2A, step e; 1.2 g, 8.4 mmol), $Pd_2(dba)_3$ (1.54 g, 1.68 mmol), xantphos (1.94 g, 3.36 mmol) and Cs_2CO_3 (5.48 g, 16.8 mmol) in toluene (45 mL) was heated at 100 °C for 1 hour. The reaction was concentrated, and the residue was purified by flash chromatography on silica eluting with MeOH: DCM = 1:40~1:20 to obtain the title compound (870 mg, yield: 29%). MS (ESI): 358 $[M+H]^+$.



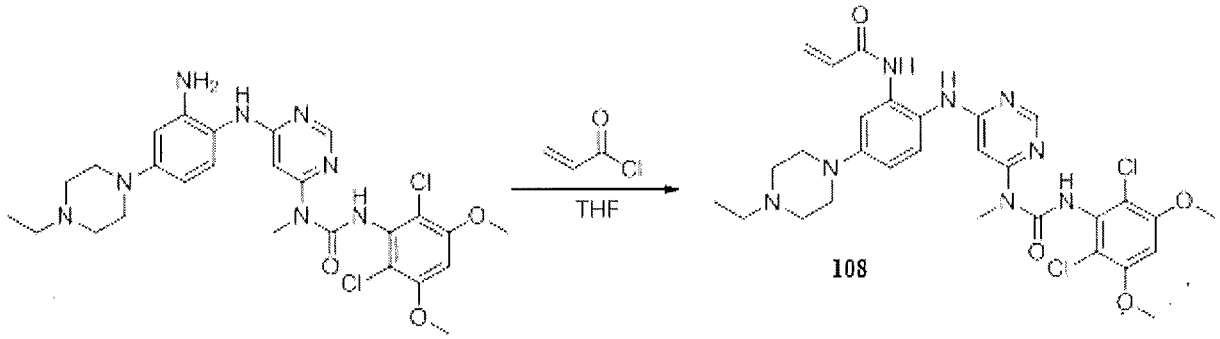
e. 3-(2,6-Dichloro-3,5-dimethoxyphenyl)-1-(6-(4-(4-ethylpiperazin-1-yl)-2-nitrophenylamino)pyrimidin-4-yl)-1-methylurea

To a solution of N^4-(4-(4-ethylpiperazin-1-yl)-2-nitrophenyl)-N^6-methylpyrimidine-4,6- diamine (870 mg, 2.44 mmol) in THF (15 mL) was added NaH (60%, 200 mg, 5 mmol) at 0 °C, and the mixture was stirred for 30 minutes at room temperature. A solution of 2,4-dichloro-3-isocyanato-1,5-dimethoxy-benzene (Procedure 2A, steps a-d; 908 mg, 3.66 mmol) in THF was added dropwise at 0 °C. The resulting mixture was stirred at room temperature for 2 hours. Saturated aqueous NH_4Cl solution (2 mL) was added to quench the reaction. The mixture was concentrated and extracted with DCM. The combined extracts were washed with brine, dried over anhydrous Na_2SO_4, and concentrated to give the crude product, which was purified by flash chromatography on silica to obtain the title compound (330 mg, yield: 21%) as a red oil. ^1H NMR (400 MHz, $CDCl_3$) δ 1.44 (t, 3H), 3.01 (t, 2H), 3.21 (q, 2H), 3.41-3.49 (m, 5H), 3.73-3.80 (m, 4H), 3.92 (s, 6H), 6.27 (s, 1H), 6.55 (s, 1H), 7.25 (d, 1H), 7.69 (s, 1H), 8.32 (d, 1H), 8.52 (s, 1H), 10.28 (br s, 1H), 12.05 (br s, 1H); MS (ESI): 605 $[M+H]^+$.



f. 1-(6-(2-Amino-4-(4-ethylpiperazin-1-yl)phenylamino)pyrimidin-4-yl)-3-(2,6-dichloro-3,5-dimethoxyphenyl)-1-methylurea

To a solution of 3-(2,6-dichloro-3,5-dimethoxyphenyl)-1-(6-(4-(4-ethylpiperazin-1-yl)-2-nitrophenylamino)pyrimidin-4-yl)-1-methylurea (330 mg, 0.546 mmol) in THF (20 mL) and MeOH (20 mL) was added Raney-Ni (suspension in water) at room temperature, the resulting mixture was stirred for 3 hours under hydrogen atmosphere (1 atm). The reaction was filtered and concentrated. The residue was washed twice with MeOH to obtain the title compound (280 mg, purity: 90%), which was used directly in the next step. MS (ESI): 575 $[M+H]^+$.



g. N-(2-(6-(3-(2,6-Dichloro-3,5-dimethoxyphenyl)-1-methylureido)pyrimidin-4-ylamino)-5-(4-ethylpiperazin-1-yl)phenyl)acrylamide

To a solution of 1-(6-(2-amino-4-(4-ethylpiperazin-1-yl)phenylamino)pyrimidin-4-yl)-3-(2,6-dichloro-3,5-dimethoxyphenyl)-1-methylurea (280 mg, purity: 90%, 0.44 mmol) in THF (30 mL) was added a solution of acryloyl chloride in THF (20 mg/mL, 2 mL, 0.44 mmol) at -10 °C, and the resulting mixture was stirred for 1 hour at this temperature. MeOH (1 mL) was added to quench the reaction. The mixture was concentrated and the residue was purified by prep-HPLC and prep-TLC to obtain the title compound **108** (20 mg, yield: 7%). ^{1}H NMR (400 MHz, $CDCl_3$) δ 1.31 (t, 3H), 2.65 (q, 2H), 2.62-2.68 (m, 4H), 3.27 (s, 3H), 3.36-3.38 (m, 4H), 3.91 (s, 6H), 5.76 (d, 1H), 5.90 (s, 1H), 6.24 (dd, 1H), 6.41 (d, 1H), 6.52 (s, 1H), 6.74 (dd, 1H), 7.07 (br s, 1H), 7.23 (d, 1H), 7.72 (br s, 1H), 7.98 (br s, 1H), 8.37 (s, 1H), 12.52 (s, 1H); MS (ESI): 629 $[M+H]^+$.

EXAMPLE 2: Assays of Biological Activity

Assay of Binding to FGFR4. Purified, recombinant FGFR4 was pre-incubated with 10 μM compound overnight at 4 °C, or for 1 hour at room temperature. Following pre-incubation,

FGFR4 was concentrated and buffer exchanged on an OPTI-TRAP protein concentrating and desalting C4 column (Optimize Technologies). Protein was eluted in acetonitrile containing 0.1% formic acid and run by direct injection on a Thermo Scientific Q Exactive™ LCMS to identify modified, intact FGFR4.

Results provided below in Table 1 confirm covalent adduct formation of the tested compound with the peptides by correspondence of the expected mass of the peptide-ligand adduct with the mass observed.

TABLE 1

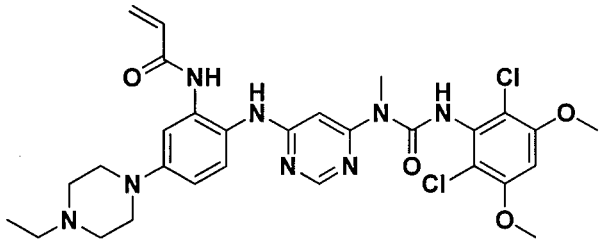
Compound #	Expected mass [Da]	Observed mass [Da]
108	35948.0	35948.1

IC_{50} Profiling of Kinase Activity Inhibition. Compounds were profiled for FGFR inhibition activity at Reaction Biology Corporation (Malvern, Pennsylvania) with their Kinase HotSpot℠ assay. *See*, Anastassiadis et al., 2011, Comprehensive assay of kinase catalytic activity reveals features of kinase inhibitor selectivity. Nat Biotechnol 29, 1039-1045.

Recombinant FGFR1 (2.5 nM), FGFR2 (1 nM), FGFR3 (5 nM), or FGFR4 (12 nM) (Invitrogen™) was prepared as a mixture with substrate KKKSPGEYVNIEFG (**SEQ ID NO:1**) (20 μM, FGFR1 substrate); and Poly [E,Y] 4:1 (0.2 mg/ml, FGFR2,3,4 substrate)] in kinase reaction buffer (20 mM HEPES-HCl, pH 7.5, 10 mM $MgCl_2$, 2 mM $MnCl_2$, 1 mM EGTA, 0.02% Brij35, 0.1 mM Na_3VO_4, 0.02 mg/ml BSA, 2 mM DTT, and 1% DMSO). Compound was added to the enzyme/substrate mixture using acoustic technology (Labcyte® Echo 550, Sunnyvale, California) (*see*, Olechno et al., 2006, Improving IC_{50} results with acoustic droplet ejection. JALA 11, 240-246) and pre-incubated for 0, 15, or 60 minutes at room temperature. After compound pre-incubation, a mixture of ATP (Sigma-Aldrich®) and ^{33}P-γ-ATP (PerkinElmer) was added to a final concentration of 10 μM to initiate kinase reactions. Reactions were incubated for 120 minutes at room temperature and then spotted onto Whatman™ P81 ion exchange filter paper. Unbound phosphate was removed by extensively washing filters in 0.75% phosphoric acid. *See*, Anastassiadis et al., 2011, Comprehensive assay of kinase catalytic activity reveals features of kinase inhibitor selectivity. Nat Biotechnol 29, 1039-1045.

Results for FGFR4 and FGFR1 are shown in Table 2. Compound 108 showed selective inhibition of FGFR4, with a higher IC_{50} for FGFR1.

TABLE 2

Structure	Compound #	FGFR4 IC_{50} (μM)	FGFR1 IC_{50} (μM)
	108	<0.001	0.173

Without wishing to be bound by theory, the IC_{50} activity with respect to FGFR1 is generally representative of the activity with respect to FGFR1, FGFR2, and FGFR3. *See also*, Dieci et al., 2013, Fibroblast Growth Factor Receptor Inhibitors as a Cancer Treatment: From a Biologic Rationale to Medical Perspectives. Cancer Discovery, F1-F16.

To confirm, the compound was also tested for FGFR2 and FGFR3 inhibition. These results shown below in Table 3 are consistent with the IC_{50} activity of FGFR1 being generally representative of the activity of FGFR1, FGFR2, and FGFR3, and further demonstrates the selectivity of this FGFR4 inhibitor.

TABLE 3

Compound #	FGFR2 IC_{50} (μM)	FGFR3 IC_{50} (μM)	FGFR1 IC_{50} (μM)	FGFR4 IC_{50} (μM)
108	1.98	2.00	0.173	<0.001

***In vivo* efficacy in tumor models.** Compound 108 was evaluated for its ability to inhibit tumor growth in nude mice bearing tumor xenografts from three different human hepatocellular carcinoma tumor cell lines. These cell lines are representative of cancers having an altered FGFR4 and/or FGF19 status. *See* Sawey et al., Cancer Cell 19(3): 347-358 (2011).

Animals: Nude mice, ages 6-8 weeks, and weighing approximately 19-25 g, were purchased from Taconic (Taconic, Hudson, New York). All animal experiments were done in accordance

with protocols approved by the Institutional Animal Care and Use Committee.

Tumor xenografts and treatment: 7.5 x 10^6 HUH7 cells (HSRRB cat. no. JCRB0403), 5 x 10^6 Hep3B (ATCC cat. no. HB8064), or 2.5 x 10^6 JHH7 cells (HSRRB cat. no. JCRB1031), each in a total volume of 100 µl, 1:1 Matrigel (Corning Inc, Corning, NY), were injected subcutanously (s.c.) into the right lateral flank. When tumors reached 150-200 mm^3, the mice were randomized into treatment groups of 5-10 animals. Dosing was performed twice daily by intraperitoneal injection at the indicated dosages for 15 days using Compound 108, formulated in a vehicle of 5% DMSO (Alfa Aesar, Ward Hill, MA), 10% PEG300 (Sigma, St. Louis, MO), 8% TWEEN® 80 (Sigma, St. Louis, MO), 77% USP Saline at the desired concentration. Tumor volumes were collected twice weekly using the formula Volume = (length*width^2)/2. Body weights were collected twice weekly, as well. All animals were observed and cared for in accordance with The Guide for Care and Use of Laboratory Animals, 8th edition (National Academies Press, Washington D.C.).

Statistical methods: Statistical comparisons were made at the end of the experiment using Repeated Measures Anova with Bonferroni post-test for comparisons of treatment groups, using GraphPad Prism 5. The following criteria were used to determine Progressive Disease, Stable Disease, Partial Regression, and Complete Regression. Progressive Disease is defined as three consecutive measurements increasing from best response or >120% initial tumor volume. Stable Disease is three consecutive measurements <120% and >50% of initial tumor volume, whereas three consecutive measurements <50% initial tumor volume qualifies as a Partial Regression. A Complete Regression is three consecutive measurements <30 mm^3. Chi-squared test was used to compare responses between treatment groups (Microsoft Excel).

Results from animals bearing tumors from HUH7, HEP3B, and JHH7 cancer cells are shown in FIGS. 1-3, respectively, and are also reflected in Table 4.

TABLE 4 – Inhibition of Tumor Growth in FGF19 amplified HCC xenografts

HUH7 (n=10 per group)

Dose (mg/kg)	Complete Regression	Partial Regression	Stable Disease	Progressive Disease
25	1	4	3	2
37.5	2	5	3	0

HEP3B (n=5 per group)

Dose (mg/kg)	Complete Regression	Partial Regression	Stable Disease	Progressive Disease
12.5	0	0	0	5
25	0	1	4	0
37.5	5	0	0	0

JHH7 (n=10 per group)

Dose (mg/kg)	Complete Regression	Partial Regression	Stable Disease	Progressive Disease
12.5	0	0	0	10
25	0	0	0	10
37.5	0	0	0	10

These data demonstrate that compound 108 is efficacious in all models. Among the three models, HEP3B is the most sensitive, JHH7 the least sensitive and HUH7 showing intermediate sensitivity to compound 108. Although a dose response can be seen in FIG. 3 for JHH7, there was Progressive Disease in all dose levels tested.

Comparative studies of Compound 108 with BGJ398. Comparative studies were done with Compound 108 and the known FGFR inhibitor BJG398.

Biochemical Kinase assay protocol to obtain IC_{50}: Recombinant FGFR1 (2.5 nM), or FGFR4 (12 nM) was prepared as a mixture with substrate KKKSPGEYVNIEFG (**SEQ ID NO:1**) (20 μM, FGFR1 substrate); Poly [E,Y] 4:1 (0.2 mg/ml, FGFR2,3,4 substrate)] in kinase reaction buffer (20 mM HEPES-HCl, pH 7.5, 10 mM $MgCl_2$, 2 mM $MnCl_2$, 1 mM EGTA, 0.02% Brij35, 0.1 mM Na3VO4, 0.02 mg/ml BSA, 2 mM DTT, and 1% DMSO). Compound was added to the enzyme/substrate mixture using acoustic technology and pre-incubated for 0, 15, or 60 minutes at room temperature. After compound pre-incubation, ^{33}P-γ-ATP was added at a final concentration of 10 μM to initiate kinase reactions. Reactions were incubated for 120 minutes at room temperature. Substrate phosphorylation was monitored by filter assay, as above. Results are shown in Table 5. The results reported show that compound 108 is a more potent FGFR4 inhibitor, whereas BGJ398 is a more potent FGFR1 inhibitor.

TABLE 5 – Comparative Testing of Compound 108 and BGJ398 with Biochemical Kinase assay

Kinase	Compound 108 IC_{50} (nM)	BGJ398 IC_{50} (nM)
FGFR4	< 0.2	13
FGFR1	513	1.0

Cellular Viability assay protocol to obtain GI_{50}: Cells lines were cultured at 37°C, 5% CO_2 and 95% humidity. Culture media were purchased from GIBCO®, USA. For viability assay, 2000 cells/well were seeded in 96 well plates, incubated for 24h before compound treatment. Following compound addition, plates were incubate for 72h at 37°C with 5% CO_2, and then measured by means of CTG assay (CellTiter-Glo® Luminescent Cell Viability Assay, Cat. No.: G7572, Promega). Results are shown in Table 6. The table shows compound 108 is more potent than BGJ398 in Hep3B cells, an FGF19 amplified line. The potency in HUH7 and JHH7, the other two FGF19 amplified lines, are comparable between compound 108 and BGJ398. HepG2 (ATCC cat. no. HB-8065), SNU398 (ATCC cat. no. CRL-2233) and SNU449 (ATCC cat. no. CRL-2234) are FGF19 non-amplified cell lines that were used as controls.

GI_{50} is the concentration of test drug where $100 \times (T - T0)/(C - T0) = 50$. *See, e.g.*, Monks et al., *Feasibility of a High-Flux Anticancer Drug Screen Using a Diverse Panel of Cultured Human Tumor Cell Lines*, J Natl Cancer Inst (1991) 83(11):757-766; Boyd et al., *Data Display and Analysis Strategies for the NCI Disease-oriented* In Vitro *Antitumor Drug Screen*, in CYTOTOXIC ANTICANCER DRUGS: MODELS AND CONCEPTS FOR DRUG DISCOVERY AND DEVELOPMENT, Valeriote et al., eds. (1990), pp. 11-34. The luminescence of the test well after a 72h period of exposure to test drug is T, the luminescence at time zero is T0, and the control luminescence is C. The GI_{50} measures the growth inhibitory power of the test agent.

TABLE 6 – Comparative Testing of Compound 108 and BGJ398 in Cellular Viability assays

Cell Line	Compound 108 GI_{50} (nM)	BGJ398 GI_{50} (nM)
HEP3B	18 ± 6 nM (n=27)	74 ± 23 nM (n=6)
JHH7	216 ± 70 nM (n=4)	178 ± 30 nM (n=2)
HUH7	408 ± 128 nM (n=4)	231 ± 100 nM (n=2)

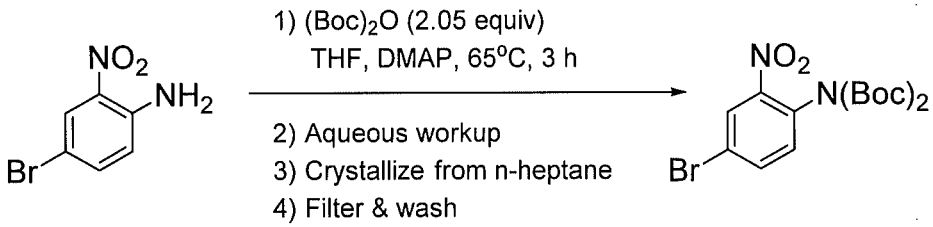
HEPG2	6506±1424 nM (n=27)	2260±1182 nM (n=6)
SNU398	> 10,000 (n=2)	not measured
SNU449	> 10,000 (n=2)	not measured

***In vivo* efficacy comparison**: Nude mice were used for these experiments as above. 5.0 x 10^6 Hep3B cells in a total volume of 100 µl, 1:1 Matrigel (Corning Inc, Corning, New York), were injected s.c. into the right lateral flank. When tumors reached 150-200 mm^3 the mice were randomized into treatment groups of 5-10 animals. Treatment was then started using Compound 108, formulated in a vehicle of 5% DMSO (Alfa Aesar, Ward Hill, MA), 10% PEG300 (Sigma, St. Louis, MO), 8% TWEEN® 80 (Sigma, St. Louis, MO), 77% USP Saline at the desired concentration. BGJ398, formulated as a suspension in 0.5% Methylcellulose (Sigma)/0.2% TWEEN® 80, was suspended at the desired concentration. Both drugs were dosed for 18 dyas, except for one treatment group (see below). Tumor volumes were collected twice weekly using the formula Volume = (length*width^2)/2. Body weights were collected twice weekly as well. All animals were observed and cared for in accordance with The Guide for Care and Use of Laboratory Animals, 8th edition (National Academies Press, Washington D.C.). The results of this comparative *in vivo* study are shown in FIG. 4.

The data show that compound 108 is more efficacious than BGJ398 at tolerable dosage levels. Although BGJ398 at 60mg/kg showed efficacy comparable to compound 108, the dosing of this BGJ398 60mg/kg group had to be terminated on Day 11 due to poor health of animals. This difference in toxicity is not due to routes of administration because the group of animals dosed orally with BGJ398 at 30mg/kg did not exhibit poor health.

EXAMPLE 3: Alternative Synthesis Methods and Crystallization of Compound 108

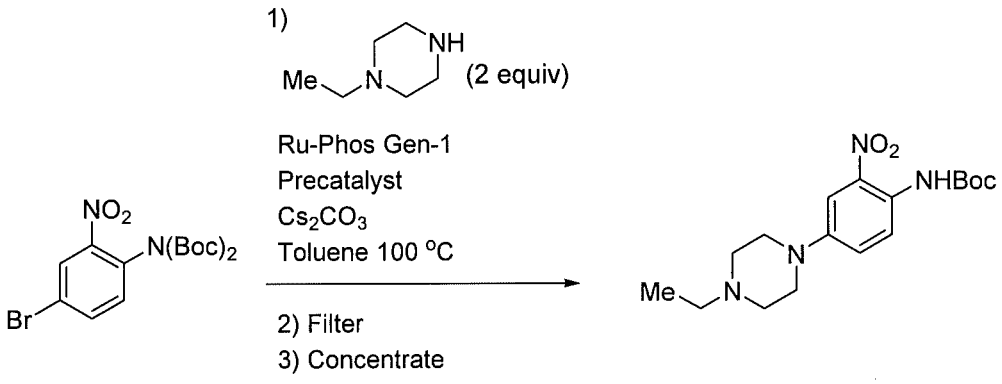
Synthesis of Bis(Boc)-4-bromo-2-nitroaniline



A 3-necked 5 L round bottom flask was charge with 4-bromo-3-nitroaniline (200g, 922 mmol), Boc anhydride (412g, 1889 mmol, 2.05 equiv), and THF (3L). To the stirred mixture

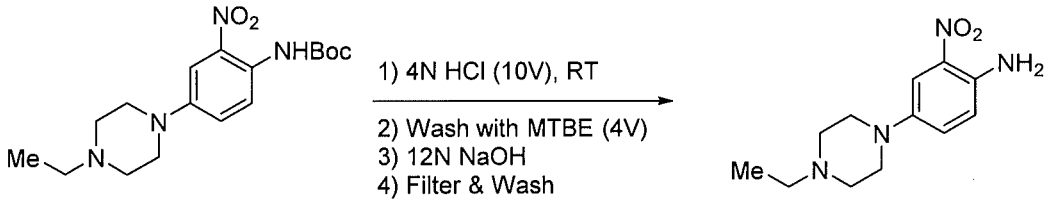
was charged DMAP (11.26g, 92.2 mmol, 0.10 equiv). The mixture was heated to 65 °C and stirred at this temperature until the reaction was deemed complete by HPLC (≤ 2% 4-bromo-3-nitroaniline remaining, ca. 3.5 hours) and then cooled to room temperature. The mixture was transferred to a 12 L workup vessel, ethyl acetate was added (3 L) and the mixture was washed sequentially with with 1N HCl (1 L), saturated aqueous $NaHCO_3$ solution (1 L), and 10% aqueous NaCl solution (1 L). The organic layer was concentrated to a minimum stirrable volume and ethyl acetate (1 L) was added. The solution was chased twice with heptane (1.5 L), concentrated the mixture to a total volume of 1.5 L following the second chase. The resulting slurry was filtered, washed with heptane (3 x 200 mL), and dried under vacuum to provide the title compound (345.5g, 90% yield) as an off-white solid.

tert-butyl (4-(4-ethylpiperazin-1-yl)-2-nitrophenyl)carbamate



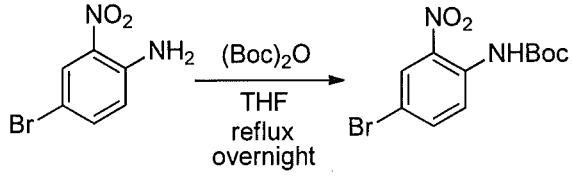
A 5 L 3-necked round bottom flask was charged with Bis(Boc)-4-bromo-2-nitroaniline (250 g, 599 mmol), cesium carbonate (234g, 719 mmol, 1.2 equiv), and Buchwald Ru-Phos pre-catalyst (CAS# 1375325-68-00, 20g, 27.4 mmol, 0.046 equiv). To the solids was charged previously degassed toluene (1 L) and *N*-ethylpiperazine (156 mL, 1228 mmol, 2.05 equiv). The resulting mixture was sparged with nitrogen gas for 30 mins, then heated the mixture to 95-105 °C and stirred at this temperature until HPLC analysis showed complete reaction (ca. 6 hours). The mixture was cooled to room temperature and filtered over Celite® 545 (125g), washing the cake with toluene (3 x 60 mL). The resulting solution was concentrateed to afford the title compound (210g, 100% yield) which was carried forward without further purification.

4-(4-Ethylpiperazin-1-yl)-2-nitroaniline



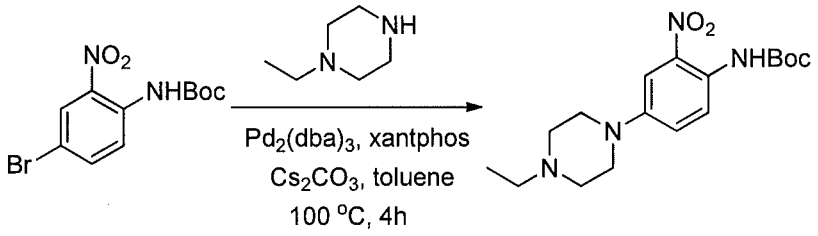
To a suspension of tert-butyl 4-(4-ethylpiperazin-1-yl)-2-nitrophenylcarbamate (210g, 599 mmol) in a minimal amount of toluene was charged 4N aqueous HCl (2.1 L, 14 equiv) with mechanical stirring, maintaining the internal temperature at $\leq$ 40 °C. The resulting slurry was stirred at room temperature with a nitrogen sweep to remove any remaining organic solvent until HPLC analysis indicated complete reaction. To the suspension was added MTBE (1 L). The mixture was agitated for 30 mins and the layers were separated. The lower aqueous layer was cooled to 0-5 °C and 12N aqueous NaOH solution was added to pH 9-10 (ca. 480 mL required). The resulting solid was filtered and washed with cold (0-5 °C) water (3 x 400 mL). The wet cake was filtered under vacuum and/or nitrogen sweep at 30 °C to afford the title compound (136.3g, 91% yield) as a red solid.

tert-Butyl 4-bromo-2-nitrophenylcarbamate – alternate procedure



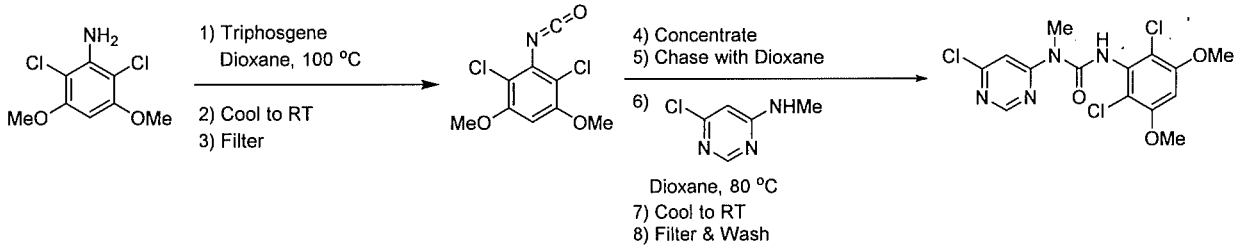
A mixture of 4-bromo-2-nitroaniline (4 g, 18.4 mmol) and $(Boc)_2O$ (4.4 g, 20.24 mmol) in THF (50 mL) was heated under reflux overnight. The mixture was concentrated and the residue was purified by flash chromatography on silica eluting with PE:EtOAc = 20:1 to obtain the title compound (5.4 g, yield: 93%). MS (ESI): 317, 319 $[M+H]^+$.

tert-Butyl 4-(4-ethylpiperazin-1-yl)-2-nitrophenylcarbamate – alternate procedure



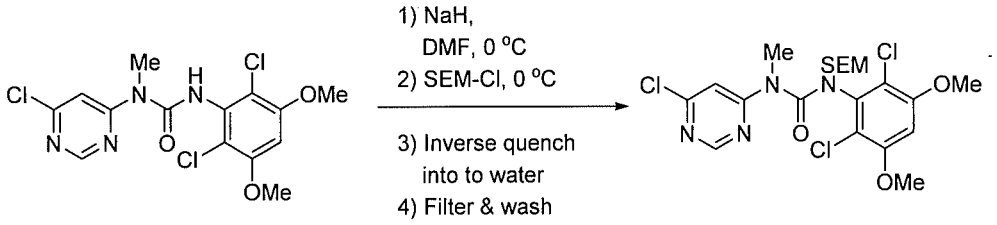
A degassed mixture of tert-butyl 4-bromo-2-nitrophenylcarbamate (5.4 g, 17 mmol), 1-ethylpiperazine (2.91 g, 25.5 mmol), $Pd_2(dba)_3$ (2.1 g, 3.4 mmol), xantphos (3.92 g, 6.8 mmol) and Cs_2CO_3 (11.1 g, 34 mmol) in toluene (85 mL) was heated at 100 °C for 4 hours. The reaction was concentrated, and the residue was purified by flash chromatography on silica eluting with MeOH: DCM = 1:50~1:20 to obtain the title compound (3.3 g, yield: 55%). MS (ESI): 351 $[M+H]^+$.

a. 1-(6-chloropyrimidin-4-yl)-3-(2,6-dichloro-3,5-dimethoxyphenyl)-1-methylurea



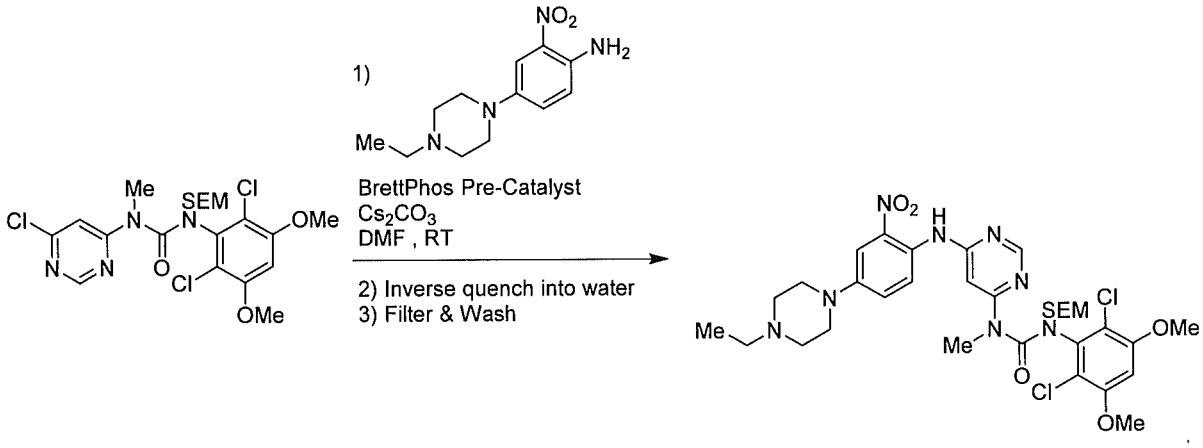
A 3 L 3-necked round bottom flask was charged with 2,6-dichloro-3,5-dimethoxyaniline (199.65g, 899 mmol), triphosgene (93g, 315 mmol, 0.35 equiv), and 1,4-dioxane (1.9 L). The mixture was heated to 100 °C and stirred at this temperature for 3.5 h. The mixture was then cooled to 20-25 °C, and filtered. The solid residue was washed with 1,4-dioxane (200 mL). The filtrate was concentrated to a minimal stirrable volume and chased 3x with dioxane (700 mL each chase). The solution was concentrated to a minimal stirrable volume following the last chase and then redissolved in 1,4-dioxane (730 mL). To this slurry was charged 6-chloro-*N*-methylpyrimidin-4-amine (129g, 899 mmol, 1 equiv). The resulting mixture was heated to 80 °C and stirred at this temperature for 60 h, during which time a substantial amount of precipitate formed. The mixture was cooled to 20-22 °C and filtered. The solid cake was washed with dioxane (2 x 90 mL) and dried under vacuum at room temperature with a nitrogen sweep to afford the title compound (191g, 54% yield) as a solid.

b. 1-(6-chloropyrimidin-4-yl)-3-(2,6-dichloro-3,5-dimethoxyphenyl)-1-methyl-3-((2-(trimethylsilyl)ethoxy)methyl)urea



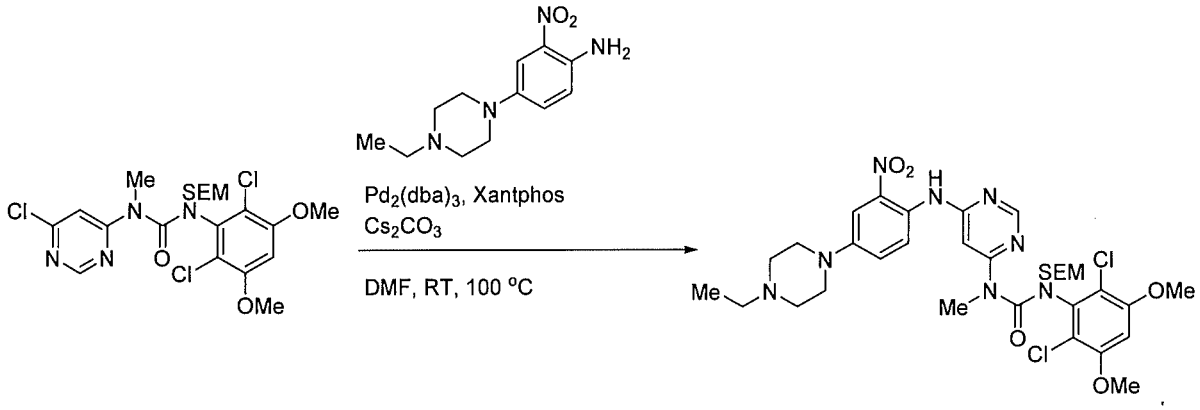
A 5 L 3-necked round bottom flask was charged with 3-(2,6-Dichloro-3,5-dimethoxyphenyl)-1-(6-(4-(4-ethylpiperazin-1-yl)-2- nitrophenylamino)pyrimidin-4-yl)-1-methylurea (135g, 345 mmol), potassium iodide (6.87g, 41.4 mmol. 0.12 equiv) and DMF (400 mL). The mixture was cooled to to 0-5 °C and NaH (60% dispersion in mineral oil, 17.9g, 448 mmol, 1.3 equiv) was charged portionwise so as to maintain the internal temperature at $\leq$ 5 °C. The mixture was allowed to stir for 1 hour at 0-5 °C, after which SEM-Cl (73.2 mL, 414 mmol, 1.2 equiv) was added dropwise so as to maintain the internal temperature at $\leq$ 5 °C. The reaction mixture was stirred at at 0-5 °C until HPLC analysis indicated complete reaction (ca. 1 h). The batch was transferred to a second 5 L 3-necked round bottom flask containing cold (0-5 °C) water (4 L). The resulting slurry was stirred for 15 mins, then filtered. The cake was washed with with water (3 x 300 mL) and dried under vacuum to afford the title compound (184g, 102%) as a solid.

c. 1-(2,6-dichloro-3,5-dimethoxyphenyl)-3-(6-((4-(4-ethylpiperazin-1-yl)-2-nitro phenyl) amino)pyrimidin-4-yl)-3-methyl-1-((2-(trimethylsilyl)ethoxy)methyl)urea



A 3 L 3-necked round bottom flask was charged with 1-(6-chloropyrimidin-4-yl)-3-(2,6-dichloro-3,5-dimethoxyphenyl)-1-methyl-3-((2-(trimethylsilyl)ethoxy)methyl)urea (182g, 349 mmol), 4-(4-ethylpiperazin-1-yl)-2-nitroaniline (87g, 349 mmol, 1 equiv), BrettPhos Pre-catalyst (CAS# 1470372-59-8, 15.6 g, 17.2 mmol, 0.05 equiv), and cesium carbonate (136g, 418 mmol, 1.2 equiv). The system was flushed with nitrogen and previously degassed DMF (910 mL) was added. The solution was sparged with nitrogen gas for 30 mins, then allowed to stir at 22-25 °C until HPLC analysis indicates complete reaction (3-4 hours). The mixture was charged into a 5 L 3-necked round bottom flask containing water (2.7 L) at such a rate as to maintain the internal temperature at ≤ 35 °C. The resulting slurry was cooled to 22-25 °C then filtered. The cake was washed with water (4 x 150 mL) and dried under vacuum to afford the title compound (257g, 100% yield) as a solid.

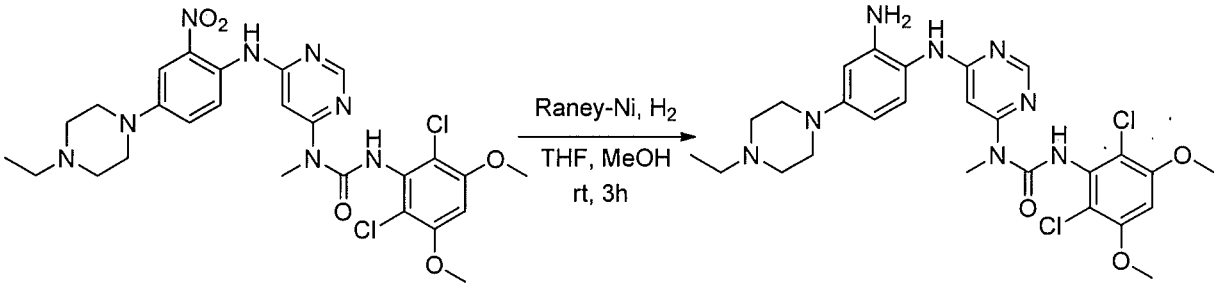
d. Synthesis of 1-(2,6-dichloro-3,5-dimethoxyphenyl)-3-(6-((4-(4-ethylpiperazin-1-yl)-2-nitro phenyl) amino)pyrimidin-4-yl)-3-methyl-1-((2-(trimethylsilyl)ethoxy)methyl)urea – alternate procedure



To a 3 L four necked round bottom flask equipped with reflux condenser, magnetic stirrer and nitrogen purging set up, was added 4-(4-ethylpiperazin-1-yl)-2-nitroaniline (50g, 0.199 mol), 1-(6-chloropyrimidin-4-yl)-3-(2,6-dichloro-3,5-dimethoxyphenyl)-1-methyl-3-((2-(trimethylsilyl)ethoxy)methyl)urea (125.1g, 0.239 mol, 1.2 equiv), DMF (500 mL) and cesium carbonate (130.17g, 0.399 mol, 2.0 equiv). The resulting mixture was purged by bubbling nitrogen through the mixture for 5-10 min at room temperature. To the mixture were added $Pd_2(dba)_3$ (18.29g, 0.0199 mol, 0.10 equiv), Xantphos (11.55g, 0.0199 mol, 0.10 equiv), and nitrogen purging was continued for another 10 min. The reaction mixture was then heated to 100°C until TLC analysis indicated complete reaction (ca. 2 h). The mixture was filtered

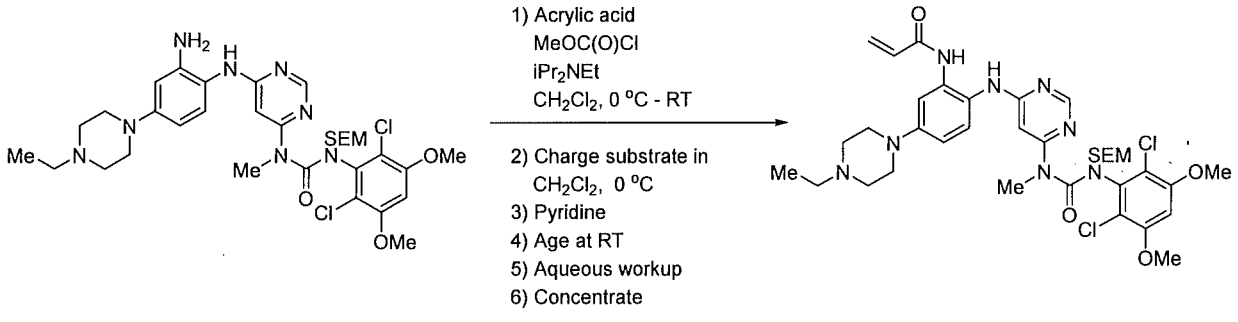
through a celite bed and an aqueous workup was performed, the desired product being extracted with EtOAc (3 x 500 mL). The combined organic phases were washed with brine solution (2 x 500 mL), dried over Na_2SO_4, and concentrated to provide the title compound as a reddish solid (142 g) which was carried forward as is.

e. 1-(6-(2-Amino-4-(4-ethylpiperazin-1-yl)phenylamino)pyrimidin-4-yl)-3-(2,6-dichloro-3,5-dimethoxyphenyl)-1-methylurea



To a solution of 3-(2,6-dichloro-3,5-dimethoxyphenyl)-1-(6-(4-(4-ethylpiperazin-1-yl)-2-nitrophenylamino)pyrimidin-4-yl)-1-methylurea (330 mg, 0.546 mmol) in THF (20 mL) and MeOH (20 mL) was added Raney-Ni (suspension in water) at room temperature, the resulting mixture was stirred for 3 hours under hydrogen atmosphere (1 atm). The reaction was filtered and concentrated. The residue was washed twice with MeOH to obtain the title compound (280 mg, purity: 90%), which was used directly in the next step. MS (ESI): 575 $[M+H]^+$.

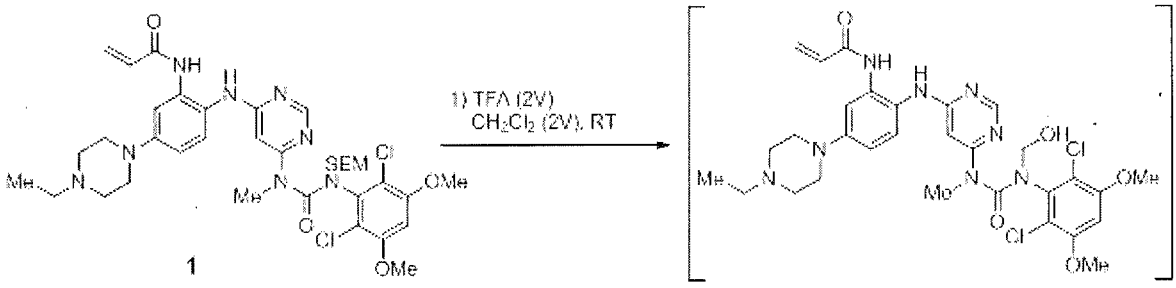
f. Preparation of *N*-(2-(6-(3-(2,6-Dichloro-3,5-dimethoxyphenyl)-1-methylureido)pyrimidin-4-ylamino)-5-(4- ethylpiperazin-1-yl)phenyl)acrylamide

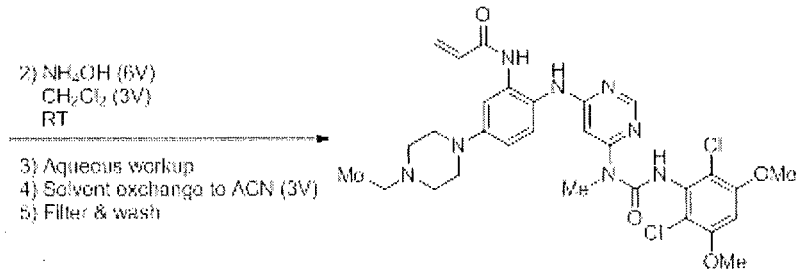


A 5 L 3-necked round bottom flask was charged with dichloromethane (1 L), acrylic acid (14.6 mL, 213 mmol, 1.5 equiv), and Hunig's base (39.5 mL, 227 mmol, 1.6 equiv). The solution was cooled to 0-5 °C and treated with methyl chloroformate (15.4 mL, 198 mmol, 1.4

equiv) at such a rate as to maintain the internal temperature at ≤ 7 °C. The mixture was warmed to 20-25 °C and stirred at this temperature for 1 h, then cooled to 0-5 °C. In a separate 500 mL round bottom flask was dissolved 1-(6-((2-amino-4-(4-ethylpiperazin-1-yl)phenyl)amino)pyrimidin-4-yl)-3-(2,6-dichloro-3,5-dimethoxyphenyl)-1-methyl-3-((2-(trimethylsilyl)ethoxy)methyl)urea (100 g, 142 mmol, 1 equiv) in dichloromethane (150 mL). The substrate solution was transferred the to the mixed anhydride solution, rinsing with dichloromethane (200 mL) and transferring this rinse to the anhydride solution as well. To the resulting mixture was added pyridine (27.5 mL, 340 mmol, 2.4 equiv) and the resulting mixture was warmed to 20-25 °C. The reaction mixture was stirred at this temperature until HPLC analysis indicated complete reaction (ca. 1 h). The mixture was then cooled to 0-5 °C and saturated aqueous $NaHCO_3$ solution (1 L) was added. The batch was agitated for for 20 mins, then the phases were settled and split. settle. The lower organic phase was washed a second time with $NaHCO_3$ solution (600 mL). The lower organic phase was then washed with 10% aqueous NaCl solution (600 mL). The lower organic phase was dried over solid Na_2SO_4 (250g), filtered, and concentrated to afford the title compound (108g, 100%) which was used in the next step without purification.

g. Synthesis and Crystallization of Free Base Form of Compound 108





Crystalline Free Base Form of Compound 108

A stirred solution of *N*-(2-((6-(3-(2,6-dichloro-3,5-dimethoxyphenyl)-1-methyl-3-((2-(trimethylsilyl)ethoxy)methyl)ureido)pyrimidin-4-yl)amino)-5-(4-ethylpiperazin-1-yl)phenyl)acrylamide (**1**, 51g, 67.12 mol) in dichloromethane (102 mL) was cooled to 0-5 °C. To this solution was added trifluoroacetic acid (102 mL, 1585 mol, 23.6 equiv) at such rate as to maintain the internal temperature ≤ 15 °C. Once addition was complete, the mixture was allowed to warm to room temperature and stirred for 3h, at which point HPLC analysis indicated complete reaction. The mixture was transferred to a second flask containing cold (0-5 °C) saturated ammonium hydroxide solution (550 mL), at such a rate as to maintain internal temperature ≤ 25 °C. The mixture was allowed to stir for 5-10 mins, at which HPLC analysis indicated complete reaction. The mixture was transferred to a separatory funnel and extracted twice with dichloromethane/methanol (5:1, 600 mL) and once with dichloromethane/methanol (5:1, 300 mL). The combined organic phases were concentrated to a minimum stirrable volume and acetonitrile (150 mL) was added. The resulting solid was slurried for 15 mins, then filtered. The solid cake was washed with acetonitrile (4 x 30 mL) and dried on the filter under vacuum with a nitrogen sweep to afford *N*-(2-((6-(3-(2,6-dichloro-3,5-dimethoxyphenyl)-1-methylureido)pyrimidin-4-yl)amino)-5-(4-ethylpiperazin-1-yl)phenyl)acrylamide (**108**, 29.56g, 70% yield) as a solid. ^{1}H-NMR (d_6-DMSO): δ 1.04 (t, *J*=7.15 Hz, 3H); 2.37 (m, 2H); 3.13 (m, 4H); 3.22 (m, 4H); 3.31 (s, 3H); 3.93 (s, 6H); 5.72 (dd, 1H, *J*=10.27, 1.83 Hz); 6.23 (dd, 1H, *J*=17.06, 1.83 Hz; br s, 1H); 6.48 (dd, 1H, *J*=16.87, 10.27 Hz); 6.81 (dd, 1H, *J*=8.99, 2.75 Hz); 6.89 (s, 1H); 7.29 (br d, *J*=9.17 Hz, 2H); 8.32 (s, 1H); 8.71 (s, 1H); 9.58 (s, 1H) (FIGS. 9A-9C). Mass spec: $[M+H]^+$ = 629.2. This was determined on a Varian Inova at 500 MHz.

Recrystallization of Free Base Form of Compound 108:

N-(2-((6-(3-(2,6-dichloro-3,5-dimethoxyphenyl)-1-methylureido)pyrimidin-4-yl)amino)-5-(4-ethylpiperazin-1-yl)phenyl)acrylamide (**108**, 42g) was dissolved in dichloromethane/methanol (4:1, 500 mL). To this solution was added acetonitrile (150 mL). The mixture was concentrated under reduced pressure to a total volume of 150 mL. To the resulting mixture was added additional acetonitrile (150 mL) and the mixture was again concentrated under reduced pressure to a total volume of 150 mL. The resulting slurry was filtered. The solid cake was washed with acetonitrile (4 x 30 mL) and dried on the filter under vacuum with a nitrogen sweep to afford recrystallized free base form of *N*-(2-((6-(3-(2,6-dichloro-3,5-dimethoxyphenyl)-1-methylureido)pyrimidin-4-yl)amino)-5-(4-ethylpiperazin-1-yl)phenyl)acrylamide (**108**, 36g, 86% recovery from recrystallization) as a solid.

EXAMPLE 4: Characterization of Crystalline Free Base Form of Compound 108 by Powder X-Ray Diffraction (PXRD)

PXRD data for samples in this Example were taken on a Rigaku MultiFlex Instrument (Target: Cu; Tube voltage: 40 kV; Tube current: 30 mA, Range 3.0-45.0=42.0°). Samples were prepared by adding powders into standard round aluminum specimen holders and leveled with a glass slide.

A crystalline free base form of Compound 108 is characterized by the PXRD pattern shown in FIG. 5, truncated to show a range of 3.0-35.0=32.0°. An overlay of the PXRD spectra from three lots of crystalline free base form of Compound 108 (FIG. 6) demonstrates the reproducibility.

As summarized in Table 7, the crystalline free base form of Compound 108 exhibits a PXRD pattern with six characteristic peaks.

TABLE 7: Characteristic crystalline free base form Compound 108 PXRD Peaks

2θ ° (± 0.2 °)
8.0
9.5
10.3
14.8
16.5
17.1
19.3
21.8
23.7
24.5

EXAMPLE 5: Characterization of Crystalline Free Base Form Compound 108 by Differential Scanning Calorimetry (DSC)

DSC for samples in this example was taken on a Mettler-Toledo DSC 1/700 (Run

conditions: Initial temperature 35 °C, Final temp 325 °C, Heating rate 10 °C/min).

Approximately 4 to 8 mg of crystalline free base form of Compound 108 was added to a 70 µL Aluminum pan, covered, crimped and pierced with a single hole. The sample and a blank vessel prepared in the same manner were added to the thermocouple surface and the instrument was equilibrated at the initial temperature. The chamber was heated to 325 °C at 10 °C/min and the differential thermogram was collected.

A differential thermogram of crystalline free base form of Compound 108 was obtained using a Differential Scanning Calorimetry (DSC) Instrument (see FIG. 7, truncated after about 254 °C). The crystalline free base form of Compound 108 is characterized by having a single endothermic peak at an onset temperature of 213.6 °C (±1 °C). A comparison of onset temperatures from three different batches of the crystalline free base form of Compound 108 is shown in Table 8 and FIG. 8 (truncated after about 246 °C).

TABLE 8 Comparison of Onset Temperatures From Three Lots

Crystalline Free Base Form of Compound 108 Lot	**Onset (°C)**
1	213.62
2	213.39
3	213.74
Mean	213.6
Range	0.35

EXAMPLE 6: Solubility of Crystalline Free Base Form Compound 108

The solubility of crystalline free base form compound 108 in 0.1 N HCl was 5.2 mg/mL.

EXAMPLE 7:

This example reports additional data prepared from a separate batch of crystalline free base form of Compound 108, than the material giving rise to the data reported above.

^{13}C-NMR (100 MHz, solid state) δ(ppm): 11.9, 31.1, 52.2, 54.8, 56.5, 88.6, 95.7, 106.2, 110.8, 112.3, 114.5, 123.0, 129.0, 130.3, 132.3, 132.9, 133.8, 149.9, 153.2, 154.8, 155.4, 160.0, 162.1, 164.4. This is shown in FIG. 10.

^{1}H-NMR spectrum (DMSO-d_6) δ(ppm): 1.03 (3H, t, J=7.2 Hz), 2.37 (2H, q, J=7.2 Hz), 2.46-2.51 (4H, m), 3.12 (4H, t, J= 5.0 Hz), 3.21 (3H, s), 3.92 (6H, s), 5.71 (1H, dd, J= 10.3, 1.7 Hz), 6.13-6.26 (1H, m), 6.22 (1H, dd, J=17.1, 1.8 Hz), 6.48 (1H, dd, J=17.0, 10.3 Hz), 6.80 (1H, dd, J= 8.9, 2.6 Hz), 6.88 (1H, s), 7.23-7.33 (1H, m), 7.28 (1H, d, J=8.9 Hz), 8.30 (1H, s), 8.69 (1H, brs), 9.57 (1H, brs), 12.05 (1H, s). This was measured using an Avance 600 MHz (Bruker). This is shown in FIG. 9D.

EXAMPLE 8: Preparation of *N*-(2-((6-(3-(2,6-dichloro-3,5-dimethoxyphenyl)-1-methylureido)pyrimidin-4-yl)amino)-5-(4-ethylpiperazin-1-yl)phenyl)acrylamide monohydrochloride crystals

A solution (4 mL) of acetone containing 10% (v/v) DMSO was spiked with hydrochloric acid solution (2.76 µL, 1eq), added to *N*-(2((6-(3-(2,6-dichloro-3,5-dimethoxyphenyl)-1-methylureido)pyrimidin-4-yl)amino)-5-(4-ethylpiperazin-1-yl)phenyl)acrylamide (20.25 mg), irradiated with ultrasound, and stirred at room temperature for 7 days. Resultant crystals were filtered off and washed with acetone to give *N*-(2-((6-(3-(2,6-dichloro-3,5-dimethoxyphenyl)-1-methylureido)pyrimidin-4-yl)amino)-5-(4-ethylpiperazin-1-yl)phenyl)acrylamide monohydrochloride crystals.

EXAMPLE 9: Preparation of *N*-(2-((6-(3-(2,6-dichloro-3,5-dimethoxyphenyl)-1-methylureido)pyrimidin-4-yl)amino)-5-(4-ethylpiperazin-1-yl)phenyl)acrylamide monohydrochloride crystals

A solution (2.5 mL) of acetone containing 10% (v/v) DMSO was spiked with hydrochloric acid solution (7.25 µL, 1eq), added to *N*-(2((6-(3-(2,6-dichloro-3,5-dimethoxyphenyl)-1-methylureido)pyrimidin-4-yl)amino)-5-(4-ethylpiperazin-1-yl)phenyl)acrylamide (53.12 mg), irradiated with ultrasound, and stirred at room temperature for a day. Crystalline form obtained in Example 8 was added to the reaction mixture and further stirred for 5 days. Resultant crystals were filtered off and washed with ethanol (1mL) to give *N*-(2-((6-(3-(2,6-dichloro-3,5-dimethoxyphenyl)-1-methylureido)pyrimidin-4-yl)amino)-5-(4-ethylpiperazin-1-yl)phenyl)acrylamide monohydrochloride crystals (50.60 mg).

EXAMPLE 10: Preparation of *N*-(2-((6-(3-(2,6-dichloro-3,5-dimethoxyphenyl)-1-

methylureido)pyrimidin-4-yl)amino)-5-(4-ethylpiperazin-1-yl)phenyl)acrylamide monohydrochloride crystals

A solution (25 mL) of acetone containing 10% (v/v) DMSO was spiked with hydrochloric acid solution (68.51 µL, 1eq), added to *N*-(2((6-(3-(2,6-dichloro-3,5-dimethoxyphenyl)-1-methylureido)pyrimidin-4-yl)amino)-5-(4-ethylpiperazin-1-yl)phenyl)acrylamide (502.1 mg), and irradiated with ultrasound. Crystalline form obtained in Example 9 was added to the reaction mixture and stirred at room temperature for 7 days. Resultant crystals were filtered off, washed with ethyl acetate (1.5mL) and dried under reduced pressure for 3 days to give *N*-(2-((6-(3-(2,6-dichloro-3,5-dimethoxyphenyl)-1-methylureido)pyrimidin-4-yl)amino)-5-(4-ethylpiperazin-1-yl)phenyl)acrylamide monohydrochloride crystals (543.0mg).

^{13}C-NMR (100 MHz, solid state) δ(ppm): 10.9, 32.1, 34.1, 45.4, 49.2, 51.9, 53.7, 56.0, 91.3, 95.7, 112.5, 121.2, 124.1, 128.2, 130.7, 134.3, 144.7, 153.6, 154.8, 160.3, 166.9. This is shown in FIG. 11.

^{1}H-NMR spectrum (DMSO-d_6) δ(ppm): 1.26 (3H, m), 2.98-3.21 (6H, m), 3.23 (3H, s), 3.55 (2H, brs), 3.77 (2H, brs), 3.92 (6H, s), 5.72 (1H, dd, J= 10.3, 1.3 Hz), 6.23 (1H, dd, J=17.0, 1.6 Hz), 6.26 (1H, brs), 6.52 (1H, dd, J=17.0, 10.2), 6.87 (1H, dd, J= 9.0, 2.0 Hz), 6.89 (1H, s), 7.37 (1H, d, J=8.8 Hz), 7.41 (1H, brs), 8.32 (1H, s), 8.88 (1H, s), 9.67 (1H, s), 10.17 (1H, brs), 12.02 (1H, s). This is shown in FIG. 12.

EXAMPLE 11:

PXRD data for samples in this Example were taken on a Rigaku RINT TTR-III Instrument (Target: Cu; Tube voltage: 50 kV; Tube current: 300 mA, Range 5.0-35.0=30°).

A crystalline *N*-(2-((6-(3-(2,6-dichloro-3,5-dimethoxyphenyl)-1-methylureido)pyrimidin-4-yl)amino)-5-(4-ethylpiperazin-1-yl)phenyl)acrylamide monohydrochloride as prepared in Example 10 is characterized by the PXRD pattern shown in FIG. 13.

As summarized in Table 8, the crystalline form of *N*-(2-((6-(3-(2,6-dichloro-3,5-dimethoxyphenyl)-1-methylureido)pyrimidin-4-yl)amino)-5-(4-ethylpiperazin-1-yl)phenyl)acrylamide monohydrochloride exhibits a PXRD pattern with at least ten characteristic peaks.

TABLE 8: Characteristic crystalline *N*-(2-((6-(3-(2,6-dichloro-3,5-dimethoxyphenyl)-1-methylureido)pyrimidin-4-yl)amino)-5-(4-ethylpiperazin-1-yl)phenyl)acrylamide

monohydrochloride PXRD Peaks.

2θ ° (± 0.2 °)
9.0
11.3
18.1
19.9
23.0
23.5
25.4
26.6
27.6
29.0

EXAMPLE 12: Preparation of *N*-(2-((6-(3-(2,6-dichloro-3,5-dimethoxyphenyl)-1-methylureido)pyrimidin-4-yl)amino)-5-(4-ethylpiperazin-1-y1)phenyl)acrylamide dihydrochloride crystals

Acetone (3 mL) was spiked with hydrochloric acid solution (12.36 µL, 3eq), added to *N*-(2((6-(3-(2,6-dichloro-3,5-dimethoxyphenyl)-1-methylureido)pyrimidin-4-yl)amino)-5-(4-ethylpiperazin-1-yl)phenyl)acrylamide (30.19 mg), irradiated with ultrasound, and stirred at room temperature for 4 days. Resultant crystals were filtered off to give *N*-(2-((6-(3-(2,6-dichloro-3,5-dimethoxyphenyl)-1-methylureido)pyrimidin-4-yl)amino)-5-(4-ethylpiperazin-1-y1)phenyl)acrylamide dihydrochloride crystals.

EXAMPLE 13: Preparation of *N*-(2-((6-(3-(2,6-dichloro-3,5-dimethoxyphenyl)-1-methylureido)pyrimidin-4-yl)amino)-5-(4-ethylpiperazin-1-y1)phenyl)acrylamide dihydrochloride crystals

A solution (10 mL) of acetone containing 10% (v/v) DMSO was spiked with hydrochloric acid solution (137.7 µL, 2eq), added to *N*-(2((6-(3-(2,6-dichloro-3,5-dimethoxyphenyl)-1-methylureido)pyrimidin-4-yl)amino)-5-(4-ethylpiperazin-1-yl)phenyl)acrylamide (504.4 mg), and irradiated with ultrasound. Crystalline form obtained in Example 12 was added to the reaction mixture and stirred at room temperature for 7 days.

Resultant crystals were filtered off, washed with ethyl acetate (1.5mL) and dried under reduced pressure for 3 days to give *N*-(2-((6-(3-(2,6-dichloro-3,5-dimethoxyphenyl)-1-methylureido)pyrimidin-4-yl)amino)-5-(4-ethylpiperazin-1-yl)phenyl)acrylamide dihydrochloride crystals (565.4mg).

^{13}C-NMR (100 MHz, solid state) δ(ppm): 9.9, 30.4, 35.0, 39.8, 41.5, 45.5, 46.7, 51.3, 53.8, 56.1, 57.6, 93.2, 96.1, 109.9, 111.5, 112.5, 115.6, 119.0, 128.2, 130.0, 131.6, 134.0, 148.6, 154.6, 161.4, 163.7. This is shown in FIG. 14.

^{1}H-NMR spectrum (DMSO-d6) δ(ppm): 1.27 (3H, t, J=7.3 Hz), 3.03-3.21 (6H, m), 3.25 (3H, s), 3.52-3.59 (2H, m), 3.72-3.83 (2H, m), 3.92 (6H, s), 5.72 (1H, dd, J= 10.3, 1.5 Hz), 6.23 (1H, dd, J=17.1, 1.6 Hz), 6.32 (1H, brs), 6.53 (1H, dd, J=17.0, 10.4), 6.88 (1H, dd, J= 8.9, 2.5 Hz), 6.89 (1H, s), 7.37 (1H, d, J=8.8 Hz), 7.42 (1H, brs), 8.34 (1H, s), 9.03 (1H, brs), 9.73 (1H, s), 10.43 (1H, brs), 11.88 (1H, brs). This is shown in FIG. 15.

EXAMPLE 14:

PXRD data for samples in this Example were taken on a Rigaku RINT TTR-III Instrument (Target: Cu; Tube voltage: 50 kV; Tube current: 300 mA, Range 5.0-35.0=30°).

A crystalline *N*-(2-((6-(3-(2,6-dichloro-3,5-dimethoxyphenyl)-1-methylureido)pyrimidin-4-yl)amino)-5-(4-ethylpiperazin-1-yl)phenyl)acrylamide dihydrochloride as prepared in Example 13 is characterized by the PXRD pattern shown in FIG. 16.

As summarized in Table 9, the crystalline form of *N*-(2-((6-(3-(2,6-dichloro-3,5-dimethoxyphenyl)-1-methylureido)pyrimidin-4-yl)amino)-5-(4-ethylpiperazin-1-yl)phenyl)acrylamide dihydrochloride exhibits a PXRD pattern with at least ten characteristic peaks.

TABLE 9: Characteristic crystalline *N*-(2-((6-(3-(2,6-dichloro-3,5-dimethoxyphenyl)-1-methylureido)pyrimidin-4-yl)amino)-5-(4-ethylpiperazin-1-yl)phenyl)acrylamide dihydrochloride PXRD Peaks.

2θ ° (± 0.2 °)
8.0
12.4
13.5
16.1
18.7

21.3
22.8
26.2
26.6
28.0

EXAMPLE 15: Preparation of *N*-(2-((6-(3-(2,6-dichloro-3,5-dimethoxyphenyl)-1-methylureido)pyrimidin-4-yl)amino)-5-(4-ethylpiperazin-1-yl)phenyl)acrylamide ethanesulfonate

Acetone (5 mL) was spiked with ethanesulfonic acid solution (13.51 μL, 1eq), added to *N*-(2-((6-(3-(2,6-dichloro-3,5-dimethoxyphenyl)-1-methylureido)pyrimidin-4-yl)amino)-5-(4-ethylpiperazin-1-yl)phenyl)acrylamide (100.6 mg), irradiated with ultrasound, and stirred at room temperature for 7 days. Resultant crystals were filtered off to give *N*-(2-((6-(3-(2,6-dichloro-3,5-dimethoxyphenyl)-1-methylureido)pyrimidin-4-yl)amino)-5-(4-ethylpiperazin-1-yl)phenyl)acrylamide ethanesulfonate crystals (103.7 mg).

EXAMPLE 16: Preparation of *N*-(2-((6-(3-(2,6-dichloro-3,5-dimethoxyphenyl)-1-methylureido)pyrimidin-4-yl)amino)-5-(4-ethylpiperazin-1-yl)phenyl)acrylamide ethanesulfonate

Acetone (20 mL) was spiked with ethanesulfonic acid solution (67.22 μL, 1eq), added to *N*-(2((6-(3-(2,6-dichloro-3,5-dimethoxyphenyl)-1-methylureido)pyrimidin-4-yl)amino)-5-(4-ethylpiperazin-1-yl)phenyl)acrylamide (500.6 mg), and irradiated with ultrasound. Crystalline form obtained in Example 15 was added to the reaction mixture and stirred at room temperature for 3 days. Resultant crystals were filtered off, washed with ethyl acetate (1.5mL), and dried under reduced pressure for 3 days to give *N*-(2-((6-(3-(2,6-dichloro-3,5-dimethoxyphenyl)-1-methylureido)pyrimidin-4-yl)amino)-5-(4-ethylpiperazin-1-yl)phenyl)acrylamide ethanesulfonate crystals (562.0mg).

^{13}C-NMR (100 MHz, solid state) δ(ppm): 10.3, 33.4, 44.0, 44.3, 45.0, 45.9, 47.0, 50.0, 53.0, 55.9, 87.6, 95.5, 107.4, 111.0, 124.8, 129.5, 131.5, 134.5, 144.2, 154.6, 159.2, 159.9, 164.1. This is shown in FIG. 17.

^{1}H-NMR spectrum (DMSO-d_6) δ(ppm): 1.05 (3H, t, J=7.5 Hz), 1.25 (3H, t, J=7.3 Hz), 2.37 (2H, q, J=7.4 Hz), 2.98 (2H, t, J=11.7 Hz), 3.13 (2H, m), 3.21 (2H, m), 3.24 (3H, s), 3.58 (2H, brd, J=11.6 Hz), 3.80 (2H, brd, J=12.9 Hz), 3.92 (6H, s), 5.72 (1H, dd, J= 10.3, 1.5 Hz),

6.22 (1H, dd, J=17.0, 1.7 Hz), 6.25 (1H, brs), 6.50 (1H, dd, J=17.0, 10.3), 6.84-6.92 (2H, m), 7.36 (1H, d, J=8.9 Hz), 7.41 (1H, brs), 8.32 (1H, s), 8.81 (1H, s), 9.34 (1H, brs), 9.58 (1H, brs), 11.99 (1H, s). This is shown in FIG. 18.

EXAMPLE 17:

PXRD data for samples in this Example were taken on a Rigaku RINT TTR-III Instrument (Target: Cu; Tube voltage: 50 kV; Tube current: 300 mA, Range 5.0-35.0=30°).

A crystalline *N*-(2-((6-(3-(2,6-dichloro-3,5-dimethoxyphenyl)-1-methylureido)pyrimidin-4-yl)amino)-5-(4-ethylpiperazin-1-yl)phenyl)acrylamide ethanesulfonate as prepared in Example 16 is characterized by the PXRD pattern shown in FIG. 19.

As summarized in Table 10, the crystalline form of *N*-(2-((6-(3-(2,6-dichloro-3,5-dimethoxyphenyl)-1-methylureido)pyrimidin-4-yl)amino)-5-(4-ethylpiperazin-1-yl)phenyl)acrylamide ethanesulfonate exhibits a PXRD pattern with at least ten characteristic peaks.

TABLE 10: Characteristic crystalline *N*-(2-((6-(3-(2,6-dichloro-3,5-dimethoxyphenyl)-1-methylureido)pyrimidin-4-yl)amino)-5-(4-ethylpiperazin-1-yl)phenyl)acrylamide ethanesulfonate PXRD Peaks.

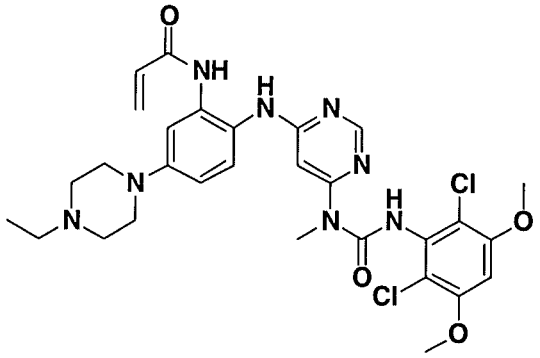
2θ ° (± 0.2 °)
9.4
11.2
15.1
19.2
20.3
21.8
22.4
23.3
23.6
24.0

The foregoing is illustrative of the present invention, and is not to be construed as

limiting thereof. The invention is defined by the following claims, with equivalents of the claims to be included therein.

WE CLAIM:

1. A crystalline form of the compound:



N-(2-((6-(3-(2,6-dichloro-3,5-dimethoxyphenyl)-1-methylureido)pyrimidin-4-yl)amino)-5-(4-ethylpiperazin-1-yl)phenyl)acrylamide

2. The crystalline compound of claim 1, wherein said compound is a crystalline free base form of compound *N*-(2-((6-(3-(2,6-dichloro-3,5-dimethoxyphenyl)-1-methylureido)pyrimidin-4-yl)amino)-5-(4-ethylpiperazin-1-yl)phenyl)acrylamide.

3. The crystalline free base compound of claim 2, wherein the crystalline free base form compound exhibits at least the following X-ray powder diffraction peaks, 2θ° (± 0.2): 10.3, 8.0, and 9.5.

4. The crystalline free base compound of claim 3, wherein the crystalline free base form compound exhibits at least the following X-ray powder diffraction peaks, 2θ° (± 0.2°): 10.3, 8.0, 9.5, 14.8, 16.5, and 17.1.

5. The crystalline free base compound of claim 4, wherein the crystalline free base form compound exhibits at least the following X-ray powder diffraction peaks, 2θ° (± 0.2°): 10.3, 8.0, 9.5, 14.8, 16.5, 17.1, 19.3, 21.8, 23.7, and 24.5.

6. The crystalline free base compound of claim 2, wherein the crystalline free base form is characterized by a powder X-ray diffraction (PXRD) pattern substantially as shown in FIG. 5.

7. The crystalline compound of claim 1, wherein said crystalline compound is a stoichiometric or non-stoichiometric HCl salt of *N*-(2-((6-(3-(2,6-dichloro-3,5-dimethoxyphenyl)-1-methylureido)pyrimidin-4-yl)amino)-5-(4-ethylpiperazin-1-yl)phenyl)acrylamide.

8. The crystalline compound of claim 7, wherein the crystalline compound is a *N*-(2-((6-(3-(2,6-dichloro-3,5-dimethoxyphenyl)-1-methylureido)pyrimidin-4-yl)amino)-5-(4-ethylpiperazin-1-yl)phenyl)acrylamide monohydrochloride salt.

9. The crystalline compound of claim 8, wherein the crystalline compound exhibits at least the following X-ray powder diffraction peaks, 2θ°(± 0.2°): 26.6, 19.9, and 11.3.

10. The crystalline compound of claim 9, wherein the crystalline compound exhibits at least the following X-ray powder diffraction peaks, 2θ°(± 0.2°): 26.6, 19.9, 11.3, 9.0, 23.5, and 25.4.

11. The crystalline compound of claim 10, wherein the crystalline compound exhibits at least the following X-ray powder diffraction peaks, 2θ°(± 0.2°): 26.6, 19.9, 11.3, 9.0, 23.5, 25.4, 27.6, 23.0, 18.1, and 29.0.

12. The crystalline compound of claim 8, wherein the crystalline compound is characterized by a powder X-ray diffraction (PXRD) pattern substantially as shown in FIG. 13.

13. The crystalline compound of claim 7, wherein the crystalline compound is a crystalline *N*-(2-((6-(3-(2,6-dichloro-3,5-dimethoxyphenyl)-1-methylureido)pyrimidin-4-yl)amino)-5-(4-ethylpiperazin-1-yl)phenyl)acrylamide dihydrochloride salt.

14. The crystalline compound of claim 13, wherein the crystalline compound exhibits at least the following X-ray powder diffraction peaks, 2θ°(± 0.2°): 26.6, 22.8, and 21.3.

15. The crystalline compound of claim 14, wherein the crystalline compound exhibits at the following X-ray powder diffraction peaks, 2θ°(± 0.2°): 26.6, 22.8, 21.3, 8.0, 26.2, and 13.5.

16. The crystalline compound of claim 15, wherein the crystalline compound exhibits at the following X-ray powder diffraction peaks, 2θ°(± 0.2°): 26.6, 22.8, 21.3, 8.0, 26.2, 13.5, 12.4, 16.1, 28.0, and 18.7.

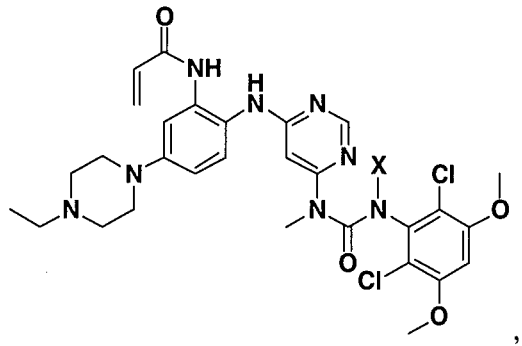
17. The crystalline compound of claim 13, wherein the crystalline compound is characterized by a powder X-ray diffraction (PXRD) pattern substantially as shown in FIG. 16.

18. A pharmaceutical composition comprising the crystalline compound of any one of claims 1-17 and a pharmaceutically acceptable carrier.

19. The pharmaceutical composition of claim 18, wherein said composition is formulated for oral, intravenous or subcutaneous administration.

20. A method for preparing the crystalline free base form compound of claim 2, comprising:

a) providing a composition comprising a compound:



, wherein X is (2-(trimethylsilyl)ethoxy)methyl, in a solvent;

b) adding an acid to said composition while maintaining a temperature of the composition ≤ 50 °C; then

c) adding to the composition saturated ammonium hydroxide solution; and then

e) extracting the composition with a mixture of immiscible solvents to form an organic phase; and

f) adding a suitable solvent to the organic phase,

to thereby form said crystalline free base form compound of claim 2.

21. The process of claim 20, wherein said acid of step b) is trifluoroacetic acid, hydrochloric acid, hydrobromic acid, sulfuric acid or methanesulfonic acid.

22. The process of claim 20 or claim 21, wherein the suitable solvent of step f) is dichloromethane, acetonitrile, 1,2-dichloroethane, or aqueous dimethyl formamide.

23. A method of treating hepatocellular carcinoma in a subject in need thereof comprising administering to said subject a treatment effective amount of the compound of any one of claims 1-17 or the pharmaceutical composition of claim 18 or claim 19.

24. The method of claim 23, wherein said hepatocellular carcinoma has altered FGFR4 and/or FGF19 status.

25. The method of claim 24, wherein said altered FGFR4 and/or FGF19 status comprises increased expression of FGFR4 and/or FGF19.

26. A method of treating hepatocellular carcinoma in a subject in need thereof, comprising:

detecting an altered FGFR4 and/or FGF19 status in a biological sample containing cells of said hepatocellular carcinoma, and if said hepatocellular carcinoma has said altered FGFR4 and/or FGF19 status,

administering a crystalline form of the compound of any one of claims 1-17 or the pharmaceutical composition of claim 18 or claim 19 to said subject in a treatment-effective amount.

27. The method of claim 27, wherein said altered FGFR4 and/or FGF19 status comprises increased expression of FGFR4 and/or FGF19.

28. Use of a crystalline form of the compound of any one of claims 1-18 or the pharmaceutical composition of claim 19 or claim 20 in a method of treatment for hepatocellular

carcinoma.

29. The use of claim 29, wherein said hepatocellular carcinoma has altered FGFR4 and/or FGF19 status.

30. The use of claim 30, wherein said altered FGFR4 and/or FGF19 status comprises increased expression of FGFR4 and/or FGF19.

31. Use of a crystalline form of the compound of any one of claims 1-18 in the preparation of a medicament.

32. The use of claim 31, wherein said medicament is for the treatment of hepatocellular carcinoma.

33. The use of claim 32, wherein said hepatocellular carcinoma has altered FGFR4 and/or FGF19 status.

34. The use of claim 33, wherein said altered FGFR4 and/or FGF19 status comprises increased expression of FGFR4 and/or FGF19.