

Effects of hydrothermal treatment on selected utilization qualities of parboiled maize

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Abstract: Moisture absorption and utilization properties developed during maize parboiling were studied, in processes of “soaking”, “soak and steam” and “steaming” for intervals from 0.5 h to 6.0 h and at temperatures of 40, 50, 60, 70 and 80°C in each process. Moisture content of each sample was first determined after which utilization properties developed were investigated and these include the Extent of cooking (E_c), minimum cooking time (M_c), and Swelling ratio (S_r). Three replications were carried out in each experiment. Moisture absorbed increased with time for all temperatures and with temperature at all time intervals and was highest in the “soak and steam” process. E_c increased with time of parboiling for all temperatures and also increased with temperature at all time intervals. At high temperatures of 60-80°C, E_c increased to above 50% within 3-4 h of parboiling and its value was highest during the “soak and steam” processes. M_c decreased with increase in time for all temperatures but decreased with temperature only after the 4 h of parboiling. However, at high temperatures of between 70-80°C, the ‘soak and steam’ processes produced unexpectedly higher M_c values than the soaking processes. Moisture absorption therefore has direct influence on and close correlation with E_c ($R^2=0.95$) and M_c ($R^2=0.87$). Time of complete gelatinization, t_g defined as when E_c is 100% provide a mathematical relationship between E_c , t_g , M_c and temperature during parboiling. As a result of the opposing reactions of E_c and M_c , a balance of parboiling processes must be reached to obtain optimal milling yield and optimal E_c at low M_c . Maximum S_r of maize at M_c cannot exceed 220% with or without parboiling.

Keywords: maize, hydrothermal reactions, moisture absorption, parboiling, utilization qualities

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1 Introduction

Food processing industries will continue to attract research studies to meet the rising demands for affordable food products for increasing population. In Africa and other developing countries drying, heating and parboiling are popular processing operations employed to effect physical and chemical changes that produce processing and utilization qualities in food products (Agrawal, Velupillai and Verma, 1987). Parboiling, as a hydrothermal process, combines the simultaneous effects

of heat and moisture to facilitate reaction within the processed materials (Chung, Velupillai and Virma, 1988). Parboiling also improves color and the structure of cooked grains, thereby increasing their market acceptability. In some grains, such as sorghum and millet, the objective of parboiling is to develop some “rice like” qualities. Such qualities include translucence, softness, discrete particles and partial cooking for reduced table cooking time. Research efforts had shown that it is possible to produce similar food qualities from parboiled maize (*Zea Mays*) (Young et al., 1990).

Moisture absorption plays an important role in grain conditioning (Velupillai, 1981). The process, however, requires that water penetrates the grain at particular temperatures. The quantity of moisture absorbed

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determines the extent of reaction that takes place in the grain. In rice the mode of such transfer is by diffusion. During diffusion, part of the absorbed moisture reacts with starch granules in the process of gelatinization. Heat plays an important role in the quantity and rate of absorption and the gelatinization process. Gelatinization is an irreversible reaction that forms an amorphous structure (fusion and swelling of particles) in the kernel (Birch and Priestley, 1973). These reactions lead to the many advantages derivable from parboiled grains.

Starch gelatinization may be used to estimate the extent of cooking during parboiling. To estimate gelatinization, microscopic examination of starch birefringence had been used. Translucency is the degree of clarity of light transmittance through a cereal grain which may be used as a measure of the degree of

gelatinization and therefore a measure of minimum cooking time (Rooney, Kirleis and Murty, 1986). In general, moisture absorption and the reaction within the grain determine the extent of cooking and other utilization properties produced. This paper presents the analysis of moisture absorption and utilization parameters developed in maize during the course of parboiling.

2 Materials and methods

Maize of the TZSR-W-1 breed, obtained from International Institute of Tropical Agriculture (IITA) was parboiled by using a parboiler equipment having a chamber made up of two concentric cylinders (Figure 1). The space between the cylinders was lagged and the inner cylinder contained a false bottom which allows water to be removed and steam introduced to the chamber.

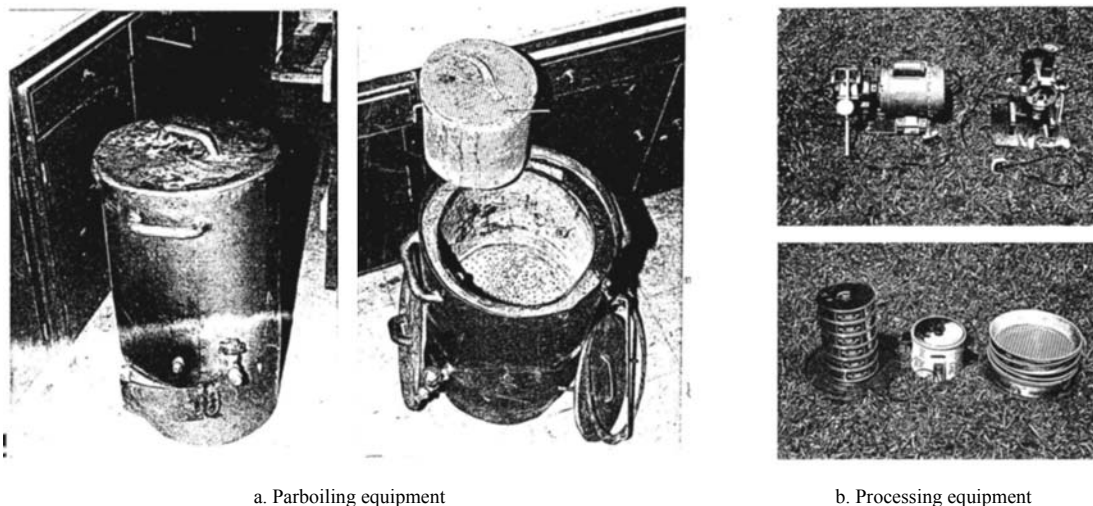


Figure 1 Equipment

Prior to experimentation, the grain properties were analyzed for kernel dimensions, physical characteristics initial and infinite tenure moisture content and utilization qualities. Utilization qualities and other parameters investigated are extent of cooking (E_c), gelatinization temperature (t_g), minimum cooking time (M_c) and swelling ratio (S_r).

For the conditioning procedure grain samples were soaked and allowed to graduate at selected temperatures kept stable by heater. Part of the samples were removed at time intervals of 0.5, 1.0, 1.5, 2.0, 3.0, 4.0, 5.0, and 6.0 h and tested. Another process of 'soak and steam' was conducted on samples divided into two parts. One

of the samples was soaked and the other steamed for additional 0.5 h after which the new steamed product was weighed and compared with its unsteamed equivalent. The two processes above were repeated for the different temperatures of 40, 50, 60, 70 and 80°C. A third process of steaming without prior soaking ($T=100^\circ\text{C}$) was conducted on similar samples, and moisture contents of all samples were determined by using the air oven method (Ajisegiri, 1987).

All samples were further tested for various physical, processing and utilization characteristics. Three replications were carried out in each experiment. Extent of cooking is the percentage to which the internal grain

materials has been cooked or gelatinized.

In evaluating the E_c , parboiled, dried and dehulled samples were ground to powder using the grain master and birefringence tests were carried out (Young et al., 1990). About 10 g of dehulled samples were boiled vigorously in 500 mL of distilled water, and tested for extent of cooking. The complete cooking were established when no opaque centre was observed in the boiled samples. The duration of cooking at that stage was the minimum cooking time. At the end of each of M_c determination, samples were mopped with filter paper and reweighed. The increase in weight at M_c over initial weights (10 g) of cooked samples were the swelling ratios (Young et al., 1990).

3 Results and discussion

3.1 Control and absorption patterns

Initial moisture content M_o of maize samples was 14.6% (w.b.) and the moisture content at infinite tenure M_∞ averaged 66% (w.b.) during the process. At room temperature and ambient conditions, ranges of grain size were as follows: between 10 – 12 mm, 31%; between 8 – 10 mm, 37% and below 8 mm, 32%. E_c was 0%, M_c was 45 min and S_r was 2.2. Maize like other cereals is a caryopsis with different cell formation. In cross section, the grain is composed of an inner endosperm covered by the mesocarp and an outer pericarp (Figure 2).

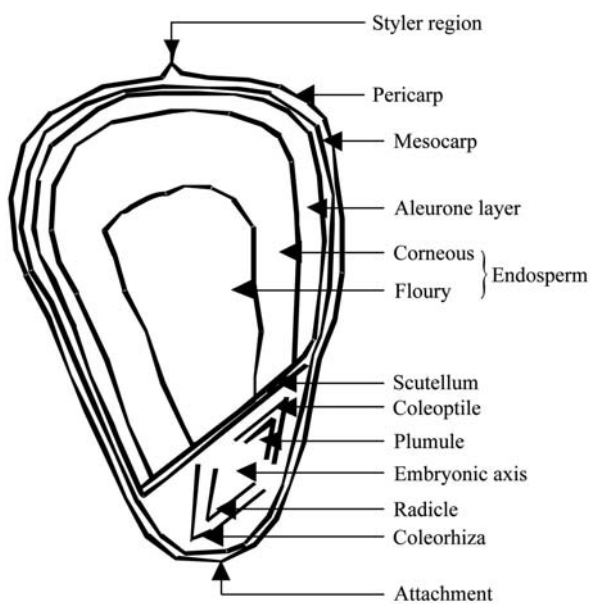


Figure 2 Structure of maize grain

The endoscarp is however preceded by the aleuronic layer that contains oil, protein, minerals and sugar. The endosperm contains starch granules. The outer parts are compact and well cemented in the outer corneous section and therefore translucent. Towards the centre of the grain, starch granules become bigger and its matrix becomes less dense. Light incident on this part is diffused and the part looks whitish. As a whole the endosperm accounts for grain texture, hard in the outer part and soft at the center and it is this structural formation that influences water diffusivity within the grain. (Atjencg M. Sarief, et al. 1987).

3.2 Moisture absorption

In the parboiling processes and in soaked samples, moisture absorbed, denoted, as Q_t , increased with time for all temperatures. Similarly, moisture absorbed also increased with temperature at all times. Figure 3 shows the plot of Q_t versus time. These plots were exponential in shape. In the “soak and steam” process the absorption trend continued (Table 1).

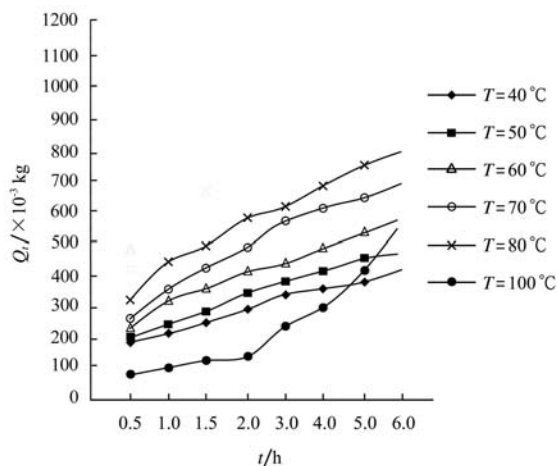


Figure 3 Moisture absorption for soaking at temperature of 40–100°C

Table 1 Quantity Q_t of moisture absorbed in time t during soaking and steaming

t/h		$T/^\circ\text{C}$				
		40	50	60	70	80
0.5	Q_{ts}/kg	313×10^{-3}	330×10^{-3}	324×10^{-3}	400×10^{-3}	480×10^{-3}
	Q_s/kg	132×10^{-3}	128×10^{-3}	124×10^{-3}	118×10^{-3}	115×10^{-3}
1.0	Q_{ts}/kg	330×10^{-3}	342×10^{-3}	346×10^{-3}	450×10^{-3}	548×10^{-3}
	Q_s/kg	125×10^{-3}	120×10^{-3}	115×10^{-3}	110×10^{-3}	105×10^{-3}
1.5	Q_{ts}/kg	348×10^{-3}	354×10^{-3}	366×10^{-3}	482×10^{-3}	567×10^{-3}
	Q_s/kg	112×10^{-3}	104×10^{-3}	90×10^{-3}	83×10^{-3}	70×10^{-3}

t/h		T/°C				
		40	50	60	70	80
2.0	Q_{ts}/kg	375×10^{-3}	392×10^{-3}	406×10^{-3}	532×10^{-3}	617×10^{-3}
	Q_s/kg	92×10^{-3}	78×10^{-3}	70×10^{-3}	60×10^{-3}	50×10^{-3}
3.0	Q_{ts}/kg	394×10^{-3}	450×10^{-3}	450×10^{-3}	581×10^{-3}	631×10^{-3}
	Q_s/kg	88×10^{-3}	63×10^{-3}	45×10^{-3}	51×10^{-3}	44×10^{-3}
4.0	Q_{ts}/kg	420×10^{-3}	492×10^{-3}	520×10^{-3}	615×10^{-3}	657×10^{-3}
	Q_s/kg	65×10^{-3}	53×10^{-3}	40×10^{-3}	38×10^{-3}	38×10^{-3}
5.0	Q_{ts}/kg	442×10^{-3}	521×10^{-3}	563×10^{-3}	662×10^{-3}	722×10^{-3}
	Q_s/kg	48×10^{-3}	41×10^{-3}	35×10^{-3}	34×10^{-3}	33×10^{-3}
6.0	Q_{ts}/kg	456×10^{-3}	582×10^{-3}	610×10^{-3}	715×10^{-3}	781×10^{-3}
	Q_s/kg	40×10^{-3}	36×10^{-3}	30×10^{-3}	28×10^{-3}	28×10^{-3}

Two absorption quantities were recorded – total moisture absorbed in both soak and steam process denoted as Q_{ts} , and moisture absorbed as a result of the steaming part of the operation denoted as Q_s . These are as shown in Table 1. While Q_{ts} increased with time at every temperature (similar to Q_t), Q_s decreased with time

at every temperature. Q_{ts} values were compared with $T=100^\circ\text{C}$ (i.e. $T=100^\circ\text{C}$ is moisture absorbed by steaming without prior soaking). Result show that moisture absorbed by ordinary steaming without prior soaking ($T=100^\circ\text{C}$) is the smallest even for the same duration of time. However, at long duration of time, after $t=5.0$ and 6.0 h, curve of $T=100^\circ\text{C}$ crossed that of $T=40^\circ\text{C}$ and $T=50^\circ\text{C}$ (Figure 3).

This shows that moisture absorption are equal at those periods. Moisture absorbed during soak and steam, Q_{ts} were always greater than those of soaking (Q_t) at all temperatures. For lower temperatures between 40 and 50°C the differences were quite distinct but at higher temperature $60 - 80^\circ\text{C}$ differences were smaller (Figure 4). Another feature of the changes was difference at the beginning and end of periods. Increases in absorption due to steaming were larger at the start of parboiling than towards the end as the curves close up.

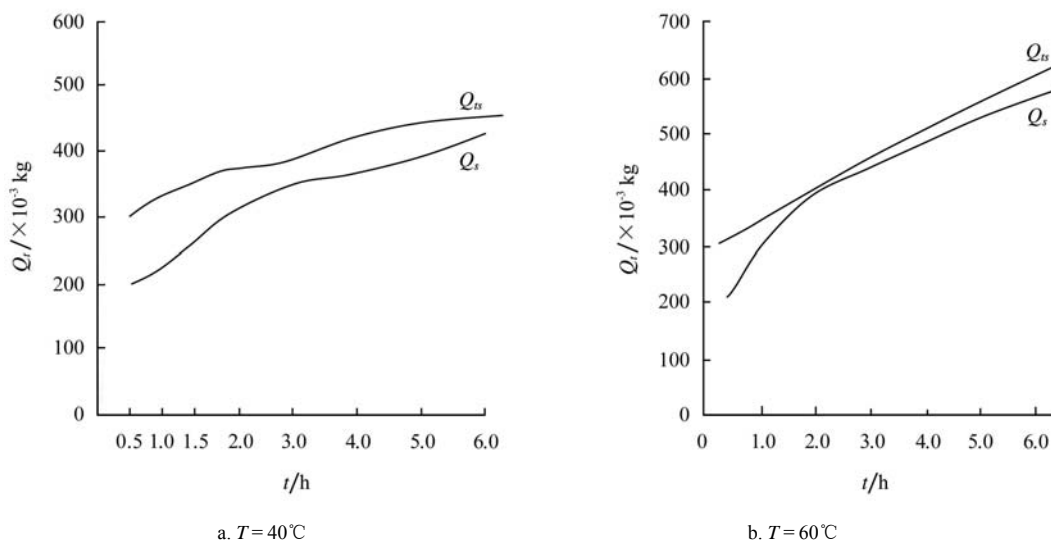


Figure 4 Moisture absorption during parboiling

Unlike absorption, the absorption rates decreased progressively during soaking for every temperature from the start to end of the period of parboiling (Table 1) and rate curves were also exponential decreasing asymptotically along the time of increases in soaking time.

3.3 Utilization parameters

3.3.1 Extent of cooking (E_c)

There is a close relationship between “extent of cooking” (E_c) and the moisture absorption patterns. (Table 2).

Table 2 Parboiling and extent of cooking (%) during soaking

t/h	T/°C					
	40	50	60	70	80	100
0.5	15	20	21	32	33	15
1.0	18	23	33	38	38	20
1.5	20	29	35	40	44	25
2.0	26	29	43	54	60	25
3.0	35	35	53	63	65	30
4.0	39	45	65	68	70	37
5.0	45	53	68	73	75	42
6.0	53	63	70	77	81	46

Soaked samples exhibited high percentage of cooking (E_c) than the control (0%). E_c increased with increased time of soaking for all temperatures, and at all intervals, soaked samples also increased with increased in temperature. At higher temperatures 60–80°C cooking increased to above 50% in just between 3 h and 4 h of parboiling. As shown in the table E_c values at $t=0.5$ h is less than E_c values at 6 h. Similarly E_c values at $T=40$ ($t=0.5$ h) is less than E_c $T=80^\circ\text{C}$ ($t=0.5$ h) E_c values for steaming without prior soaking ($T=100^\circ\text{C}$) were smaller than those of soaking at temperatures from 50°C in all time intervals. The graphs of cooking against time (Figure 5) show the gradual change between T of 40 – 80°C.

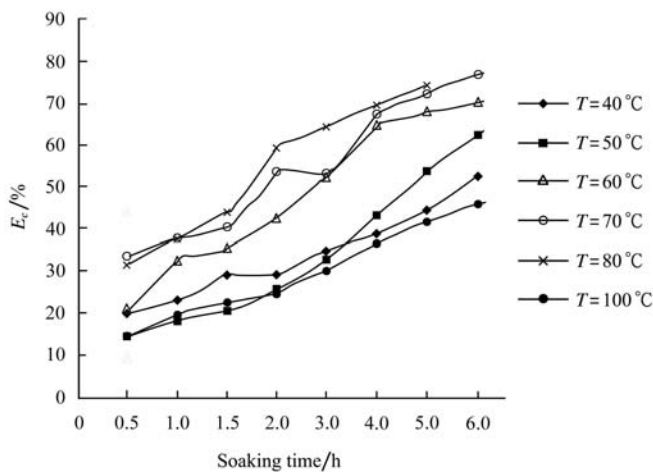


Figure 5 Extent of cooking for soaking at temperature of 40–100°C

Each curve was exponential in conformity with trend of moisture absorption. Note that the same trend also manifested for soaked and steamed (T_s) samples (Figure 6)

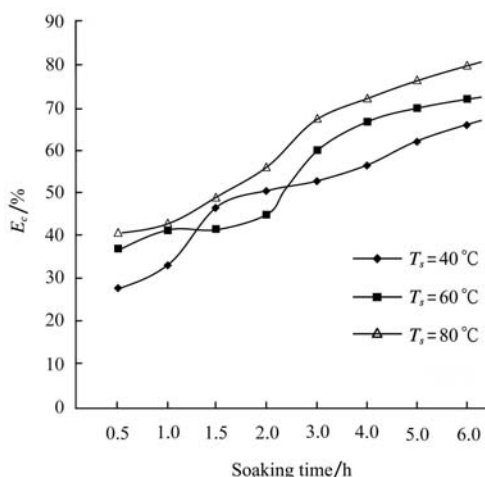


Figure 6 Extent of cooking for soaking and steaming of 40–60°C

as E_c values increased with increases in temperature at all intervals of time, and increased with time at all temperatures.

Thus E_c ($T_s=80^\circ\text{C}$) is greater than E_c ($T_s=40^\circ\text{C}$). The figure also shows that the change in E_c in the T_s processes were more distinct than in the T series, which implies that “soak and steam” creates higher extent of cooking (E_c) than the corresponding soaking at the same temperature in Tables 2 and 3.

Table 3 Parboiling and extent of cooking (%) during soaking and steaming

T/h	40°C	60°C	80°C
0.5	28	37	41
1.0	34	42	43
1.5	48	42	50
2.0	52	46	58
3.0	54	63	69
4.0	58	68	74
5.0	64	72	78
6.0	68	74	82

E_c values for steaming without prior soaking ($T=100^\circ\text{C}$) was far less than both soaking and “soak and steam” at the same temperature which is the same pattern as in moisture absorption. (Figures 3 and 5).

3.3.2 Minimum cooking time (M_c)

There were regular patterns in changes that occurred as a result of effect of parboiling on minimum cooking time (M_c) (Table 4).

Table 4 Minimum cooking time (min) for samples subjected to soaking T series

T/h	40°C	50°C	60°C	70°C	80°C	100°C
0.5	43	42	41	35	25	45
1.0	38	42	38	33	25	40
1.5	37	40	36	22	15	35
2.0	35	38	33	23	14	25
3.0	34	39	28	19	14	25
4.0	34	34	25	19	17	18
5.0	32	28	21	18	12	15
6.0	31	22	17	15	8	13

During soaking M_c decreased with increase in time for all temperatures and also decreased with increase in temperature for all interval of time. However, M_c at $T=100^\circ\text{C}$ (i.e. steaming without prior soaking) showed even with high values it also decreased with increase in time. At the start of soaking, M_c ($T=100^\circ\text{C}$) was very high, but

towards the end after long duration of steaming the values decreased lower and ranked with $T=80^{\circ}\text{C}$. M_c values for the “soak and steam” (T_s) processes (Table 5) show relatively similar pattern as in the above processes (T).

Table 5 Minimum cooking time (min) for samples subjected to soaking and steaming (T_s series)

T/h	40°C	60°C	80°C
0.5	41	40	38
1.0	38	40	37
1.5	35	38	31
2.0	34	35	23
3.0	33	35	22
4.0	30	26	21
5.0	28	25	21
6.0	28	22	20

Although it decreased with increase in intervals of time for every temperature, it also decreased with increases in temperature for most intervals especially after four hours of parboiling. However, the T_s series show unpredictable higher M_c values over the T processes at temperatures above 60°C in all intervals of time. The increase was very high at higher temperatures of $T_s = 70^{\circ}\text{C}$ and $T_s = 80^{\circ}\text{C}$ interval of soaking. M_c decreases were also exponential in nature (Figure 7), showing that there is a correlation between M_c and absorption patterns.

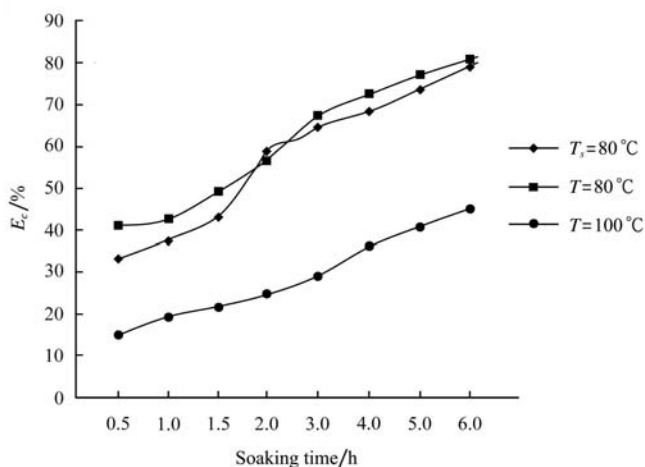


Figure 7 Comparison of extent of cooking $T=80^{\circ}\text{C}$, $T_s=80^{\circ}\text{C}$

3.3.3 Swelling ratio (S_r)

The swelling ratios as a measure of change in weight of samples during M_c determination were similar and closer to that of control at averagely 2.2% or 220% for samples conditioned at temperatures of 40, 50, and 60°C for most time intervals. The values however reduced at

high temperatures and there were no differences between S_r values for “soaking” and for “soak” and steam, processes. At higher temperatures, 70°C and 80°C swelling ratios of samples reduced after 2 h of parboiling (Table 6).

Table 6 Parboiling and swelling ratio (%) during soaking

T/h	40°C	50°C	60°C	70°C	80°C	100°C
0.5	2.29	2.27	2.10	2.15	2.19	2.03
1.0	2.20	1.98	2.04	2.10	2.29	1.88
1.5	2.01	2.04	2.04	1.81	2.08	2.05
2.0	2.10	2.14	2.15	1.80	1.90	2.03
3.0	2.05	2.19	2.10	2.01	1.90	1.59
4.0	2.12	1.90	2.02	1.78	1.95	1.83
5.0	2.05	1.80	1.94	1.70	1.84	1.68
6.0	2.22	1.82	2.01	1.65	1.80	1.60

3.4 Analysis of results

Results above showed that quantity of moisture absorbed at any time and temperature has direct influence on E_c and M_c , due to the gelatinization process. These findings agree with those of other studies (Velupillai and Verma, 1982; Young et al., 1990). There is a close correlation between moisture absorbed (Q_t), the extent of cooking (E_c), and minimum cooking time (M_c). Q_t at 60°C , $R^2 = 0.75$; E_c at 60°C , $R^2 = 0.80$ and Q_t at 70°C , $R^2 = 0.90$ while M_c at 70°C , $R^2 = 0.95$. Therefore, moisture absorption can be used as a measure of both E_c and M_c . (Agrawal et al., 1987). The reason for low percentage of cooking at low temperature and short time is quite obvious. Cooking is defined as the process of moisture uptake during a hydrothermal treatment whereby water molecules react with the particles of the cooking substance. The reaction process is gelatinization (Barkshi, 1979), and at low temperature and time, the moisture uptake process is low. Cooking can therefore be described as a process of gelatinization. E_c increases with temperature. When there is adequate heat, the crystalline structure of starch changes to amorphous particle. It is a transformation of high density opaque white starch granules to large translucent gelatinous bodies of low density materials usually accompanied by loss of materials (Agrawal, Velupilai and Verma, 1987). At $T=100^{\circ}\text{C}$ where E_c were less than the $T=80^{\circ}\text{C}$ series, it is as a result which show that moisture is limited despite high steam heat. This therefore implies that E_c

cannot be improved by increased heating (increased temperature) without moisture. This fact agrees with findings on physical characteristics that both soaking and steaming increase E_c . At higher temperature, continuous increases in absorption and reaction leads to excessive moisture uptake and rupture, therefore although severe parboiling will increase E_c the kernel strength will be weakened.

Time of complete gelatinization t_g in the study can be defined as time when E_c is 100%. This time can only be achieved experimentally at low temperature $T=40^\circ\text{C}$ and $T=60^\circ\text{C}$ over long duration, because at high temperature rupture will occur. However, applying the above definition from the study t_g for 40, 50, 60, 70 and 80°C were 15.2, 12.9, 10.3, 9.9 and 9.43 h. Applying regression analysis result of soaking process (T series), gave the expression:

$$t_g = 20.31 - 0.146T \quad (R^2 = 0.935) \quad (1)$$

where, t_g is time of complete gelatinization (hours) at temperature T of parboiling. Comparing (1) above with the Barkshi and Singh (1979) rice simulation model, the two equations are:

$$\text{Rice } t_g = 8.9010 - 5.83429 \times 10^{-2} T \quad (R^2 = 0.99)$$

$$\text{Maize: } t_g = 20.31 - 14.6 \times 10^{-2} T \quad (R^2 = 0.87)$$

Again from above, minimum cooking time can be defined as time required to extend cooking from its parboiled level to a point of complete cooking i.e. extension of cooking to 100% level, but this later condition would be understated, at severe pressure and high temperature ($T_s=100^\circ\text{C}$). The pattern of changes are therefore obvious from E_c values that the more the E_c , the less the M_c . These are reasons for M_c decreases with time and high temperature of parboiling (Figure 8).

The practical significance of this finding is that although steaming improves kernel strength, it prolongs minimum cooking time. So while the processor wants a high milling yield, a low minimum cooking time is the desirable food quality. Therefore, in parboiling, a balance of soak and steam is necessary to give such result that would produce high milling yield at low M_c . The values of swelling ratio after minimum cooking time can be interpreted in two ways. There is a limit to moisture uptake after full gelatinization and this cannot exceed

220%. Also, increase in size due to expansion and fusion of granules cannot go beyond 220% of the uncooked size with or without parboiling.

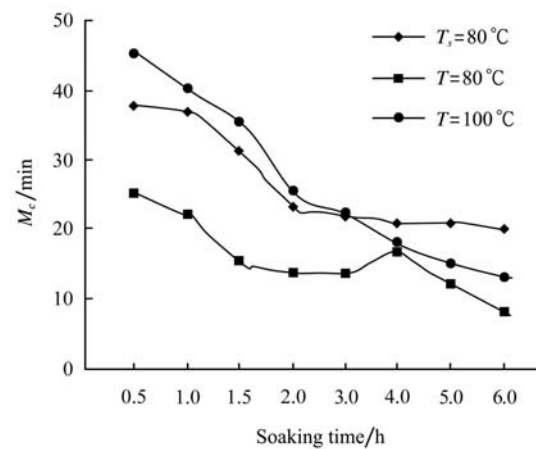


Figure 8 Minimum cooking time for different parboiling

3.5 Summary

During parboiling, structure of particles changed because the constituents expanded and fused permanently with absorbed moisture in a reaction of gelatinization. The reaction is responsible for increases in sizes, strength characteristics, and extent of cooking.

Moisture absorption (Q_t) can therefore be used to depict both Extent of Cooking (E_c) and Minimum cooking time (M_c). In maize extent of cooking can be defined as the level of both moisture uptake and the reaction with the grain particles during hydrothermal treatment and is also a level of starch gelatinization. Extent of cooking cannot be improved by increased temperatures without moisture. Time of complete gelatinization t_g is defined as time in a particular temperature when extent of cooking (E_c) is 100% which gives a mathematical relationship between t_g and temperature during parboiling. Similarly, minimum cooking time (M_c) can be defined as time required to extend cooking from its parboiled level to a point of complete cooking which is 100% again but under severe temperature and pressure. Therefore, minimum cooking time varies with extent of cooking, decreases with time and temperature of parboiling, but increases with steaming. Since low minimum cooking time is the desired quality and steaming produce high milling yield, a balance must be established that would give optimal

milling yield at low M_c .

4 Conclusion

Moisture absorption increased during a parboiling process, but rate of absorption decreased with time for every temperature from start to end of all processes. There is a close correlation between “extent of cooking” and moisture absorption ($R^2=0.87$) which implied that extent of cooking increased with time for all temperatures and with temperature at all time intervals, and the increases were exponential in nature.

At higher temperatures, extent of cooking increased over 50% of control in just after three h of parboiling in soaked processes. Minimum cooking time decreased with increase in time for all temperatures and with temperature at all times, but the “soak and steam” process showed unpredictably higher M_c values above other processes at temperatures above 60°C at all time intervals. The swelling ratio values increased up to but not higher than 220% for most temperatures and time intervals. A balance of parboiling processes is required to produce optimal milling yield at low M_c .

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