ORIGINAL ARTICLE

Twin-screw Extrusion of Rice Flour, Carrot Flour and Soy Protein Isolate (SPI) Blends: A Response Surface Analysis

Addisalem Hailu Taye[1*], Yetenayet B. Tola[2], Ali Mohammed[3]

1Jimma University College of Agriculture and Vetrinary Medicine, Department of Postharvest Management, Email: addisalemh@gmail.com
2J imma University College of Agriculture and Vetrinary Medicine, Department of Postharvest Management, Email: yetenayet@gmail.com; yetenayet.bekele@ju.edu.et
3J imma University College of Agriculture and Vetrinary Medicine, Department of Postharvest Management, Email: alimhmd@yahoo.com
*Corresponding author: addisalemh@gmail.com

ABSTRACT

The present study focused on the use of the blends of Carrot, Rice and Soy Protein isolate flours to produce ready-to-eat snack products using extrusion cooking. Response surface methodology (RSM) was used to optimize the process. Response (dependent) variables were Expansion ratio (ER), Bulk density (BD), Rehydration ratio (RR), Water Solubility Index (WSI), and Breaking stress (BS). Independent variables were blended with Carrot (5-15%), SPI (15-25%), and Rice (60-80%). All other processing variables (barrel temperature, screw speed, feed moisture, and die diameter) was kept constant (170 °C, 90r.p.m, 26%, and 30 mm respectively). The result indicated that optimum ER, BD, RR, BS, and WSI were found to be 1.49, 824.249 kg.m^{-3}, 65.76%, 27.56 N and 3.41%, respectively, at a blend of Carrot (5 %), SPI (15%) and Rice (80%).

Keyword: Extrusion, physical properties, functional properties, response surface, optimization

INTRODUCTION

Extrusion cooking is a well-known HTST (High-Temperature Short Time) processing technique widely used in the food and feed industries. It comprises a substantial fraction of the snack food market ranging from breakfast cereals, noodles, and pasta, confectionaries expanded crunchy snacks, baby food, besides modified starch, and pet foods. Extrusion cooking is used to make products having better flavor, digestibility, storage life, and safety (Jish et al., 2010). According to Kumar et al. (2010), Rice (*Oryza sativa*) is a staple food crop for a large part of the world's human population, making it the second most consumed cereal grain next to maize. It contains 7.3% protein, 2.2% fat, 64.3% available carbohydrate, 0.8% fiber and 1.4% ash content (Zhoul et al., 2002). Rice flour has become an attractive ingredient in the extrusion industry due to its bland taste, attractive white color, and ease of digestion (Kadan et al., 2003). However, it tends to be low in protein, and hence to improve its poor biological value due to its limited essential amino acid content is necessary to fortify with pulse protein to produce nutritious snack foods rich in lysine (Kumar et al., 2010).

Among food legumes, Soybean is a low cost, superior protein source available in the world. Besides protein fortification, soy-based supplementary foods also provide many other nutritional benefits. Soya containing foods have been shown to reduce the risks of breast and other cancers (Yu and Ramaswamy, 2011). The authors reported that soy proteins are produced from raw whole soybeans by a multi-step process that removes the lipid and indigestible components to concentrate the protein and increase its availability.

It is common also to fortify snack foods with fruits or vegetables as a minor ingredient (Caltinoglu et al., 2014). Among many candidates, a carrot is a rich beta-carotene source to fight against vitamin A related diseases. (Arscott and Tanumihardjo, 2010). According to Haddad et al. (2004), approximately 140 million pre-school children and 7 million pregnant women face vitamin A deficiency, thereupon up to 3 million of that population die in a year. Applying Carrot as an ingredient for snack food preparation is an alternative solution to provide Vitamin A for pregnant women and pre-school children. Therefore, the objective of this study is to determine the optimum blending ratio for the preparation of extruded food made from rice, soy protein isolate, and carrot.

Table 1. Design constraints and actual values used to study the formulation according to D-optimal mixture design

Design constraints		
Low	≤ Constraint	≤ High
5	≤ A: Carrot powder	≤ 15
15	≤ B: Soya Protein Isolate	≤ 25
60	≤ C: Rice flour	≤ 80
	A+B+C=100%	

A= Carrot powder ,
B=Soya Protein Isolate
C= Rice flour

D-Optimal mixture design: actual values of ingredients			
Run	Dried Carrot powder	Soya Protein Isolate	Rice flour
1	12.5	20	67.5
2	10	15	75
3	5	15	80
4	5	25	70
5	10	25	65
6	15	25	60
7	5	15	80
8	15	15	70
9	15	15	70
10	5	25	70
11	15	20	65
12	15	25	60
13	5	20	75
14	10	20	70

MATERIALS AND METHODS

Rice flour from Brar Natural Flour Mills (Winnipeg, MB, Canada) was purchased locally. SPI was received from American Health & Nutrition (Ann Arbor, MI, USA) and Carrot was purchased locally from Adonis. The moisture contents of the flours were measured before mixing. The flours were mixed using a Hobart mixer (Hobart Food Equipment Group, North York, ON, Canada). The appropriate amount of water was added to adjust the mixture to obtain moisture contents of 26 %.

Extrusion runs

The extrusion was performed in a corotating twin-screw extruder (DS32-II, Jinan Saixin Food Machinery, Shandong, P.R. China). The diameter of the screw was 30mm. The diameter to length ratio of the barrel is 1:20. with the length of the die is 27 mm with a diameter of the hole in the die of 5 mm.

Experimental design

A statistical software package (Design-Expert ®, version 6.2) was used for the generation of test formulations and analysis of the results. D-Optimal mixture design was used to blend three ingredients (Carrot, SPI, and Rice) with nine (3^3) factorial points (three levels for each variable). Table 1 presents design constraints and the actual values of the ingredients used to determine selected parameters.

Collected data

Expansion ratio (ER)

ER was determined as the ratio of extruded product diameter to the diameter of the die hole (Deshpande & Poshadri, 2011). According to Deshpande & Poshadri(2011), the diameter of the extrudate was determined as the mean of 30 measurements made with a caliper.

Bulk density (BD)

Bulk density (BD) was measured using a solid displacement method (Seker2005). Extrudates were cut into pieces about 2.5 cm long and around 15 g strands were weighed and placed in a 100 ml cylinder. Then yellow millet particles were added to fill the cylinder to determine the volume of extrudates by difference method. Measured (Vym, ml) volume of the extrudate used to determine BD using the following equation.

$$BD = \frac{M_{ext}}{100 - V_{ym}}$$

Rehydration ratio (RR)

About 35-mm-long strands of the extrudate approximately 20 g strands in weight (M_1) placed in 500 ml of distilled water at 30°C for 15 min. The water was then drained, and the rehydrated sample weighed (M_2) to determine the RR defined as:

$$RR = \frac{m_2 - m_1}{m_1} \times 100$$

Water solubility index (WSI)

The water solubility index (WSI) was determined using the method of Anderson et al. (1969). According to this method, the ground extrudates suspended in water at room temperature for 30 min, gently stirred then centrifuged at 3000 g for 15 min. The supernatant carefully decanted into an evaporating dish of known weight. The WSI was the weight of dry solids in the supernatant expressed as a percentage of the original weight of the sample.

Breaking stress (BS)

Breaking stress (BS) was measured using a single cycle compression test in a Lloyd texture machine with a 500-

N load cell (Lloyd model LRX, Lloyd Instruments Ltd., Fareham, Han, UK). A three-point breaking test was used to measure the maximum force required to break the extrudate samples. The extruded product approximately cut 35-mm-long strands, and placed at the right angle position on two rounded stands (bridge) 30 mm apart. The rounded crosshead exerting force in the middle of the bridge was moving down at 5 mm/min until breaking. Ten measurements were made on each product, and the average value of the maximum force recorded to determine the BS.

Statistical analysis

Analysis of Variance (ANOVA) was used to determine the significance of the factors on the response variable. A statistically significant difference between means was taken at $p< 0.05$. Optimization was performed using a multivariate response method called the overall desirability index by selecting the desired values of the parameters as indicated in table 2. The desirability index is a multi-criteria optimization approach used to show how desirable the various responses are. The desirability index ranges from zero (least desirable) to one (most desirable). Desired goals for independent and dependent variables for making good extrudate are presented in Table 2.

Table 2. Desired goals for the independent and the dependent variables to optimize formulation

Dependent and indipendent variables	Goal	Importance (1= least important,...5= very important
Carrot	is in range	3
SPI	is in range	3
Rice	is in range	3
ER	Maximize	5
BD	Minimize	5
RR	Maximize	5
BS	Minimize	5
WSI	Maximize	5

RESULTS AND DISCUSSION

Dependent variable (Expansion ratio, Bulk density, Rehydration ratio, Breaking stress, and Water solubility index) were investigated. A second-order model was tested to decide the variation of the dependent variable (responses) with independent variables. In all case, lack of fit for the fitted models was not significant which indicate the adequacy of the model. To aid visualization on responses with respect to the independent variables, a series of contour plots (Figure 1 to 6) were drawn using design expert software.

Expansion Ratio (ER)

Expansion is the formation of aerated internal structures when melted feed material at high temperature and pressure suddenly release the pressure, and superheated water flashed off at the die of the extruder (Harper, 1981). It is an important quality parameter in products like breakfast cereals and ready-to-eat snack foods. Figure 1 depicts the contour plot of the expansion ratio of extrudates. The figure shows, similar to the report of Kumar et al. (2010), as the proportion of the rice in the feed increase, the value of the expansion ratio of the extrudate also increases. Deshpande & Poshadri, 2011 reported the expansion ratio of extrudates decreased with an increased level of cereal starch and decreased the portion of proteins in the composite flour. The expansion ratio of the extrudate as a function of the blend (Carrot, Rice, and SPI) is shown in equation 1. From the equation, the expansion ratio of the extrudate of Carrot, SPI, and Rice best fit linear regression. The coefficient of each term is greater than unity. This indicates the presence of aerated internal structure in extrudate than the feed. High expansion of the extrudate was observed with the increase in the proportion of rice. The observance of high expansion of extrudate with the increase in the proportion of Rice was due to higher starch content of Rice. The expansion properties of cereals have been related to the degree of gelatinization and a greater starch gelatinization resulted in higher expansion volume (Chiang and Johnsson, 1977).

$$ER=1.27 A + 1.31 B + 1.49 C + 0.29 AC \qquad (1)$$

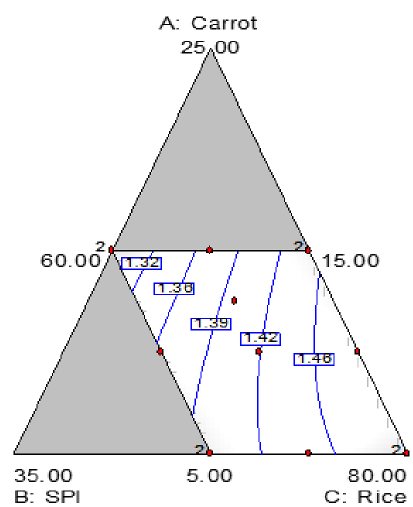

Figure 1. Contour plot of effect of composition on ER of the extrudate

Bulk Density (BD)

Bulk density is an important variable for many products since it will greatly affect the products' packaging volume and acceptability. The contour plot of bulk density is shown in Figure 2. The bulk density of the extrudates ranged between 820 and 1370kgm-3. It was perceived from Figure 2 that bulk density decreased with an increase in Rice proportion.

Table 3. ANOVA for quality attribute by response surface linear and quadratic models

Source	ER	BD	RR	BS	WSI
	Prob > F	Prob > F	Prob > F	Prob > F	Prob > F
Model	<0.0001	<0.0001	0.0002	<0.0001	<0.0001
Linear Mixture	<0.0001	<0.0001	0.0005	<0.0001	<0.0001
AB	-	0.0040	0.0002	<0.0001	<0.0001
AC	0.0249	-	0.0428	<0.0001	<0.0001
BC	-	-	-	<0.0001	0.0004
ABC	-	-	-	<0.0001	-
Lack of Fit	0.0977	0.2679	0.1602	0.085	0.3251
R^2	0.93	0.90	0.90	0.99	0.99

ER=Expansion Ratio, BD= Bulk Density, RR= Rehyderation Ratio, BS= Breaking strength, WSI= Water Solubility Index

Density was reported to decrease with the increase in starch proportion due to starch gelatinization (Sacchetti et al., 2004). Camire et al. (1990) reported that samples with large expansion ratios generally exhibit lower bulk density, which is in agreement with this finding. The Bulk density of the extrudate as a function of Rice, Carrot, and SPI best fit to linear regression. The surface figure shows the response surface as a function of Rice, SPI, and Carrot. The result indicated that the linear effects of all blends were significant. The resultant polynomial for these variables was

BD=1371.27A+ 1842.69 B+ 824.25 C -1376.16 AB (2)

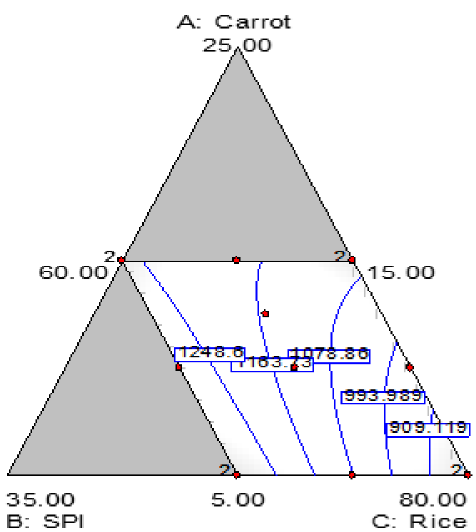

Figure 2. Contour plot of effect of composition on BD of extrudate

Rehydration Ratio (RR)

Extrudates are frequently rehydrated prior to consumption like in breakfast cereal or used as an ingredient in the cooking preparations. The RR is an important parameter for such considerations as it will define the ability of how much liquid the extrudate can absorb (Yu et al., 2012). The contour plot of the rehydration ratio of the extrudate is presented in Figure 3. The rehydration ratio of extrudates ranged from 45 to 68 % with an average value of 55%. The model and other statistics are given in Table 2. The model is significant (P = 0.0002). As indicated in Table2, the R^2 value shows that the regression model explains 90 % of the variance in RR. It was observed from Equation 3 that the coefficient of A is negative, but that of B, C, AB, and AC are positive. Therefore, the increase in the proportion of Carrot may reduce the RR, whereas the increase in SPI, Rice, the combination of Carrot and SPI, and the combination of Carrot and Rice may increase RR of the product.

RR=-3.44 A +25.88 B + 65.76 C +184.98 AB +63.39 AC (3)

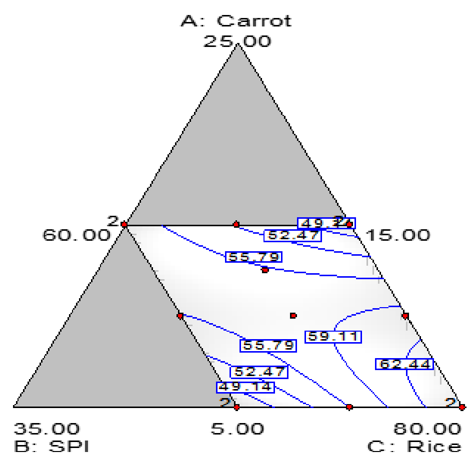

Figure 3. Contour plot effect of composition on RR of extrudates

Breaking Stress (BS)

The breaking stress (BS) of the extrudate as a function of Carrot, SPI, and Rice is shown in Figure 4. The breaking stress of the extrudates ranged from 27 to 66 N with an average value of 54.6 N. The model and other statistics are given in Table 3. The model is significant (P < 0.0001). As indicated in Table 3, the R^2 value shows that the regression model explains 99 % of the variance in BS. It was observed from Equation 4 that the coefficient of B and ABC are negative, but that of A, C, AB, AC, and BC are positive. Therefore, the increase in the proportion of SPI may reduce in breaking strength, whereas an increase in Carrot, Rice, the combination of Carrot and SPI, the combination of Carrot and Rice, and the combination of Rice and SPI may increase the strength of the product. Generally, shear strengths of extrudate related to expansion volume. The greater the expansion volume, the lower is the shear strength (Jáuregui et al., 2000). This agrees with this finding.

BS= 56.46 A - 45.25 B + 27.56 C + 189.77 AB + 104.01 AC + 301.62 BC - 711.89 ABC (4)

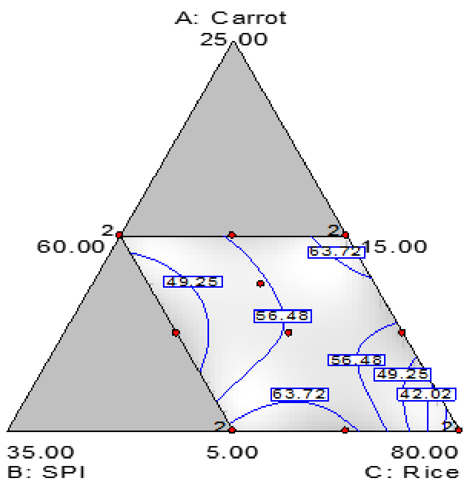

Figure 4. Contour plot of effect of composition on BS of extrudate

Water Solubility Index (WSI)

The water solubility index was used as an index of the extent of molecular degradation and was correlated with intrinsic viscosity for extruded starch (Ollet *et al.*, 1999). The contour plot of the WSI of the extrudate is presented in Figure 5. The water solubility index of the extrudates ranged from 3.08 to5.12% with an average value of 3.99%. Kumar et al.(2010) reported the water solubility index of extrudates made from carrot pomace, rice flour, and pulse powder ranged from 3.31 to 8.1%. The model and other statistics are given in Table 3. The model is significant ($P < 0.0001$). As indicated in Table 3, the R^2 value shows that the regression model explains 99% of the variance in WSI. It was observed from Equation 5 that the coefficients of A and B are negative, but that of C, AB, AC, and BC are positive. Therefore, the increase in the proportion of Carrot and SPI may reduce the water solubility index, whereas the increase in Rice, the combination of Carrot and SPI, the combination of Carrot and Rice, and the combination of Rice and SPI may increase the water solubility index of the product. The Highest positive value was observed for the coefficient of AB. This indicates the increase in the combination of Rice and SPI resulted in high WSI value. According to Yu & Ramaswamy, 2011, the WSI is contributed by the nature of the major components in the feed mix the carbohydrates and proteins and their status whether they are in their native state or in the gelatinized/denatured state. The increase in WSI with an increase in the proportion of Rice (starch) and SPI (protein) might be due to the increase in gelatinized/ denatured state of the mix as the proportion of starch and protein increase.

WSI= -5.59 A- 1.15 B + 3.41 C + 34.02 AB + 16.85 AC + 6.08 BC (5)

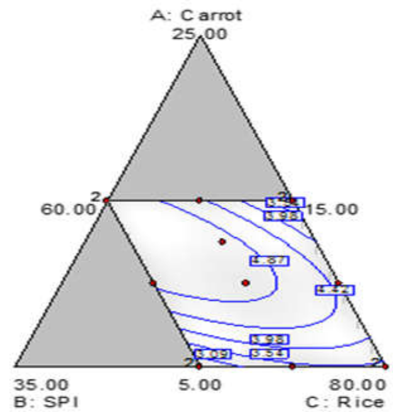

Figure 5. Contour plot of effect of composition of WSI of the extrudate

Optimization

The optimum blend of the extrudate was determined to obtain the criteria minimum BD and BS, and maximum ER, WSI, and RR. To meet the requirements, variables can be weighed by their importance (1-5) as indicated in Table 3. Optimum ER, BD, RR, BS, and WSI were found to be 1.49, 824.249 kg.m^{-3}, 65.76%, 27.56 N, and 3.41%, respectively, at a blend of Carrot (5 %), SPI (15%) and Rice (80%). The desirability of the results was 0.871. The contour plot of the desirability for the optimum parameters is shown in Fig 6.

CONCLUSION

Response parameters such as the expansion ratio (ER), bulk density (BD), rehydration ratio (RR), water solubility index (WSI), and breaking stress (BS) indicators described product quality of extradites carrot, SPI and rice flour extruded. High values of ER and RR, and low values of BD, WSI, and BS were obtained. These results are expected as values of a better quality of extraditing by the consumers. According to the set criteria, the better quality of extraditing was obtained at a blend of carrot (5 %), SPI (15%), and rice (80%). Further study is required to study the effect of the extrusion process on the nutritional content of the extrudates.

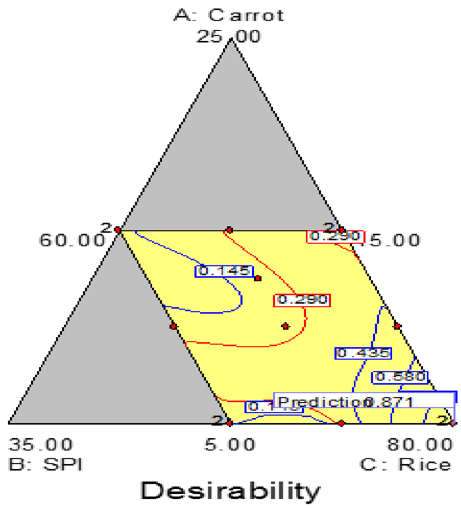

Figure 6. The contour plot of the desirability index for optimization of blending ratio

ACKNOWLEDGMENTS

The authors wish to acknowledge the Canadian International Development Agency and the Postharvest Management to Improve Livelihoods project for their financial support.

REFERENCES

Anderson, R. A., Conway, H. F., Pfeifer, V. F., & Griffin, L. E. J. (1969). Gelatinization of corn grits by roll- and extrusion cooking. Cereal Science Today, 14(4–7), 11–12.

Arscott, S. A., & Tanumihardjo, S. A. (2010). Carrots of many colors provide basic nutrition and bioavailable phytochemicals acting as a functional food. Comprehensive Reviews in Food Science and Food Safety, 9(2), 223-239.

Caltinoglu, C., Tonyalı, B., & Sensoy, I. (2014). Effects of tomato pulp addition on the extrudate quality parameters and effects of extrusion on the functional parameters of the extrudates. International Journal of Food Science & Technology, 49(2), 587-594.

Camire, M.E.; Camire, A.; Krumhar, K. Chemical and nutritional changes in foods during extrusion. Crist. Rev. Food Sci. Nutr. 1990, 29, 35–36.

Chiang, B.Y., and J. A. Johnson, (1977). Gelatinization of starch in extruded products. Cereal Chemistry 54: 436-433.

Deshpande, H. W., & Poshadri, A. (2011). Physical and sensory characteristics of extruded snacks prepared from Foxtail millet-based composite flours. *International Food Research Journal*, *18*(2), 751–756.

Haddad, L., Ross, J., Oshaug, A., Torheim, L. E., & Cogill, B. (2004). Nutrition trends and implications for attaining the MDGs. In the 5th report on the world nutrition situation. Nutrition for improved development outcomes. Retrieved from: http://www.unscn.org/layout/modules/resources/files/rwns5.pdf [last accessed on 05.09.2014]

Harper, J.M. (1981). Extrusion of foods. Vol. I, Boca Raton, FL CRS press. 281p.

Jáuregui, R. N. C., Silva, M. E. M. P. E., & Arêas, J. A. G. (2000). Extrusion Cooking Process for Amaranth (Amaranthus caudatus L .). *Journal of Food Science*, *65*(6), 1009–1015. http://doi.org/10.1111/j.1365-2621.2000.tb09408.x

Jisha, S., Sheriff, J. T., & Padmaja, G. (2010). Nutritional, functional, and physical properties of extrudates from blends of cassava flour with cereal and legume flours. *International Journal of Food Properties*, *13*(5), 1002–1011. http://doi.org/10.1080/10942910902934090

Kadan RS, Bryant RJ, Pepperman, AB (2003). Functional properties of extruded rice flours. J. Food Sci., 68: 1669-1672.

Kumar, N., Sarkar, B. C., & Sharma, H. K. (2010). Development and characterization of extruded product of carrot pomace, rice flour, and pulse powder, *4*(November), 703–717.

Seker, M. (2005). Selected properties of native or modified maize starch/soy protein mixtures extruded at varying screw speed.

Yu, L., & Ramaswamy, H. S. (2011). Extrusion processing of protein-rich food formulations, *NR78839*(August), 210. Retrieved from http://search.proquest.com/docview/1079018247?accountid=10267

Yu, L., Ramaswamy, H. S., & Boye, J. (2012). Twin-screw Extrusion of Corn Flour and Soy Protein Isolate (SPI) Blends A Response Surface Analysis. *Food and Bioprocess Technology*, *5*(2), 485–497. http://doi.org/10.1007/s11947-009-0294-8

Zhoul Z, Robards K, Helliwell S, Blanchard C (2002). Composition and functional properties of rice. Int. J. Food Sci. Technol., 37: 849-868.

ISSN 2220-9325 (Online), ISSN 2203-5802(Print)