# Desirability Function Optimization of Garification Process Machine

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**Abstract-** Optimal operational parameters of an automated batch process garification machine were determined in this study to make its use economical in terms of labour, time and energy requirement, thereby reducing cost of quality gari in our markets. A two level response surface experimental design/modeling was used in the investigation and quantification of the relationship between the operational and performance parameters of the machine, while desirability function optimization technique was applied to determine the optimal settings of the operating parameters investigated. The results of this performance analysis revealed 9, 20kg, 25 and 15 minutes, 57oC, 90oC and 90.91oC as the respective optimal number of pressing paddles, quantity of sifted cassava mash processed per batch, cooking and drying durations per batch, initial, cooking and drying temperatures of garification trough. The machine produced gari with moisture content, grain size and acidity level of 12.04 % (wb), 2.00 mm and 0.62% respectively at these optimal operational factor settings and these quality attributes conform to CODEX standards. In addition, its throughput increased by 13.55%, while its charcoal and specific energy consumption reduced to 12.57% and 24.20% respectively at its optimal factor settings.

**Keywords:** Automated batch process, cassava, gari, garification, machine, optimal parameters

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## 1 INTRODUCTION

Gari production from fresh cassava tubers involves sequential unit operation of peeling, washing, grating, fermenting, pressing, sieving, and garification. Mechanization of these processes has been fully achieved except peeling and garification (Olusegun and Ajiboye, 2010; Kudabo et al., 2012). Successful mechanization of cassava peeling has been hindered by the irregular profiles of cassava tubers, as a result of this, peeling of cassava tubers is still done manually using knives (Ette, et al., 2012). Although, works of Odigboh and Ahmed (1984), Igbeka and Akinbolade (1986), Igbeka (1995), Gbasouzor and Maduabum (2012), Olagoke et al (2014) in mechanizing garification process reduced drudgery extensively, the quality attributes of gari processed with their technologies fall short of the one processed by native/manual method, which has quality attributes that conform to the standards recommended by Oti et al., (2010) and CODEX (1989).

Hence, these innovations were not generally adopted, thereby leaving the manual garification method as the only option for gari processors recently. However, manual operation cannot cope with emerging trend of gari demand in Nigeria, which requires mechanized systems for higher output. Thus, Oti and Obi (2016) on identification of distinct operational features of the manual garification process which involves batch process cooking and drying operations, developed an automated batch process garification machine (Fig. 1), whose product replicated quality attributes of the manual process. Performance test of the machine at design values of some of its operational parameters (paddle-press-conveyor speed, initial temperature of trough, cooking and drying trough temperatures of 20rpm, 58$^{o}$C, 70$^{o}$C and 100$^{o}$C respectively), produced gari with a moisture content, acidity level and grain size of 11.98%, 0.753% and 2.0 mm respectively. Also, test indicated throughput and specific energy consumption of the machine as 17.30kg/hr and 349.01kJ/kg, respectively, while an average of 8.43kg of charcoal was utilized for the garification operation.

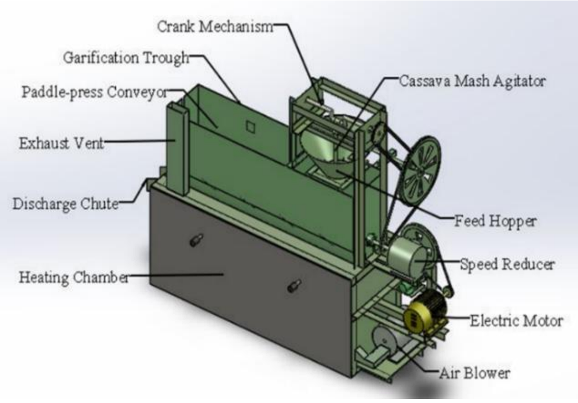

Fig. 1: Automated batch process garification machine

. Oti and Obi (2016), further indicated that initial temperature of the garification trough, temperature of the trough during the cooking stage, temperature of the trough during the drying stage, duration of the cooking stage, duration of the drying stage, number of pressing paddles, total quantity of sieved cassava mash processed per batch, paddle-press-conveyor speed, quantity of sieved cassava added intermittently and time interval for the intermittent addition affect the quality attributes (moisture content, acidity level and grain size) of gari and other performance indicators of this machine, such that some improves while others deteriorates with the variation of factors' level/settings. It is desired that the machine produces gari that has moisture content, acidity level and grain size of 12% (wet bulb), 0.6% – 1.0% and 2.0 mm (for coarse grain size) respectively, which are the recommended standards (CODEX, 1989; Oti et al., 2010). Hence, a multi-factors/responses optimization is required to determine the optimal operational parameters settings at which the gari processed using the machine, will conform to CODEX recommend specifications as well as improve its capacity and energy consumption. Thus, this work determined the optimal operational parameters of the automated batch process garification machine using response surface methodology.

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## 2 METHODOLOGY

The sieved cassava mash with a moisture content of 45% wet bulb, used for the performance test of the garification machine was processed from cassava tubers procured from Ndoro market in Ikwuano, Abia state, Nigeria. Performance parameters (response variables or responses) of the automated batch process garification machine evaluated are the moisture content, acidity level and grain size of the processed gari as well as its throughput, charcoal and specific energy consumption rate. The operational parameters (factors) of the machine investigated include temperature of the trough before garification operation, temperature of the trough during the cooking stage, temperature of the trough during the drying stage, duration of the cooking stage, duration of the drying stage, number of pressing paddles, and total quantity of sieved cassava mash processed per batch were investigated in this study to determine their effects on the three responses.

The determination of the optimal settings of the operational factors of the automated garification machine involves experimental design, model fitting, model selection, model validation and optimization (NIST/SEMATECH. 2012). The empirical relationships between the performance and operational parameters of the automated garification machine were evaluated using a fractional factorial design generated with MINITAB. This is a completely randomized, single replicate fractional factorial design comprising of sixteen factorial points (1, −1) amounting to sixteen experimental runs based on seven factors with one-eight (1/8) fraction.

The high and low levels of the factors were determined from experimental tests and the limits are shown in Table 1. In each of the test for the determination of the high and low levels of the temperature of the trough before garification operation, the other six factors; temperature of the trough during the cooking stage, temperature of the trough during the drying stage, duration of the cooking stage, duration of the drying stage, Number of pressing paddles, and total quantity of sifted cassava mash processed per batch were kept constant at their design settings, while the initial temperature of the trough was varied from $50^{o}$C to $80^{o}$C. The temperature of the trough during the process is displayed by a digital thermometer which is connected to a thermocouple attached to the trough. To reduce the trough temperature when required, jets of water are sprayed directly under the trough and on the burning charcoal inside the heating chamber, thereby, reducing the heat being generated. The performance of the machine was evaluated at each combination of the variables by feeding 5kg of sifted cassava mash into the garification trough and processing it for 15 minutes.

Thereafter, the moisture content, $(\mathrm{M})$ grain size, $(\mathrm{G.S})$ and the total acidity, $(\mathrm{T.A})$ of the processed gari were evaluated as follows; Moisture content of 10g processed gari sample was determined in each test using drying oven method at $105^{o}$ C (AOAC, 1990). In this experiment, 100g of processed gari sample was turned into a container of known weight and placed in the drying oven, with the temperature of the oven set to 100oC. At intervals of 30 minutes, the sample is checked and re-weighed. The experiment ends when the sample starts changing colour and a constant weight is noticed over a period of time, thus the samples moisture content was computed from the following relation in Equation (1),

$$\frac{w_1 - w_2}{w_1} \times 100 \qquad (1)$$

Where $w_1$ and $w_2$ are the Initial and final masses of the gari sample, respectively.

The acidity level of the processed gari was evaluated as the total titratable acidity, expressed as percentage of the lactic acid content of gari, and was determined by the method described by AOAC (1990). Each test involves dissolving 10g of processed gari sample collected at the end of each garification process in 100 ml distilled water and allowed to stand for 30 minutes in a beaker. Thereafter, the solution was filtered with Whatman filter paper before titrating 25ml of the filtrate against 0.1moles of NaOH, using phenolphthalein as indicator. With the mean titration value, $\mathrm{X}$ obtained from triplicate determination, the percent titratable acidity of each specimen was computed from the relation in Equation (2), given by Owuamanam et al. (2011).

$$\mathrm{T.A}(\%) = 0.01\mathrm{X} \qquad (2)$$

The grain sizes of the processed gari samples collected at the end of each garification operation were determined by placing 300g of each gari samples in the uppermost sieve of a particle size shaker (Endocotts Model BS410/196 Test Sieve Shaker, London, England). The shaker was fitted with ten sieves, with standard mesh sizes of 6.73 mm, 4.76 mm, 4.00 mm, 3.360 mm, 2.830 mm, 2.00 mm, 1.680 mm, 1.41mm, 1.190 mm and 1.00 mm respectively. The sieving was done for 10 minutes. Gari samples retained on each mesh were weighed and computed as percentage retention.

The same procedure was applied in the determination of the actual factor levels of the trough temperature during the cooking and drying stages, duration of the cooking and drying stages, number of pressing paddles and sieved cassava mash processed per batch. In each test, other variables were held constant at their design settings. The transformation formulae relating the coded factors $x_i$ and actual factors $X_i$ were obtained from the relation in equation (3), given by NIST/SEMATECH (2012).

$$x_i = \frac{X_i - \left(\frac{X_{high} + X_{low}}{2}\right)}{\left(\frac{X_{high} - X_{low}}{2}\right)} \qquad (3)$$

Where $i = 1, 2\ldots, k$ (k is the number of factors), $X_{high}$ and $X_{low}$ are the high and low values of the factors determined from experiments. Thus, equations (4) to (10) shows the transformation formulae derived from equation (3), for the respective factors considered.

$$x_1 = \frac{T_1 - 66}{9} \qquad (4)$$

$$x_2 = \frac{T_2 - 82.5}{7.5} \quad (5)$$

$$x_3 = \frac{T_3 - 105}{15} \quad (6)$$

$$x_4 = \frac{t_c - 20}{5} \quad (7)$$

$$x_5 = \frac{t_d - 12.5}{2.5} \quad (8)$$

$$x_6 = \frac{n - 12}{3} \quad (9)$$

$$x_7 = \frac{m_T - 17.5}{2.5} \quad (10)$$

The completely randomized, single blocked fractional factorial design layout, used in this investigation is shown in Table 2. In the test to check the success of the optimization results, the mass of gari collected, mass of charcoal loaded into the stove before garification and the mass of unburnt charcoal retained inside the stove after garification were weighed and recorded as per each run. After which the throughput, TP (kg/h) and specific energy consumption, SE (kJ/kg) of the machine were determined using Equation (12) and (13) respectively.

$$TP\ \ (kg/hr) = \frac{m_g}{t} \times 60 \quad (12)$$

$$SE\ \left(\frac{kJ}{kg}\right) = \frac{Q_1 + Pt}{m_g} \quad (13)$$

$$m_g = m_t - m_r \quad (14)$$

$$m_t = \frac{m_d}{(1 - m_2)} \quad (15)$$

$$Q_1 = CV_f \times m_{f1} \quad (16)$$

$$m_d = m_o - m_w \quad (17)$$

$$m_{w1} = m_1 \times m_o \quad (18)$$

Where $m_o$, t, $m_t$, $m_g$, $m_r$, $m_{f1}$, $m_{f2}$, $m_f$, $m_d$, $m_w$, $m_1$, $m_2$, P, $Q_1$ and $CV_f$ are the mass of cassava mash processed per batch, garification time, mass of gari expected per batch, mass of gari collected, mass of gari retained in the trough, mass of charcoal loaded into the stove, mass of charcoal retained after garification, mass of charcoal utilized for garification, mass of dry matter in the cassava mash, mass of water content in the cassava mash, moisture content of cassava mash before garification, moisture content of gari, electric energy utilized, heat energy generated from charcoal and calorific value of charcoal (405.7 kJ/kg. Kulla and Obi, 2005), respectively.

Table 1: Limits of the Automated Garification Machine operational parameters.

| **S/N** | **Factor Description** | **Factor symbols** | | **Factor Values** | |
|---|---|---|---|---|---|
| | | **Coded** | **Actual** | **High (+1)** | **Low (-1)** |
| 1 | Initial temperature of trough | $x_1$ | $T_1$ | 75 | 57 |
| 2 | Trough temperature during the cooking stage | $x_2$ | $T_2$ | 90 | 75 |
| 3 | Trough temperature during the drying stage | $x_3$ | $T_3$ | 120 | 90 |
| 4 | Duration of the cooking stage | $x_4$ | $t_c$ | 25 | 15 |
| 5 | Duration of the drying stage | $x_5$ | $t_d$ | 15 | 10 |
| 6 | Number of pressing paddles | $x_6$ | n | 15 | 9 |
| 7 | Mass of sieved cassava mash processed per batch. | $x_7$ | $m_T$ | 20 | 15 |

## 3 RESULTS AND DISCUSSION

Equations 19 to 21 constitutes the coded responses functions while Equations 22 to 24 are the actual responses functions of the automated batch process garification machine studied. Figures 2 to 4 shows that the percentage errors between the actual and predicted values of the responses lie within plus and minus five percent (i.e., ±5%). This result indicates that the developed models statistically fitted the responses of the automated garification adequately, and therefore, can be used for further analysis/optimization of the system.

$$M\ (\%\ wb) = 12.34 + 0.05x_1 - 0.444x_2 - 0.325x_3 - 0.431x_4 - 0.62x_5 + 0.66x_7 + 0.22x_1x_3 + 0.26x_1x_4 - 0.125x_1x_5 - 0.17x_1x_7 \quad (19)$$

$$GS\ (mm) = 2.42 + 0.29x_1 + 0.33x_2 + 0.19x_3 + 0.045x_4 - 0.19x_5 - 0.15x_6 + 0.125x_1x_4 - 0.15x_1x_6 \quad (20)$$

$$TA\ (\%) = 0.68 - 0.014x_1 - 0.034x_2 - 0.03312x_3 - 0.023x_4 + 0.0019x_5 - 0.0044x_6 - 0.017x_7 + 0.012x_1x_5 - 0.017x_1x_6 + 0.013x_1x_7 - 0.011x_2x_4 + 0.01x_2x_5 \quad (21)$$

$$M\ (\%\ wb) = 24.72 - 0.076T_1 - 0.062T_2 - 0.13T_3 - 0.47t_c + 0.12t_d + 0.78m_T + 0.00162T_1T_3 + 0.00583T_1t_c - 0.00556T_1t_d - 0.0078T_1m_T \quad (22)$$

$$GS\ (mm) = -3.629 + 0.0444T_1 + 0.0443T_2 + 0.0079T_3 - 0.174t_c - 0.0756t_d + 0.3192n + 0.0028T_1t_c - 0.0056T_1n \quad (23)$$

$$TA\ (\%) = 2.28 - 0.0109T_1 - 0.0052T_2\ 0.00221T_3 + 0.0188t_c - 0.0753t_d + 0.0398n - 0.0453m_T + 0.000528T_1t_d - 0.000625T_1n + 0.00058T_1m_T - 0.000284T_2t_c + 0.0005T_2t_d \quad (24)$$

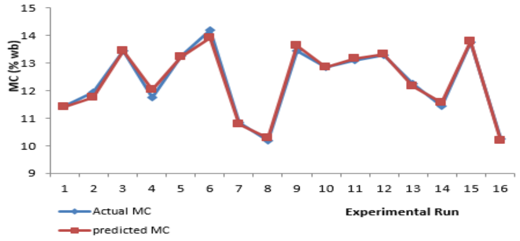

Fig. 2: Confirmation of moisture content model.

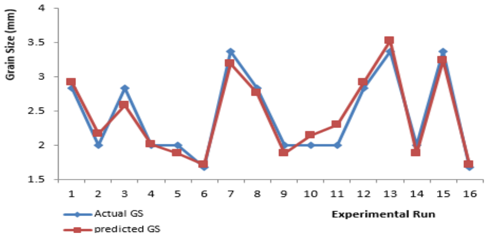

Fig. 3: Confirmation of grain size model

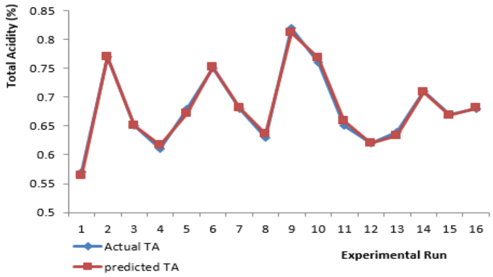

Fig. 4: Confirmation of total acidity model

The result of the desirability function optimization of the models is presented in Figure 5, while Table 3 shows the result of the tests carried out to evaluate the success of the optimization results on the performance of the automated garification machine.

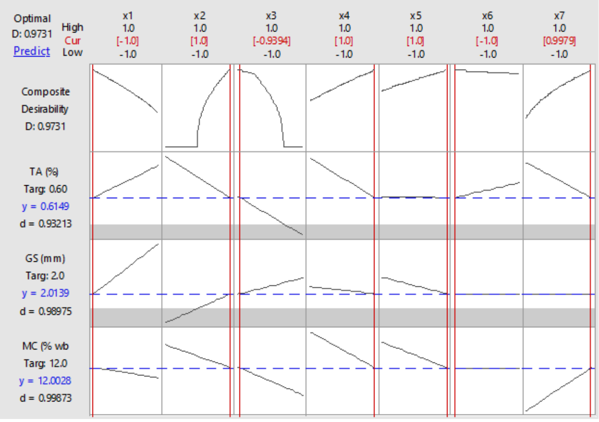

Fig 5: Desirability plot for the machine models

Table 2. Design Table for the response surface study of the garification machine

| **Design order** | | **Coded factors** | | | | | | | **Responses** | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Std. Order** | **Run Order** | $x_1$ | $x_2$ | $x_3$ | $x_4$ | $x_5$ | $x_6$ | $x_7$ | **M (%)** | **G.S (mm)** | **T.A (%)** |
| 16 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 11.45 | 2.83 | 0.57 |
| 3 | 2 | -1 | 1 | -1 | -1 | 1 | 1 | -1 | 11.95 | 2.00 | 0.77 |
| 4 | 3 | 1 | 1 | -1 | -1 | -1 | 1 | 1 | 13.45 | 2.83 | 0.65 |
| 11 | 4 | -1 | 1 | -1 | 1 | 1 | -1 | 1 | 11.75 | 2.00 | 0.61 |
| 5 | 5 | -1 | -1 | 1 | -1 | 1 | 1 | 1 | 13.25 | 2.00 | 0.68 |
| 9 | 6 | -1 | -1 | -1 | 1 | -1 | 1 | 1 | 14.20 | 1.68 | 0.75 |
| 8 | 7 | 1 | 1 | 1 | -1 | 1 | -1 | -1 | 10.85 | 3.36 | 0.68 |
| 15 | 8 | -1 | 1 | 1 | 1 | -1 | 1 | -1 | 10.20 | 2.83 | 0.63 |
| 1 | 9 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | 13.45 | 2.00 | 0.82 |
| 2 | 10 | 1 | -1 | -1 | -1 | 1 | -1 | 1 | 12.85 | 2.00 | 0.76 |
| 6 | 11 | 1 | -1 | 1 | -1 | -1 | 1 | -1 | 13.10 | 2.00 | 0.65 |
| 7 | 12 | -1 | 1 | 1 | -1 | -1 | -1 | 1 | 13.30 | 2.83 | 0.62 |
| 12 | 13 | 1 | 1 | -1 | 1 | -1 | -1 | -1 | 12.25 | 3.36 | 0.64 |
| 10 | 14 | 1 | -1 | -1 | 1 | 1 | 1 | -1 | 11.45 | 2.00 | 0.71 |
| 14 | 15 | 1 | -1 | 1 | 1 | -1 | -1 | 1 | 13.75 | 3.36 | 0.67 |
| 13 | 16 | -1 | -1 | 1 | 1 | 1 | -1 | -1 | 10.25 | 1.68 | 0.68 |

Table 3: Evaluation of the success of the optimization results

| **Evaluation Parameters** | **Experimental Runs** | | | |
|---|---|---|---|---|
| | **1** | **2** | **3** | **Average** |
| Mass of sieved cassava mash processed in each batch, $m_o$ (kg) | 20 | 20 | 20 | 20 |
| Garification time, t (min) | 35 | 35 | 35 | 35 |
| Mass of gari expected from each batch, $m_t$ (kg) | 12.51 | 12.50 | 12. 51 | 12.51 |
| Mass of gari collected, $m_g$(kg) | 11.67 | 11.67 | 11.68 | 11.67 |
| Mass of gari retained in the trough after garification, $m_r$ (kg) | 0.84 | 0.83 | 0.83 | 0.83 |
| Mass of charcoal loaded into the stove, $m_{f1}$ (kg) | 12 | 12 | 12 | 12 |
| Mass of charcoal retained after garification, $m_{f2}$ (kg) | 4.5 | 4.7 | 4.7 | 4.63 |
| Mass of charcoal utilized for garification, $m_f$ (kg) | 7.5 | 7.3 | 7.3 | 7.37 |
| Moisture content of the gari discharged MC (% wb) | 12.05 | 11.97 | 12.10 | 12.04 |
| Grain size of the gari discharged GS (mm) | 2.00 | 2.00 | 2.00 | 2.00 |
| Acidity level of the gari discharged TA (%) | 0.62 | 0.61 | 0.62 | 0.62 |
| Heat generated in the heating chamber, $Q_1$(kJ) | 3043 | 2962 | 2962 | 2989 |
| Electric energy utilized, P (kJ/sec.) | 2.86 | 2.86 | 2.86 | 2.86 |
| Throughput, TP (kg/hr.) | 20.01 | 20.01 | 20.02 | 20.01 |
| Specific energy consumption, SE (kJ/kg) | 269 | 262 | 262 | 265 |

The optimization result (Fig. 5) indicate that the optimal moisture content, grain size and acidity level of the gari processed using the machine are respectively 12.0028% (wb), 2.0139 mm and 0.6149% with the optimal settings of the coded input variables at −1, 1, −0.9394, 1, 1, −1 and 0.9979 respectively. Now substituting these values of the coded optimal input variables in the transformation equations, the approximate optimal values of initial temperature of trough, $T_1$ trough temperature during the cooking stage, $T_2$ trough temperature during the drying stage, $T_3$ duration of the cooking stage, $t_c$ duration of the drying stage, $t_d$ number of pressing paddles, n and total quantity of sifted cassava mash processed per batch, $m_T$ are respectively 57°C, 90°C, 91°C, 25 minutes, 15minutes, 9 and 20kg. Substituting the values of these approximated optimal actual factors into the actual response functions (Equations 13 to 15), the moisture content, grain size and acidity level of the gari processed are respectively 12.00115% (wb), 2.08041 mm and 0.6146%. Furthermore, this analysis showed that all the factors investigated influenced the acidity level of the gari significantly, while only six factors excluding the number of pressing paddles on the paddle-press-conveyor, affected the moisture content of the processed gari and similarly the total quantity of sifted cassava mash processed per batch has insignificant effect on the grain size.

Table 3 revealed that the moisture content, grain size and acidity level of the gari processed when the machine operates at the optimal factor setting are respectively 12.04% (wb), 2.00 mm and 0.62%. While the average throughput and specific energy consumption of the machine were respectively computed as 20.30kg/hr. and 264.60kJ/kg, indicating a 13.55% increment in the throughput while the specific energy consumption was reduced by 24.20%. Similarly, the quantity of charcoal utilized for the garification operation was reduced by 12.57%.

## 4 CONCLUSION

The study revealed 57°C, 90°C, 91°C, 25 minutes, 15minutes, 9 and 20kg as the optimal initial temperature of trough, temperature of trough during the cooking stage, temperature of trough during the drying stage, duration of the cooking stage, duration of the drying stage, number of pressing paddles, and batch quantity of sifted cassava mash for the automated garification machine respectively. The gari processed by the machine at these optimal factor settings has moisture content, grain size and acidity level of 12.04% (wb), 2.00 mm and 0.62% respectively. Operating the automated garification machine at these optimal factor settings also increased the throughput by 13.55% and reduced the specific energy consumption and quantity of charcoal utilized for the garification operation by 24.20% and 12.57% respectively. Since this automated garification machine performs better at these optimal settings of the operational parameters, it is recommended that the replication and operation of this machine should be based on this optimal factor setting.

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