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%Modified cell model for the dynamic of aiiA inside the Erwinia

%Numerical method with ode23s to solve a nonlinear ordinary differential
%equations

clear all
close all
clc

%Initial conditions for x0 vector
x0(1)=0;%Initial condition of EamI
x0(2)=0;%Initial condition of EamR-AHL complex
x0(3)=0; %Initial condition of intracellular AHL
x0(4)=0; %Initial condition of extracellular AHL

%Parameters
RT=0.5; %Total concentration of EamR monomers [nM]
v=8*10^(-4);%AHL synthesis rate[1/min]
betha=0.5; %AHL binding rate with EamR to create dimers[1/(min*nM^3)]
gamma=0.02; %Dissociation rate of AHL from EamR [1/min]
nu=0.6;%Rate of diffusion of extracellular AHL from the population (out of the system)
[1/min]
phi_0=0.05; %k_I*alpha_0/dm_I [nM/min]
phi=10; %k_I*alpha/dm_I [nM/min]
d_I=0.07;% Degradation rate of EamI [1/min]
D=1000;%Extracellular AHL loss rate [1/min]
K=0.01;% Dissociation constant of the binding events between the complex AHL-EamR and the
operon area [nM]
%p=2000; % cell density [arbitrary units]
tetha=0.5; %0.5;%1.19*10^(-2);%6.588*10^(-7); %aiiA affinity rate with AHL [1/(nM*min)]
E=0.6; % aiiA concentration in quasi-steady-state [nM]

%Time vector
n=10000;
tspan=linspace(0,300,n);

p(1)=0;
%ODE's system
fg=@(t,x) [phi_0+phi*x(2)/(K+x(2))-d_I*x(1);...
    betha*(x(3)^2)*((RT-2*x(2))^2)-gamma*x(2);...
    v*x(1)-nu*(x(3)-x(4))-2*betha*((x(3))^2)*((RT-2*x(2))^2)+2*gamma*x(2)-
tetha*E*x(3);...
    p(1)*nu*(x(3)-x(4))-D*x(4)];
%Solution with ode23s
[t,x]=ode23s(fg,tspan,x0);
X_1(:,1)=x(:,1);
X_2(:,1)=x(:,2);
X_3(:,1)=x(:,3);
X_4(:,1)=x(:,4);

for i=2:50
    p(i)=p(i-1)+100;
    fg=@(t,x) [phi_0+phi*x(2)/(K+x(2))-d_I*x(1);...
    betha*(x(3)^2)*((RT-2*x(2))^2)-gamma*x(2);...
    v*x(1)-nu*(x(3)-x(4))-2*betha*((x(3))^2)*((RT-2*x(2))^2)+2*gamma*x(2)-
tetha*E*x(3);...
    p(i)*nu*(x(3)-x(4))-D*x(4)];...
    [t,x]=ode23s(fg,tspan,x0);
    X_1(:,i)=x(:,1);
    X_2(:,i)=x(:,2);
    X_3(:,i)=x(:,3);
    X_4(:,i)=x(:,4);
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end

%Graphics

%Variables throught time
figure(1)
plot(t,x(:,1),'-b')%EamI behavior through time
hold on
plot (t,x(:,2),'--g')%Complex AHL-EamR behavior through time
plot (t,x(:,3),':c')%AHL intracellular behavior through time
plot (t,x(:,4),'-.m')%AHL extracellular behavior through time
xlabel('t (min)')
ylabel('I,P,A,Ae (nM)');
%ylim([-0.2 1.2])
%title('EamI, Regulator Complex,Intracellular AHL,Extracellular AHL concentrations')
legend ({ 'I(t)', 'P(t)', 'A(t)','Ae(t)'})

%Variables VS cell density
figure(2)
plot(p,X_1(end,:),'b')
hold on
plot(p,X_2(end,:),'--g')
plot(p,X_2(end,:),':c')
plot(p,X_2(end,:),'-.m')
ylim([-2 2])
xlabel('p (arbitrary units)')
ylabel('I,P,A,Ae (nM)');
%title('EamI, Regulator Complex,Intracellular AHL,Extracellular AHL concentrations VS
cell density')
legend ({ 'I(t)', 'P(t)', 'A(t)','Ae(t)'})

%Cell density VS I
figure(3)
plot(p,X_1(end,:),'b')
xlabel('p (arbitrary units)')
ylabel('I (nM)');
%title('Regulator Complex concentrations VS cell density')
legend ({  'I(t)'})

%Cell density VS Complex AHL-EamR
figure(4)
plot(p,X_2(end,:),'--g')
xlabel('p (arbitrary units)')
ylabel('P (nM)');
legend ({  'P(t)'})

%Cell density VS Intracellular AHL
figure(5)
plot(p,X_3(end,:),'c')
xlabel('p (arbitrary units)')
ylabel('A (nM)');
legend ({  'A(t)'})

%Cell density VS Extracellular AHL
figure(6)
plot(p,X_4(end,:),'-.m')
xlabel('p (arbitrary units)')
ylabel('Ae (nM)');
legend ({  'Ae(t)'})
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