Joe Phua, Ph.D.

4*$5678%9:"66;%6<%("*%=,(8%
96#("*,>%4*("65'8(%?>'@*,8'(-%
?AB",*-%C**%D*>(*,0%EE22%F-*,%9(G0%
F$;;$80%HI%JK12K%
!"6>*L%M1.3N%JOPQO.EE%
RA$';%L%SB"#$T8A#G*5#%

%

!"GFGO%	0%12..0%D6AA#>':$('6>%
%	
4G=GO%	0%12230%D6AA#>':$('6>%4$>$U*A*>(%
%	
VG=GO%	0%12210%D'>*A$%$>5%4*5'$%9(#5'*8%
%	

F',*:(6,0%H*A*,;'>%=5@*,('8'>U%M>8('(#(*0%4*$5678%9:"66;%6<%("*%=,(8%M)$;;%1211%

=88'8($>(%!,6<*886,%MH*>#,*Q(,$:\NO%F*B$,(A*>(%6<%=5@*,('8'>U%$>5%!#+;':%
Y*;$('6>80%Z,$5-%D6;;*U*%6<%[6#,>$;'8A%$>5%4$88%D6AA#>':$('6>%M)$;;%12..%X%
9B,'>U%12.JN%

%
H6B%!$B*,%=7$,5%12110%=7$,5*5%+-L%=886:'$('6>%<6,%R5#:$('6>%'>%[6#,>$;'8A%
$>5%4$88%D6AA#>':$('6>%M=R[4DNO%=5@*,('8'>U%F'@'8'6>G%
%
Y*8*$,:"%)*;;678"'B%D6AB*('('6>%=7$,5%121.Q1211O%=7$,5*5%+-L%=A*,':$>%
=:$5*A-%6<%=5@*,('8'>U%M===NG%
%
V*8(%=,(':;*%=7$,5%12.P%6<%][6#,>$;%6<%W>(*,$:('@*%=5@*,('8'>U^0%=7$,5*5%+-L%
=A*,':$>%=:$5*A-%6<%=5@*,('8'>U%M===NG%
%
_6#>U%9:"6;$,%=7$,5%12.P%M`6A'>**NO%W>(*,>$('6>$;%D6AA#>':$('6>%=886:'$('6>%
MWD=NG%
%
H6B%!$B*,%=7$,5%12.OO%=7$,5*5%+-L%W>(*,>$('6>$;%D6AA#>':$('6>%=886:'$('6>%
MWD=NO%9B6,(8%D6AA#>':$('6>%W>(*,*8(%Z,6#BG%
%
F'88*,($('6>%6<%("*%_*$,%=7$,5%12.10%=7$,5*5%+-L%W>(*,>$('6>$;%D6AA#>':$('6>%
=886:'$('6>%MWD=N%$>5%`$('6>$;%D6AA#>':$('6>%=886:'$('6>%M`D=NO%a*$;("%
D6AA#>':$('6>%F'@'8'6>8G%
%
9#AA*,%F6:(6,$;%9:"6;$,8"'B%12.2O%=7$,5*5%+-L%bc<6,5%W>(*,>*(%W>8('(#(*%MbWWNO%
?>'@*,8'(-%6<%bc<6,50%bc<6,50%?>'(*5%d'>U56AG%
%
&'8'('>U%9:"6;$,%)*;;678"'B%12.2O%=7$,5*5%+-L%9'>U$B6,*%W>(*,>*(%Y*8*$,:"%
D*>(*,%M9WYDNO%`$>-$>U%H*:">6;6U':$;%?>'@*,8'(-O%9'>U$B6,*G%
%
H6B%9(#5*>(%!$B*,%=7$,5%122/0%=7$,5*5%+-L%`$('6>$;%D6AA#>':$('6>%
=886:'$('6>%M`D=NO%a#A$>%D6AA#>':$('6>%$>5%H*:">6;6U-%F'@'8'6>G%
%
H6B%9(#5*>(%!$B*,%=7$,5%122PO%=7$,5*5%+-L%W>(*,>$('6>$;%D6AA#>':$('6>%
=886:'$('6>%MWD=NO%W>(*,U,6#B%D6AA#>':$('6>%W>(*,*8(%Z,6#BG%
%

%
?>'@*,8'(-%6<%Z*6,U'$0%Z,$>(%F*@*;6BA*>(%!,6U,$A%!$,(':'B$>(%12.3Q12.OO%
b7*>8%W>8('(#(*%<6,%V*"$@'6,$;%Y*8*$,:"%MbWVYNG%
%
?>'@*,8'(-%6<%Z*6,U'$0%D"$,;*8%VG%d>$BB%R$,;-%D$,**,%9:"6;$,%=7$,5%12.O%
M`6A'>**NO%?>'@*,8'(-%6<%Z*6,U'$%Y*8*$,:"%)6#>5$('6>%M?Z=Y)NG%

! "#$%&'($%E%) *+,#$,-%. /0%1213
% %

%%
?>'@*,8'(-%6<%Z*6,U'$0%C';;-%H*$:"'>U%) *;;67%12.1Q12.30%D*>(*,%<6,%H*$:"'>U%$>5%
C*$,>'>U%MDHCNG%
%
?>'@*,8'(-%6<%96#("*,>%D$;'<6,>'$0%Y*8*$,:"%=7$,5%<6,%W>(*,>$('6>$;%F'88*,($('6>%
9(#5-%12.2Q12..0%=>>*>+*,U%9:"66;%<6,%D6AA#>':$('6>%$>5%[6#,>$;'8AG%
%
?>'@*,8'(-%6<%96#("*,>%D$;'<6,>'$0%F6:(6,$;%9(#5'*8%) *;;678"'B%=7$,5%122OQ12..0%
=>>*>+*,U%9:"66;%<6,%D6AA#>':$('6>%$>5%[6#,>$;'8AG%

[Note: * denotes undergraduate or graduate co-authors at the time research was conducted; ISI Web of Science Impact Factor in parentheses.]

G S C S (F 19, 2024):

C : 6,010 - : 28, 10- : 40

(0)

%
.G% `'\6;'>$\6#0=>U*;'\'0% 0%$>5%R#>%966\%d76>%W>%!,*88NG% e "$(%
F,'@*8%=55':6>%6>%96:'$;%4*5'$%9'(*8f%H"*%Y*;$('6>8"'B8%+*(7**>%
!8-:"6;6U':$;%e *;;QV*'>U%9($(*80%96:'$;%4*5'$%=55':('6>0%V,$>5%=55':('6>0%
$>5%WAB#;8*%V#-'>U%6>%96:'$;%4*5'$G% %
g121.%WAB$:(%)$:(6,L%PG/KJh%
%
1G% C**0%_*>QW0%_'>UQD"'$%a8#i0% 0%H$'Q_**%e #0%$>5%9$,$"%a$:"A$>i%

%

%

OG% , 0%$>5%F6>U%[$*%C'Ai%M121ENG%D$>%e$,>'>U%;$+*;8%A'('U$(*%
R<<*:(8%6<%=5@*,('8'>U%4*88$U*%D;$'A8%'>%D*;*+,'(-QR>56,8*5%W>8($U,$AQ
V$8*5%R;*:(,6>':%D'U$,*((*%=5@*,('8*A*>(8f%W><;#*>:*%6>%96:'$;%4*5'$%
?8*,8j%RQD'U$,*((*%=(('(#5*8%$>5%V*"$@'6,$;%W>(*>('6>8G%
MKN0%3KKQ3JK %

%

JG% !<*#<<*,0%=;*c$>5*,0%$>5% %M1211

%

11G% , 0%["'"Q9-#$>%C'>0%$>5%F6>U%[$*%C'Ai%M12.PNG%?>5*,8($>5'>U%
D6>8#A*,%R>U$U*A*>(%7'("%D*;*+,'(-QR>56,8*5%RQD'U$,*((*%=5@*,('8'>U%
6>%W>8($U,$AG% 0%/EQ.21G%
g121.%WAB$:(%)$:(6,L%PG/KJh%

%

1EG% , 0%!6QC'>%!$>0%$>5%d#$>Q[#%D"*>i%M12.PNG%9B6,(%H*$A

% %

%

33G%['>0%9*#>U$%&*>#80%$>5% %M12.3NG%)6;;67'>U%D*;*+,'('*8j%H7**(8%
$+6#(%V,$>58L%H"*%WAB$:(%6<%H7'((*,QV$8*5%R;*:(,6>':%e6,5Q6<Q46#("%
M*e64N%6>%D6>8#A*,8j%96#,:*%D,*5'+';'(-%!*,:*B('6>0%V#-'>U%W>(*>('6>0%
$>5%96:'$;%W5*>('<':$('6>%7'("%D*;*+,'('*8G% M1NO%
.P.Q./KG%
g121.%WAB$:(%)$:(6,L%OGK1Ph%
%
%

3KG% , %M12.ENG%!$,(':'B$('>U%'>%a*$;("%W88#*Q9B*:'<':%96:'$;%`*(76,\'>U%
9'(*8%M9`98N%(6%k#'(%9A6\'>UL%a67%56*8%b>;'>*%96:'$;%
W>(*,:6>>*:(*5>*88%'><;#*>:*%9A6\'>U%D*88$('6>%9*;<QR<<':$:-f%
MKNO%/EEQ/K1G%%
g121.%WAB$:(%)$:(6,L%KGJK2h%

3OG% , %M12.ENG%H"*%Y*<*,*>:*%Z,6#B%!*,8B*:('@*%<6,%9A6\'>U%
D*88$('6>L%=>%Rc$A'>$('6>%6<%("*%W><;#*>:*%6<%96:'$;%`6,A8%$>5%96:'$;%
W5*>('<':$('6>%7'("%Y*<*,*>:*%Z,6#B8%6>%9A6\'>U%D*88$('6>%9*;<

L% 0%H"6#8$>5%b$\80%D=L%9$U*0%

J12QJ1PG%

(1)

. G% ! <*#<<*,0%=;*c$>5*,0% 0%$>5%4$,';->%!,'A6@':i%M1213NG%H,#8(%+#(%

9:,#('>'n*f%Q%

. OG% , 0%9*#>U$%&*>#8%['>%$>5%['"66>%d'A i%M12. /NG%W>(*,$:('6>%R«*:(%
6<%96#,:*%H-B*%$>5%4*88$U*%&$;*>:*%'>%W>8($U,$AQ+$8*5%=5@*,('8'>U%
4*88$U*8%$+6#(%&*U$>'8AG%

13G% , 0%$>5%['"66>%d'A i%M12 . PNG%9($,,'>U%'>%_6#,%b 7>%9>$B : "$(%
=5@*,('8* A *>(L%W><;#*>: *%6<%9*;<QV,$>5%D6>U,#'(-0%9*;<QY*<*,*>:'>U%$>5%
! *, : *'@*5%a#A6,%6>%V,$>5%=(('(#5*%$>5%!#, : "$8*%W>(*>('6>%6<%=5@*,('8*5%
V,$>58G%
`*7%_6,\0%`_0%4$, : "%12 . PG%
%
1KG%D$A*,6>0%d,'8(*>i0% 0%$>5%9B*>: *,%H'>\"$A%M12 . PNG%H"*%R<<*: (%6<%
! 6;'(': $;%D$>5'5$(*%=#(" *>(': '(-%$>5%96#, : *%D, *5'+';'(-%6>%&6('>U%V*"$@'6,%
'>%(" *%12 . 0%?G9G%!, *8'5*>('$;%R;* : ('6>L%4 *88$U*0%4 *5'$0%$>5%H$,U*('>U%
WAB;': $('6>8%<6,%=5@*,('8'>U%!,$: (': *G%
`*7%_6,\0%`_0%4$, : "%12 . PG%
%
1OG% , 0%["'`"Q9-#$>%C'>%$>5%F6>U%[$*%C'Ai%M12 . JNG%Rc$A'>'>U%RQ
:'U$,*((*%=5@*,('8'>U%(",6#U"%96: '$;%4 *5'$L%R<<*: (8%6<%D6>8#A*,QD*;*+,'(-%
Y'8\Q

% %

%

E1G% , 0%9*#>U$%&*>#8%['>0%$>5%['"66>%d'A i%M12.ONG%?8*8%$>5%
Z,$('<':$('6>8%6<%96:'$;%`*(76,\'>U%9'(*8%<6,%96:'$;%D$B'($;L%D6AB$,'>U%
)$:*+66\0%H7'((*,0%W>8($U,$A0%$>5%9>$B:"$(G%
0%)#\#6\$0%[B>0%[#>*%12.OG%

%

EEG%! $>0%! 6QC'>0% 0%$>5%D"$>U% e $>% e 66%M12.ONG%! *,:*'@*5%V,$>5%
! *,86>$;'(-%(",6#U"%9B6,(8%9B6>86,8"'BL%C6:$('>U%$%V;#,,*5%C'>*%+*(7**>%
R>(*,($'>A*>(%$>5%! *,8#$8'6>%'>%4*5'$(*5%9B6,(8G%
0%)#\#6\$0%[B>0%
[#>*%12.OG%

%

%

E3G% , 0%9*#>U$%&*>#8%['>0%$>5%['"66>%d'A i%M12.ONG%Z,$('<':$('6>8%6<%
#8'>U%)$:*+66\0%H7'((*,0%W>8($U,$A0%$>5%9>$B:"$(%(6%<6;;67%V,$>58L%
W><;#*>:*%6>%V,$>5%D6AA#>'(-

% %

32G% , 0%

! "#$%&'($%. P%) *+,#$,-%. / 0%1213
% %

! ,6U,$A%R5#: $('6>%M9 ` = ! QR5N0^%) _12 . K0%D6Q ! ,'>: 'B$;%W>@*8('U$(6,0%
! ,6S* : (%qL%31J22Q232Q22222E201 /

?>'(*5%9($(*8%F*B$,(A *>(%6<%=U,': #;(#, *%M? F 9 = N0%) 665%$>5% ` #(,'('6>%9 *,@': *0%Z =%
F*B$,(A *>(%6<%a#A$>%9 *,@': *80%]Z *6,U'$%9#BB;* A *>($;% ` #(,'('6>%=88'8($>: *%
! ,6U,$A%R5#: $('6>%M9 ` = ! QR5N0^%) _12 . K0%D6Q ! ,'>: 'B$;%W>@*8('U$(6,0%
! ,6S* : (%qL%31J22Q232Q22222E201 /
%

( ) $3 , 2

?>'@*,8'(-%6<%Z *6,U'$0%= F ! Y%) $: #;(-%=5%a6: %9 * *5%Z ,$>(0%]?8'>U% ` $('@*%
=5@*,('8'>U%<6,%RQD'U$,*((*% ! ,*@*>('6>% ! #+;': %9 *,@': *%=>>6#>: * A *>(8%M ! 9 = 8NL%
R<<* : (8%6<%F'8 : ;68#,*%H-B*0% ! #+;': $('6>%H-B*%$>5%b ,U$>'n$('6>%H-B*%6>%
D6>8# A *,8j%=(('(#5*8%(6 7$,58%RQD'U$,*((*80%W>(*>('6>8%(6%#8*%RQD'U$,*((*8%$>5%
9 *;<Q

! "#$%&'($% %

=F ! Y%) $:#;(-%9*$,:"%D6A A'((**%M?Z=%Z,$5-%D6;;*U*N%M12. .N%

&

Y*@'*7*,0%[6#,>$;%6<%4$,*('>U%D6AA#>':$('6>8%M12.P%X%!,*8*>(N%
Y*@'*7*,0%D6AA#>':$('6>%Y*8*$,:"%Y*B6,(8%M12.P%X%!,*8*>(N%
Y*@'*7*,0%H*;*A$(':8%$>5%W><6,A$(':8%M12.P%X%!,*8*>(N%
Y*@'*7*,0%D6AA#>':$('6>%k#$,(*,;-%M12.P%X%!,*8*>(N%
Y*@'*7*,0%[6#,>$;%6<%D"';5,*>%t%4*5'$%M12.P%X%!,*8*>(N%
Y*@'*7*,0%[6#,>$;%6<%D#,,*>(%W88#*8%t%Y*8*$,:"%'>%=5@*,('8'>U%M12.P%X%!,*8*>(N%
Y*@'*7*,0%W>(*,>$('6>$;%[6#,>$;%6<%9(,$(*U':%D6AA#>':$('6>%M12.P%X%!,*8*>(N%

! "#$%&'($%11%) *+,#$,-%. /0%1213
% %

=A*,':$>%=:$5*A-%6<%=5@*,('8'>U%M===N0%4*A+*,8"'B%D6AA'((**0%4*A+*,%
M12.O%X%12./N%
W>(*,>$('6>$;%D6AA#>':$('6>%=886:'$('6>%MWD=N0%a*$;("%D6AA#>':$('6>%F'@'8'6>%
4*>(6,8"'B%!,6U,$A0%4*>(6,%M12.O%X%!,*8*>(N%
Z*6,U'$%a*$;(":$,*%)6#>5$('6>0%R@$;#$('6>%Y*86#,:*%D*>(*,%MRYDN0%Z,$>(%
Y*@'*7*,%$>5%!,6U,$A%R@$;#$(6,%M12.E%Q%1211N%
D6>86,('#A%<6,%Z;6+$;%4*5'$%D#;(#,*%$>5%D6AA#>':$('6>0%4*A+*,%M12.E%Q%1211N%
?9D%=>>*>+*,U%D6AA#>':$('6>%Z,$5#$(*%9(#5*>(%=886:'$('6>0%4*A+*,%M1220%X%
12..N%
?9D%`6,A$>%H6BB'>U%D6AA#>'(-%b#(,*$:"%=886:'$('6>0%4*A+*,%M1220%X%12..N%
%

?>'@*,8'(-%6<%Z*6,U'$0%D$,**,%D*>(*,%MD6>(,'+#('6>%(6%D$,**,%F*@*;6BA*>(%6<%
?Z=%9(#5*>(8N%M=7$,5*5%<6,%12.30%12.K0%12.O0%12.J0%12.P%$>5%1212N%
?>'@*,8'(-%6<%Z*6,U'$0%=;B"$%bA':,6>%!'0%C$A+5$%9'UA$%D"$B(*,%MD*,('<':$(*%6<%
=BB,*:'$('6>N%M=7$,5*5%<6,%121.N%
?>'@*,8'(-%6<%Z*6,U'$0%=F!Y%F*B$,(A*>($;%H*$:"*,%6<%("*%_*$,%12.E%M`6A'>**N%
%

[Y 4 D%P2K2%M `$"%Y$-%a$>N0%9B,'>U%12 . P%
[Y 4 D%P2K2%MD$,6;'>*%d6B6(N0%) $;;%12 . J%
[Y 4 D%J112%M 4 $(("* 7%! 'A *>($N0%9#A A *,%12 . K%
[Y 4 D%P2K2%M_$>%9 "$>N0%) $;;%12 . E%
[Y 4 D%P2K2%M[#>U%a 7$>%! $, \N0%9B,'>U%12 . E%
[Y 4 D%J112%MD",'8('>*%Y6+*,(8N0%9#A A *,%12 . 1%
[Y 4 D%P2K2%MR#>%966\%d 76>N0%) $;;%12 . 1%
[Y 4 D%P2K2%Md#$>Q

[Y 4 DP . E2L%F'U'($;%$>5%96 : '$;% 4 *5'$%=5@*,('8'>U%D6 A A#>' : $('6>%9(,$(*U'*8%
M9B,'>U%12 . 30%9B,'>U%12 . K0%9B,'>U%12 . O0%

=F ! YKJO2L%F'U'($;%$>5%96 : '$;%D6 A A#>' : $('6>%9(,$(*U'*8%M) $;;%12 . E0%9B,'>U%
12 . 30%) $;;%12 . 3%$>5%) $;;%12 . K0%9B,'>U%12 . O0%) $;;%12 . O0%9B,'>U%12 . J0%) $;;%12 . J0%
9#A A*,%12 . P0%) $;;%12 . P0%9B,'>U%12 . /0%9#A A*,%12 . /0%) $;;%12 . /0%9B,'>U%12120%
) $;;%12120%9B,'>U%121 . 0%) $;;%121 . 0%9B,'>U%1211N%
=F ! YKJ . 2L%=5@*,('8'>U%$>5%D6 A A#>' : $('6>%4 $>$U* A *>(%M9B,'>U%12 . 10%) $;;%
12 . 10%9B,'>U%12 . E0%) $;;%12 . E0%) $;;%12 . 30%) $;;%12 . K0%) $;;%12 . O0%9B,'>U%12 . J0%) $;;%
12 . J0%9B,'>U%12 . P0%) $;;%12 . P0%9B,'>U%12 . /0%) $;;%12 . /0%9B,'>U%12120%9B,'>U%121 . 0%
9B,'>U%1211N%
=F ! YK/ / 2L%F'U'($;%=5@*,('8'>U%M) $;;%12 . . 0%) $;;%12 . 1N%
) _ b 9% . 22 . L%96 : '$;% 4 *5'$0%=5@*,('8'>U%$>5%V,$>5'>U%M) $;;%12 . P0%9B,'>U%12 . /0%
) $;;%12 . /N%
) _ b 9% . 22 . L%a67%(6% 4 $,\ *(%$%V,$>5%#8'>U%96 : '$;% 4 *5'$%M) $;;%12120%) $;;%121 . N%
%

Db 4 4E1 . L%D6 A A#>' : $('6>%'>%(" *%&',(#$;%Z,6#B%M9B,'>U%12 . . N%MW>8(,#:(6,%6<%
Y* : 6,5N%
Db 4 4E12L%9 A$;;%Z,6#B%$>5%H*$A%D6 A A#>' : $('6>%M) $;;%12 . 2N%MW>8(,#:(6,%6<%
Y* : 6,5N%
Db 4 4121L%W>(,6%(6%D6 A A#>' : $('6>%H* : '>6;6U-%M) $;;%122 / N%MH=N%
Db 4 4122L%D6 A A#>' : $('6>%$8%$%96 : '$;%9 : '*> : *%M) $;;%122PN%MH=N%
Db 4 4E2 . CL%RAB',' : $;%Y*8*$, : "%'>%D6 A A#>' : $('6>%M9B,'>U%122PN%MH=N%
Db 4 4EPEL%9B6,(80%D6 A A#>' : $('6>%$>5%D#;(#,*%M) $;;%122JN%MH=N%
Db 4 4E/0L%) $8"'6>0%D6 A A#>' : $('6>%$>5%D#;(#,*%M9B,'>U%122JN%MH=N%
Db 4 4E22L%) 6#>5$('6>8%<6,%9(#5-%6<%R>(*,($'>A *>(0%D6 A A#>' : $('6>%$>5%96 : '*(-%
M) $;;%1220N%MH=N%