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Review

Kinetics of cooking of rice: A review

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A B S T R A C T

Rice is an important source of food for a major portion of the world's population, with a production capacity of about 700 MTPA. Thus efforts are being made continuously to improve the yields of rice crops and also to make them more nutritious. Of the total energy consumption in the world, a sizeable amount, about 40%, is used for cooking purposes in the developing world. Existing methods of cooking are about 10–15% thermally efficient. The ever increasing population will need more amount of energy to be spent on cooking purposes. Thus more efficient methods of cooking need to be developed. For this purpose the kinetics of cooking of rice grains must be well understood. It is known that the kinetics is a combination of complex fluid mechanics outside and inside the grains and intrinsic reactions. This paper analyses the published work and presents a critical review in terms of rate controlling steps and the estimation of overall rates of cooking. An attempt has also been made to suggest improvements in the energy efficiency of cooking process.

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Nomenclature

a	constant, Eq. (4), (–); radius of cylinder whose volume is identical to that of rice grain, Eq. (20), (m)
A	constant, Eq. (15), $D_e n^2 \pi^2$; dimension/moisture content, Eq. (3)
AC	amylose content
ASV	alkali spreading value
A_1	model constant, Eq. (21) (–)
b	constant, Eq. (4) (–)
B	constant, Eq. (15), $kr_h^2 + A$; moisture content on dry basis, Eq. (6), (kg water/kg dry matter); dimension/moisture content, Eq. (3)
C	water content, Eqs. (7), (14), (15) (%);(19)–(22), (24), (kg water m^{-3}(kg dry matter)$^{-1}$); dimension/moisture content, Eq. (3)
D	dimension (length/width/perimeter/projected area), Eq. (4), (m); moisture diffusivity in rice grain (endosperm/white rice), Eqs. (6), (8), (14), (19), (21), (22), (m^2/s)
$D(\rho_A)$	moisture dependant diffusion coefficient, Eq. (25) (m^2/s)
D_e	diffusion rate constant, Eqs. (14), (15) (m^2/s)
D_{eff}	effective diffusivity, Eqs. (16), (17), (23) (m^2/s)
D'	moisture diffusivity in Testa, Eq. (22), (m^2/s)
Ea	activation energy of cooking, Eq. (2) (J mol^{-1})
GC	gel consistency
GT	gelatinization temperature
j	water flux, Eq. (8)
k	cooking rate constant, Eqs. (1), (2), (9) (min^{-1}), Eq. (14) (m^3 s^{-1}); model constant, Eq. (17) (min^{-1})
k_o	pre-exponential factor, Eq. (2) (min^{-1})
K_s	mass transfer coefficient, Eq. (21) (m s^{-1})
m	amount of water absorbed, Eq. (5) (g)
$m(x)$	actual moisture content on DB, Eq. (7), (kg water/kg solid)
$m_{clg}(x)$	ceiling moisture content, Eq. (7) (kg water/kg solid)
M	moisture content on DB, Eq. (16), (%); molecular weight of water, Eq. (10) (mol^{-1})
n	number of observations, Eqs. (15), (16) (–)
N	model constant, Eq. (18) (–)
p	constant, Eq. (5) (–)
PC	protein content
q	constant, Eq. (5) (–)
Q	amount of water absorbed during soaking, Eq. (15)

r	radius of rice grain, Eqs. (6), (14), (19)–(22); radius of sphere, Eq. (25) (m)
r_c	radius of uncooked core, Eq. (10) (m)
r_h	hydraulic radius of rice grain, Eq. (14), (15) (m)
R	universal gas constant, Eq. (2) (J mol^{-1} K^{-1}); cooking rate, Eq. (10) (mol/min); radius of rice grain, Eqs. (11), (12), (13) (m); equivalent radius of rice, Eqs. (16), (17); instantaneous radius of solid, Eq. (25) (m)
S_m	change in dimension in relation to original value due of hydration, Eq. (5) (mg water/ 100 g dry mass)
SL	solid Loss during cooking, Eq. (18) (% db)
SR	Swelling ratio, Eq. (1) (–)
t	time of cooking, Eqs. (1), (4), (6), (18), (23); of soaking in Eqs. (3), (14)–(16), (18), (19), (24), (25) (min)
T	absolute temperature, Eq. (2) (K)
u	constant, Eq. (18) (–)
WD	water demand, Eqs. (7), (8) (g water/g solid)
x	position, Eq. (8) (m)
X	concentration of water, Eq. (23), (kg water/kg solid); model parameter, Eq. (3)
Y	model parameter, Eq. (3)
Z	model parameter, Eq. (3)
α	degree of cooking, Eq. (9) (–)
α_{xx}, α_{yy}	mass diffusivity in x and y directions, Eq. (24) (m^2/s)
δ	thickness of Testa, Eq. (22) (m)
θ	time of cooking, Eqs. (9), (10) (min); time of cooking expressed as a fraction of time required for complete cooking, Eq. (11), (12), (13) (–)
ρ	amount of water absorbed per unit volume of uncooked grain, Eq. (10) (kg m^{-3})
ρ_A	local concentration of water in rice grain, Eq. (25) (kg m^{-3})
ρ_{solid}	dry matter bulk density, Eq. (8) (kg m^{-3})

Subscripts

C	uncooked core
e	at equilibrium condition
f	at final condition
o	at initial condition
s	at surface
t	at any time t

1. Introduction

Among the cereals, rice and wheat share equal importance as leading food sources for humankind. On the basis of mean grain yield, rice crops produce more food energy and protein supply per hectare than wheat and maize. Hence, rice can support more people per unit of farmland than the two other staples (Lu and Chang, 1980). It is, therefore, not surprising to find a close relationship in human history between an expansion in rice cultivation and a rapid rise in population growth. According to Food and Agriculture Organization (FAO)statistics, the world production of rough rice in the past decade has increased from 599 million tonnes in 2000 to 672 million tonnes in 2010 (IRRIa). The estimated production of rough rice (paddy) in the world for 2011–2012 was 721.4 million tonnes which corresponds to 481.2 million tonnes of milled rice. Of this, the Asian countries account for 652.7 million tonnes (435.5 million tonnes, milled basis) which is about 90% of the total world production. China and India account for 200.78 million tonnes (137.5 million tonnes, milled basis) and 154.5 million tonnes (103.0 million tonnes milled basis) (FAO, 2012a). The forecasted value for 2012–2013 is 481.9 million tonnes of milled rice (FAO, 2012b).

Rice is a staple food for nearly one-half of the world's population. According to an FAO report 20% of energy supply through diet in the world is provided by rice, while the corresponding figures for wheat and maize are 19%and 5% respectively. Vitamins such as thiamine, riboflavin and niacin are also present in good quantities. Unmilled rice is rich in dietary fibre. Rice also contains high amounts of glutamic and aspartic acid, and small amounts of lysine. The gene pool of the rice plant is highly diverse with many types being grown on the earth. Unmilled rice is better in terms of health properties and is thus highly recommended. (FAO, 2004).

Rice is an integral part of many cultures in the world. Each culture has its own unique preference for the properties of rice like taste, texture, etc. Over the years, various heating methods ranging from three-stone fires to electrical, microwave and induction ovens, and cooking devices such as vessels of aluminium/stainless steel, pressure cooker, electric rice cooker, and recently eco-cooker (Joshi et al., 2012a, 2012b;Singhal et al., 2012) have been used for cooking. Depending on the method used, the efficiency of cooking