Research, Society and Development, v. 10, n. 1, e52710111454, 2021
(CC BY 4.0) | ISSN 2525-3409 | DOI: http://dx.doi.org/10.33448/rsd-v10i1.11454

Gluten-free pasta elaborated with taro flour (*Colocasia esculenta*): a study of the employ of egg white and transglutaminase on the technological properties[1]

Massa alimentícia sem glúten elaborada com farinha de taro (*Colocasia esculenta*): estudo do emprego de clara de ovo e transglutaminase nas propriedades tecnológicas

Pasta sin gluten elaborada con harina de taro (*Colocasia esculenta*): estudio del uso de clara de huevo y transglutaminasa en propiedades tecnológicas

Received: 12/22/2020 | Reviewed: 12/23/2020 | Accept: 01/22/2021 | Published: 01/30/2021

Brunna Vilarinho Pereira Campos
ORCID: https://orcid.org/0000-0002-2241-7347
Federal University of Rio de Janeiro, Brazil
E-mail: brunnacamposf@gmail.com
Eveline Lopes Almeida
ORCID: https://orcid.org/0000-0002-4222-3208
Federal University of Rio de Janeiro, Brazil
E-mail: eveline@eq.ufrj.br

Abstract
Taro (*Colocasia esculenta*), like any tuber, lacks the proteins that form the gluten network, making it a possible source of carbohydrates in the production of gluten-free products. This study aimed to enable the production of gluten-free pasta elaborated with taro flour. To help with the pasta structure, egg white was used as a protein source, and the transglutaminase enzyme was used as a processing aid. Pasta was produced with varying the contents of egg white powder (5 to 50% replacement in flour) and transglutaminase (0.005 to 0.05% flour base) according to a complete 2^2 factorial design containing 7 assays. The pasta was evaluated for pH, instrumental color parameters, cooking properties, and texture. The results were analyzed using Response Surface Methodology. Egg white contributed to increasing the chroma and hue angle, while transglutaminase only increased the chroma. Both egg white and transglutaminase showed a positive interaction effect for cooking time and increased weight of cooked pasta, and a negative interaction effect on firmness. However, these raw materials had no significant effect on the volume increase of the cooked pasta and cooking loss. The lowest contents of egg white and transglutaminase enzyme used in this study have already sufficient to structure the gluten-free pasta elaborated with taro flour, which provides adequate technological characteristics to it.
Keywords: Tuber; Rhizome; Enzyme; Protein; Processing aid.

Resumo
O taro (*Colocasia esculenta*), como todo tubérculo, não possui as proteínas formadoras da rede de glúten, tornando-o uma possível fonte de carboidratos na elaboração de produtos *gluten free*. O objetivo deste estudo foi viabilizar a produção de massa alimentícia *gluten free* elaborada com farinha de taro. Para ajudar na estruturação da massa, foi utilizada a clara de ovo como fonte proteica e a enzima transglutaminase como coadjuvante de tecnologia no processo. Massas alimentícias foram produzidas com variação dos teores da clara de ovo em pó (5 a 50% substituição da farinha) e da transglutaminase (0,005 a 0,050% base farinha) de acordo com planejamento fatorial completo 2^2 contendo 7 ensaios. As massas alimentícias foram avaliadas quanto ao pH, cor instrumental, propriedades de cozimento e textura. Os resultados foram analisados pela Metodologia de Superfície de Resposta. A clara de ovo contribuiu para aumentar o croma e o ângulo de tonalidade, enquanto a transglutaminase contribuiu apenas para o aumento do croma da massa. A clara de ovo e a transglutaminase apresentaram efeito de interação positivo para tempo de cozimento e aumento da massa cozida e, efeito de interação negativo na firmeza. Porém, estas matérias primas não apresentaram efeito significativo no aumento de volume da massa cozida e perda de sólidos solúveis durante o cozimento. Os menores teores de clara de ovo e da enzima transglutaminase empregados neste estudo já foram suficientes para estruturar a massa *gluten free* elaborada com farinha de taro, proporcionando à mesma características tecnológicas adequadas.
Palavras-chave: Tubérculo; Rizoma; Enzima; Proteína; Coadjuvante de tecnologia.

[1] Trabalho apresentado no CBCP 2020 - Congresso on-line Brasileiro de Tecnologia de Cereais e Panificação, selecionado para publicação na forma de artigo completo.

Resumen
El taro (*Colocasia esculenta*), como cualquier tubérculo, carece de las proteínas que forman la red del gluten, que lo convierte en una posible fuente de carbohidratos en la elaboración de productos sin gluten. El objetivo de este estudio fue posibilitar la producción de pasta sin gluten elaborada con harina de taro. Para ayudar con la estructuración de la masa, se utilizó clara de huevo como fuente de proteína y la enzima transglutaminasa como coadyuvante tecnológico en el proceso. Las pastas se produjeron con diferentes niveles de polvo de clara de huevo (5 a 50% reemplazo de harina) y transglutaminasa (0,005 a 0,05% base harina) de acuerdo con un diseño factorial completo 2^2 que contiene 7 ensayos. Se evaluó la pasta para determinar el pH, color instrumental, las pruebas de cocción y textura. Los resultados se analizaron utilizando la Metodología de Superficie de Respuesta. La clara de huevo contribuyó a aumentar el croma y el ángulo de tonalidad, mientras la transglutaminasa solo contribuyó al aumento del croma de la pasta. La clara de huevo y la transglutaminasa mostraron un efecto de interacción positivo para el tiempo de cocción y absorción del agua de cocción y un efecto de interacción negativo sobre la firmeza. Sin embargo, estas materias primas no tuvieron un efecto significativo sobre el aumento de volumen de la pasta cocida y las pérdidas por cocción. Los niveles más bajos de clara de huevo y transglutaminasa utilizados en este estudio fueron suficientes para estructurar la masa sin gluten elaborada con harina de taro, aportando a la misma características tecnológicas adecuadas.
Palabras clave: Tubérculo; Rizoma; Enzima; Proteína; Coadyuvante tecnológico.

1. Introduction

About 10-15% of the world population has some food-related disorder related to cereal proteins. The most known are wheat allergy, celiac disease, and non-celiac gluten sensibility (O'Bryan et al., 2012). The only effective treatment for such disorders is a diet that restricts these proteins. Some of this treatment's problems are the cost and availability of foods free from cereals proteins and its eventual nutritional deficiency (Ciantelli et al., 2012; Figueira et al., 2011). The development of new products using raw materials with added nutritional value is essential in improving individuals' nutritional aspects with food-related disorders to cereal proteins (Tomicki et al., 2015). Taro, being a tuber, lacks the proteins that form the gluten network. It has a high nutritional and energetic value, a rich source of carbohydrates, vitamins, and minerals, besides resistant starch and mucilage. Therefore, it becomes a possible source of nutritionally essential compounds in the production of gluten-free products. Besides, taro is an exciting matrix from a technological point of view, as it has a large amount of starch in its composition, around 70-80% on a dry basis (Kaushal et al., 2015). It is known that starch and proteins form the basis for structuring pasta (Larrosa et al., 2016). In comparison with wheat, used in traditional pasta, taro has a low protein content (taro = around 2% dry basis x wheat = 9 - 16% “as is” weight of whole grain**),** in addition to presenting much smaller starch granules (taro = 0.25 - 0.5 μm x wheat = 1 - 45 μm) (Bekes & Wrigley, 2004; Kaushal et al., 2015; Lawton, 2004). Thus, to structure a pasta containing taro as a single source of starch, it would be necessary to insert in the formulation a protein resource that could form a network to retain the small starch granules of the taro in the structure, thus avoiding the cooking loss.

Egg white is an interesting protein raw material because, it was found that its inclusion in the formulation of gluten-free bread could increase the cohesiveness and elasticity of the dough during the process, improve color and taste perception due to Maillard Reaction, in addition to reducing their glycemic index (Stantiall & Serventi, 2017). Egg white proteins greatly benefit human nutrition because they have a high content of essential amino acids, which reach 385 amino acids only in ovalbumin, predominantly containing lysine and sulfur (Seuss-Baum et al., 2011). Among the proteins, the main ones can be highlighted: ovalbumin, ovotransferrin, ovomucoid, ovomucin, lysozyme, and globulin (Strixner & Kulozik, 2011).

The insertion of transglutaminase into the gluten free pasta could also help in product structuring as it catalyzes the formation of intra and intermolecular cross-linking in proteins through a transfer mechanism of an acyl group involving proteins that have glutamine residues and primary amines, including the ε-amino group of the lysine residues of certain proteins (Steffen et al., 2017; Susanna & Prabhasankar, 2015). Egg white proteins have been shown to be a suitable substrate

for the action of this enzyme in studies of gluten-free bread (Smerdel et al., 2012; Onyango et al., 2010), gels (Alavi et al., 2020) and edible films (Peng et al., 2017).

This study aimed to make feasible gluten-free pasta production made with taro flour, verifying whether the egg white powder and the enzyme transglutaminase could act as product structuring agents.

2. Material and Methods

A hypothetical scientific method and quantitative assessment to collect data were used in this study as described by Pereira et al. (2018).

2.1. Taro flour production

The rhizomes were selected, washed in tap water, peeled, and sliced with a stainless peeler (Vitorinox, Brazil). The slices, approximately 2 mm thickness, were placed on a stainless steel baking sheet and taken to dry in a turbo oven (FTT150, Tedesco, Brazil) with forced ventilation at 50°C and open exhaust for 3.5 h. The dried slices were milled using a grinder (Metvisa, Brazil) until obtaining particles lower than 28 mesh. The flour obtained was stored in polyethylene bags and kept in a freezer at -12 ± 2 °C.

2.2. Characterization of raw materials

Taro flour and egg white powder (Maxxi Eggs, Brazil) were characterized in terms of moisture content, pH and water absorption and water solubility indexes (WAI and WSI) according to methods 44-16.01 and 02-52.01 of AACC Approved Methods of Analysis, and Almeida et al. (2010), respectively.

2.3. Pasta production

For the pasta production, the flour was considered a mixture of taro flour and egg white powder. The egg white powder content in this mixture varied from 5 to 50% in the flour. The transglutaminase content (Alphamalt PT21006, Mühlenchemie, Germany) ranged from 0.005 to 0.050% flour basis according to a complete 2^2 factorial experimental design containing 7 assays (Table 1). The amount of water in tests 5, 6, and 7 was determined experimentally. For the other tests, it was calculated proportionally considering the moisture content and water absorption index of the proportion of raw materials present in the flour's composition.

Table 1: Factorial experimental design.

Assays	Coded values		Actual values		Water (% flour basis)
	EW	TG	Egg white (% in flour)	TG (% flour basis)	
1	-1	-1	5	0.0050	22.59
2	1	-1	50	0.0050	16.41
3	-1	1	5	0.0500	22.59
4	1	1	50	0.0500	16.41
5	0	0	27.5	0.0275	19.50
6	0	0	27.5	0.0275	19.50
7	0	0	27.5	0.0275	19.50

EW = egg white (coded value); TG = transglutaminase (coded value)
Source: Authors (2021).

The pasta production process was carried out according to method 66-42.01 of AACC Approved Methods of Analysis with minor changes. It started with the manual mixing of all previously weighed ingredients. To improve the enzymatic performance of transglutaminase, the water added was previously heated to 50.1 ± 0.8 °C. The formed pasta, with a temperature of 28.6 ± 1.6 °C was left to rest for 10 min; then it was laminated and formatted into tagliatelle by a benchtop pasta machine (Atlas 150 Marcato, Brazil) at room temperature (25.8 ± 2.2 °C). The pasta drying was carried out in a turbo oven (FTT150, Tedesco, Brazil) in five stages: pre-drying at 55 °C for 15 min with the exhaust semi-open and the fan on; two rest stages at 50ºC for 30 min with the exhaust closed and the fan turned off; interspersed by two dryings at 60 °C for 30 min with the exhaust open and the fan on. The pasta was packed in polyethylene packaging and stored at room temperature.

2.4. Evaluation of technological properties of pasta

2.4.1. pH

The pH was determined according to method 02-52.01 of AACC Approved Methods of Analysis.

2.4.2. Instrumental color

Instrumental color of uncooked pasta was determined in CR-400 Chroma Meter (Konica Minolta, Japan) with 10° observation angle, illuminant D65, and using CIEL*C*h color space.

2.4.3. Cooking test

The cooking properties of the pasta were evaluated according to method 66-50.01 of AACC Approved Methods of Analysis with slight adaptations. Portions (6 g) of pasta were added to 100 mL beakers containing 60 mL of distilled water at 100°C. Beakers were partially capped to reduce evaporation and maintain a constant temperature. Every 30 s a pasta piece was removed and pressed between two glass plates until the optimum cooking time was observed. The experiment was repeated until the cooking time but without taking out samples, to make the other evaluations. After the cooking, pasta was washed with distilled water and then drained for 1 min. Cooking loss was carried out by placing the cooking and rinsing water in previously tared crucibles to evaporation until constant weight in an oven at 100°C. It was calculated by using the Eq. 1. The weight increase was calculated by difference between weights of cooked and uncooked pasta according to Eq. 2. To determine the

volume increase, the uncooked pasta and cooked pasta were placed separately in one 25 mL graduated cylinder containing 15 mL of petroleum ether and the volume displaced was measured. It was calculated by using the Eq. 3.

Cooking loss = (weight of residue in water evaporation/weight of uncooked pasta) x 100 (Eq.1)
Weight increase = [(weight of cooked pasta - weight of uncooked pasta)/weight of uncooked pasta] x 100 (Eq.2)
Volume increase = [(volume of cooked pasta - volume of uncooked pasta)/volume of uncooked pasta] x 100 (Eq. 3)

2.4.4. Firmness

The pasta's firmness at the optimum cooking time was performed using a CT3 Texture Analyzer version 2.1 "load range" 4.5 kg (Brooksfield, USA) with the aid of TexturePro CT software. The evaluation was carried out by compressing the TA7 (knife-edge) probe into 5 cooked samples placed parallel to each other, perpendicular to the probe. The compression was 100% to the initial height, with a pre and post-test speed of 2 mm/s and a test speed of 0.2 mm/s.

2.5. Statistical analysis

All analyzes were performed in triplicate, except for texture analysis, which was performed using eight replicates. The results of characterization of the raw materials were evaluated by Analysis of Variance (ANOVA) and by Tukey's test ($p < 0.05$) if necessary, and the results of technological properties of pasta were analyzed by Response Surface Methodology ($p < 0.05$) by using Statistica 13.4.0.14 (TIBCO Software Inc., USA).

3. Results and Discussion

3.1. Characterization of raw materials

The moisture content and pH values found for taro flour were expected (Table 2). They are close to that found by Rodríguez-Miranda et al. (2011): 6.22 ± 0.06 % and 6,78, respectively. The pH for egg white is also according to expected. The pH of egg white from a newly laid egg is 7,6-8,5, and it increases until 9,7 throughout storage (Stadelman & Cotterill, 2013). The pH of these raw materials is extremely important because they will make up most of the pasta formulation. In this way, they will interfere in the pH of the pasta and, consequently, in the enzymatic activity of the transglutaminase (Damodaran & Parkin, 2017).

Table 2: Characterization of raw materials

Raw materials	Moisture (%)	pH	WAI (g of centrifugation residue/ g of unsolubilized dry matter)	WSI (% soluble residue)
Taro flour	6.11 ± 0.49[a]	6.12	9.32 ± 0.47[a]	6.33 ± 3.85[b]
Egg white	2.62 ± 0.42[b]	7.47	3.74 ± 0.29[b]	93.59 ± 0.29[a]

Values expressed as mean ± standard deviation (n=3, except pH). WAI = water absorption index; WSI = water solubility index. WAI and WSI were calculated considering the weight of the sample on a dry basis. Values followed by the same letter on the same column do not differ by the Tukey test ($p < 0.05$)
Source: Authors (2021)

Taro flour had a higher water absorption index, and lower water solubility index than egg white powder (Table 2). These differences are directly related to the inherent composition of these raw materials. Egg white is predominantly made up of proteins, while carbohydrates, lipids and minerals are minor components (Mine, 2008). Taro has a high content of carbohydrates, fibers and minerals and a low content of proteins and lipids (Kaushal et al., 2015). Carbohydrates and proteins in the taro combine to form a water soluble gum or mucilage, which has considerable thickener and stabilizer potential (Njitang et al., 2014). The presence of this mucilage in the taro was possibly responsible for the considerable WAI presented. WAI e WSI can be used to predict how materials will behave in a future process. WAI reflects the amount of water bound by the product, while WSI reflects the amount of small molecules solubilized in water (Oikonomou & Krokida, 2011). The WAI value was taken into account along with the moisture content value of raw materials to calculate the amount of water to be added to the pasta. The results are showed in Table 1. Thus, it is observed that the higher the content of taro flour in the flour, the greater the amount of water added to the pasta formulation.

3.2. Technological characteristics of pasta

3.2.1. pH

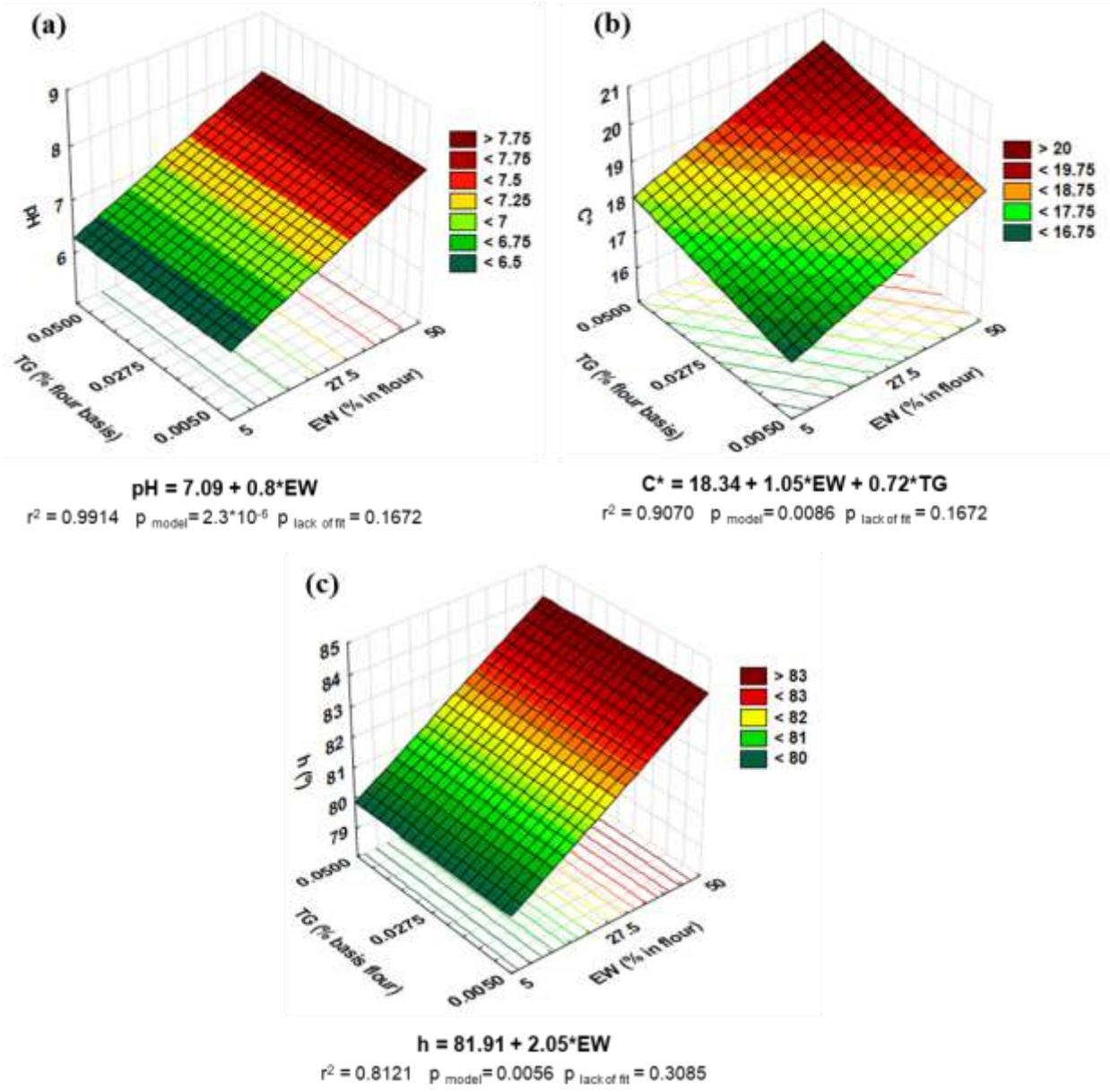
The pasta's pH value varied from 6.35 ± 0.01 to 7.99 ± 0.01 (Table 3). The egg white had a positive effect in this parameter, as observed in the mathematical model and response surface obtained for this parameter. The increase of egg white content promoted an increase in the pH value of the pasta (Figure 1). No influence on the pH of pasta was observed with the variation of transglutaminase content. pH is among the most important environmental factors the influence enzyme activity, and change this parameter compromise one of the principal physical means to control enzyme action in food matrices (Damodaran & Parkin, 2017). In this way, the increase in the egg white content in the formulation will affect the activity of transglutaminase by affecting the pH of the pasta. According to the enzyme manufacturer (Mühlenchemie, 2013), the transglutaminase employed in this study has an optimum pH between 6.0-7.0. This pH range was obtained in the pasta elaborated with egg white content between 5- 25% (Figure 1).

Table 3: pH and instrumental color parameters of pasta .

Assays	pH	L*	C*	h (º)
1	6.35 ± 0.01	73.45 ± 0.27	16.20 ± 0.33	75.50 ± 0.31
2	7.99 ± 0.01	75.98 ± 0.81	18.59 ± 0.58	83.73 ± 0.35
3	6.27 ± 0.03	74.79 ± 0.06	17.94 ± 0.05	80.64 ± 0.05
4	7.83 ± 0.02	76.26 ± 0.04	19.74 ± 0.17	83.62 ± 0.23
5	7.08 ± 0.03	73.41 ± 0.11	18.61 ± 0.23	81.54 ± 0.16
6	7.06 ± 0.02	74.47 ± 0.06	18.89 ± 0.12	82.64 ± 0.07
7	7.03 ± 0.02	74.49 ± 0.03	18.42 ± 0.02	82.69 ± 0.13

Values expressed as mean ± standard deviation (n=3)
Source: Authors (2021).

Figure 1: Coded models and response surfaces for (a) pH, and (b) (c) instrumental color parameters (C* and h) of pasta as a function of egg white and transglutaminase contents.

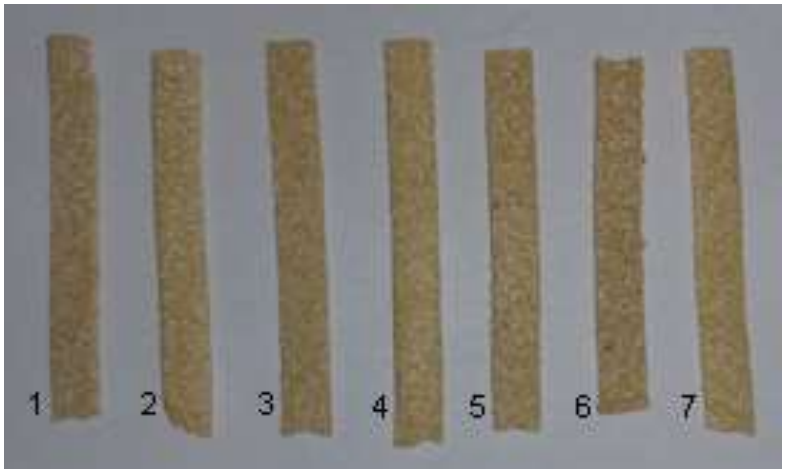


In the models: EW = coded value of egg white (-1 to 1); TG = coded value of transglutaminase (-1 to 1)
Source: Authors (2021)

3.2.2. Instrumental color

Through the results of the instrumental color parameters evaluated (Table 3), it is observed that the uncooked pasta had lightness (L*) between 73.41 and 76.26, chroma (C*) between 16.20 and 19.74, and hue angle (h) between 75.50° and 83.73°, that is, pasta presented a very pale yellowish color according to Konica Minolta (2015), which can be observed in Figure 2. The pasta color is an essential criterion for assessing the quality of the pasta as it is the first characteristic noticed by consumers, which leads to the immediate acceptance or rejection of the product (Bouasla et al., 2017; Marti et al., 2013). The ideal conventional pasta should present a uniform pale yellow color without cracks (Rosarlo et al., 1999; Sicignano et al., 2015).

Figure 2: Pasta of the seven assays according to experimental design showed in Table 1.



Source: Authors (2021).

The increase in the egg white content contributed to an increase in the yellowish hue (h) of the pasta and increase the color saturation (C*), as can be observed in the mathematical models and response surfaces obtained for these parameters (Figure 1). The egg white powder presents a dark yellow color, which is developed during its hot-air drying process. The egg white has glucose (reducing sugar) and proteins with an amino group, that allows the occurrence of the Maillard Reaction (Katekhong & Charoenrein, 2017).

Transglutaminase had no significant effect on the hue angle but also increased color saturation (C*). With the increase in the enzyme content, there is an increase in the polymerization of the egg white proteins (Alavi et al., 2020), which can alter the reflection/refraction of light. Higher values of chroma were found when higher levels of egg white and transglutaminase were used together.

Egg white and transglutaminase had no significant effect on the pasta lightness (Table 4); regardless of the variation in the contents of these raw materials, the lightness value was within an average value standard deviation that was 74.69 ± 1.09.

Table 4: Effects of egg white and transglutaminase on some technological properties of pasta.

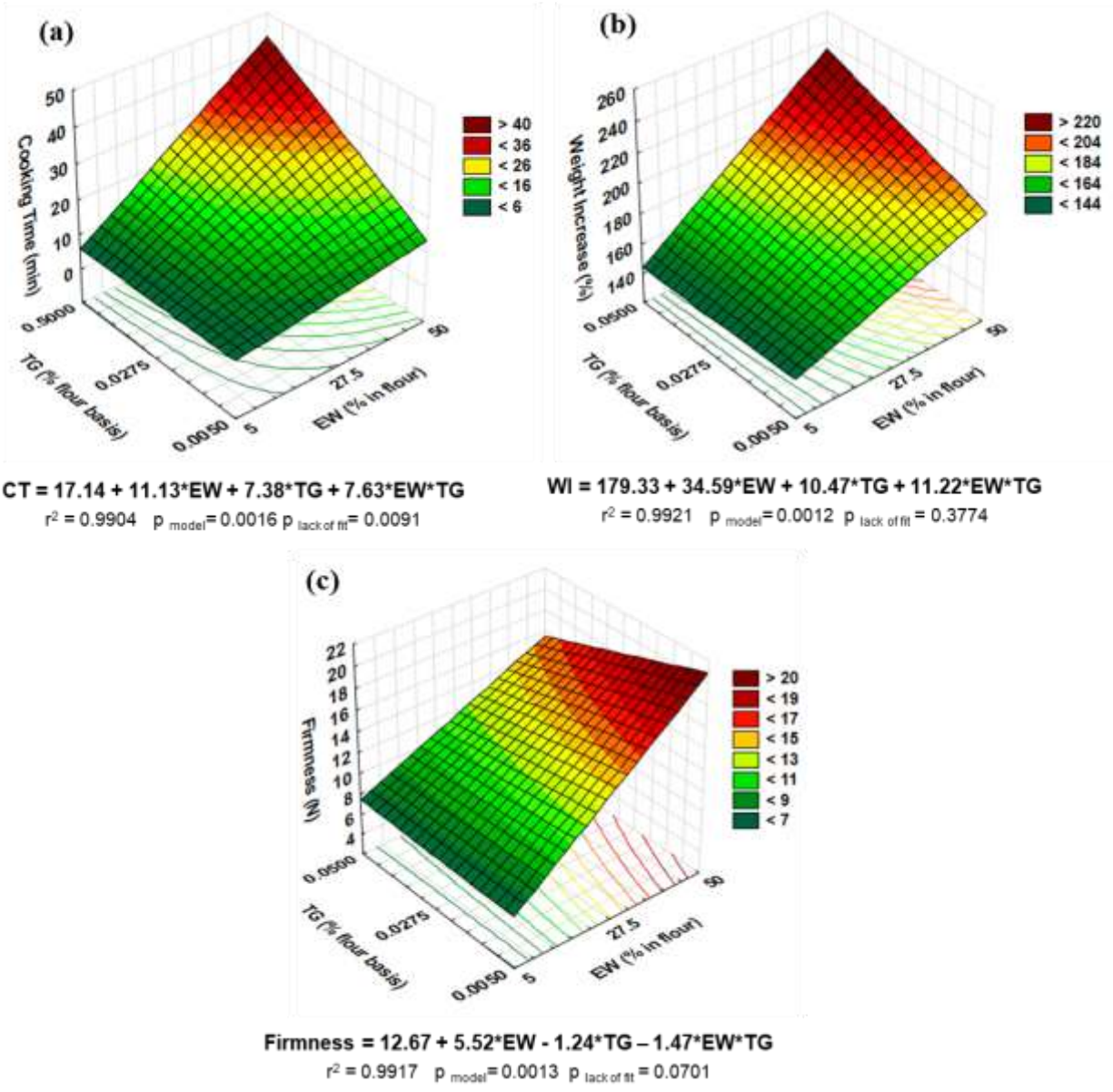
	Factors	Estimated effect	Standard error	t (2)	p-value
Lightness (L*)	**Mean****	74.69000	0.234056	319.1119	0.000010
	EW	1.99500	0.619254	3.2216	0.084340
	TG	0.80750	0.619254	1.3040	0.322124
	EW x TG	-0.52750	0.619254	-0.8518	0.484034
Volume Increase	**Mean****	24.92063	1.454786	17.13010	0.003391
	EW	7.22222	3.849002	1.87639	0.201416
	TG	3.88889	3.849002	1.01036	0.418682
	EW x TG	-2.77778	3.849002	-0.72169	0.545455
Cooking Loss	**Mean****	9.120279	0.103003	88.54389	0.000128
	EW	-0.341313	0.272520	-1.25243	0.337011
	TG	0.642428	0.272520	2.35736	0.142475
	EW x TG	0.674403	0.272520	2.47469	0.131773

**indicates statistically significant factors ($p < 0.05$). EW= egg white; TG = transglutaminase
Source: Authors (2021).

3.2.3. Cooking test

Through the analysis of the results, it was possible to obtain mathematical models that explain how variations in the egg white and transglutaminase contents influenced the variation in cooking time and weight increase of cooked pasta (Figure 3). Egg white and transglutaminase contributed positively to the increase in cooking time and weight increase, showing a positive interaction effect in these two parameters. The cooking time between 7.3 and 44.3 min was obtained in the assays; that is, there was a significant variation in this parameter (Table 5). Very long cooking times are not feasible both from an energy point of view and from a practical point of view. These very long periods were obtained when we used the highest contents of egg white and transglutaminase together. In conditions where we used low levels of transglutaminase and high levels of egg white simultaneous and, in high levels of transglutaminase and low levels of egg white simultaneous, we observed that the cooking time remained at the lowest values found in the study. Therefore, the isolated increase of only one of these ingredients was not as impactful in the cooking time as the increase in these two variables together. This demonstrates the possible role of transglutaminase on the amino acids of egg white proteins because we verified these variables' interdependence. We know that for an enzyme to express its activity, the presence of its substrate is necessary. Transglutaminase cross-links with protein molecules through covalent bonds formed between ε-amino and γ-carboxamide, resulting in isopeptide bonds 20 times stronger than non-covalent bonds (Alavi et al., 2020). As Yao et al. (2020) pointed out, pasta with a higher protein content tends to have a more compact structure that makes it difficult for water to enter, increasing its cooking time (Wang et al., 2011).

Figure 3: Coded models and response surfaces for (a) cooking time, (b) weight increase on cooking, and firmness of pasta as a function of egg white and transglutaminase contents.



CT = 17.14 + 11.13*EW + 7.38*TG + 7.63*EW*TG

$r^2 = 0.9904$ $p_{model} = 0.0016$ $p_{lack\ of\ fit} = 0.0091$

WI = 179.33 + 34.59*EW + 10.47*TG + 11.22*EW*TG

$r^2 = 0.9921$ $p_{model} = 0.0012$ $p_{lack\ of\ fit} = 0.3774$

Firmness = 12.67 + 5.52*EW - 1.24*TG – 1.47*EW*TG

$r^2 = 0.9917$ $p_{model} = 0.0013$ $p_{lack\ of\ fit} = 0.0701$

In the models: CT = cooking time; WI = weight increase; EW = coded value of egg white (-1 to 1); TG = coded value of transglutaminase (-1 to 1)
Source: Authors (2021).

Table 5: Cooking properties and texture of pasta.

Assays	CT (min)	WI (%)	VI (%)	CL (%)	Firmness (N)
1	7.3 ± 0.5	144.11 ± 2.67	20.0 ± 0	8.78 ± 0.49	7.24 ± 0.36
2	14.3 ± 0.6	190.86 ± 6.06	30.0 ± 11.6	7.77 ± 0.29	21.22 ± 1.65
3	6.8 ± 0.7	142.61 ± 5.43	26.7 ± 11.6	8.75 ± 0.23	7.71 ± 0.59
4	44.3 ± 1.4	234.23 ± 10.01	31.1 ± 10.2	9.08 ± 0.40	15.81 ± 1.65
5	16.0 ± 0.3	178.91 ± 7.38	20.0 ± 0	9.57 ± 0.10	12.46 ± 0.62
6	15.5 ± 0	185.46 ± 2.75	26.7 ± 11.56	10.11 ± 0.26	12.32 ± 0.92
7	16.0 ± 0.4	179.10 ± 7.25	20.0 ± 0	9.77 ± 0.32	11.93 ± 0.32

Values expressed as mean ± standard deviation (n=3, except firmness n=8). CT = cooking time; WI = weight increase; VI = volume increase; CL = cooking loss
Source: Authors (2021).

Regarding the weight increase, these same findings are valid, which can be observed by the similarity of the response surfaces obtained (Figure 3). Pasta of the experimental assays showed 144.11 to 234.23% weight increase during cooking (Table 5). The action of transglutaminase on egg white proteins probably allowed the formation of a more interconnected protein network that increased the product's water absorption capacity, which reflected in a weight increase.

It was not possible to verify a significant effect of egg white and transglutaminase on the volume increase of cooked pasta and cooking loss (Table 4); that is, regardless of the variation in the contents of these raw materials, the volume increase and cooking loss values were within an average value and its standard deviation, which were 24.9 ± 8.6% and 9.12 ± 0.79%, respectively.

3.2.4. Firmness

Regarding firmness, higher values were found in formulations with higher contents of egg white and lower contents of transglutaminase (Figure 3). At medium and higher levels of egg white, the increase of transglutaminase made the product softer. This effect of the enzyme was already verified in a previous study using protein gels. Sakamoto et al. (1994) found that transglutaminase's addition to a specific concentration increased the gel's firmness. However, in excess, the enzyme made the gels soft and fragile. These authors believe that the excessive formation of cross-links between glutamine and lysine could inhibit the protein network's uniform development.

4. Conclusion

The production of gluten-free pasta elaborated with taro flour was possible through the insertion of egg white and transglutaminase as structuring agents. The lower levels of egg white and transglutaminase used in the study (5% flour replacement in flour and 0.005% flour base, respectively) have already allowed pasta to have good color, cooking properties, and texture, which shows good performance from a technological point of view. Further studies are needed to investigate the sensory perception, nutritional value and functional properties attributed to the gluten-free pasta elaborated with taro.

Acknowledgments

The authors would like to thank Tovani Benzaquen Ingredientes for kindly donating the enzyme used in this study; the National Council for Scientific and Technological Development (CNPq) and the Federal University of Rio de Janeiro

(UFRJ) for the scholarship from the Institutional Scholarship Program for Initiation Scholarships in Technological Development and Innovation.

References

AACC Approved Methods of Analysis (11th ed.) http://methods.aaccnet.org/default.aspx

Alavi, F., Emam-Djomeh, Z., & Chen, L. (2020). Acid-induced gelation of thermal co-aggregates from egg white and hempseed protein: impact of microbial transglutaminase on mechanical and microstructural properties of gels. *Food Hydrocolloids*, *107*, 105960. https://doi.org/10.1016/j.foodhyd.2020.105960

Almeida, E. L., Chang, Y. K., & Steel, C. J. (2010). Effect of adding different dietary fiber sources on farinographic parameters of wheat flour. *Cereal Chemistry*, *87*(6), 566–573. https://doi.org/10.1094/CCHEM-05-10-0063

Bekes, F., & Wrigley, C. (2004). Cereals: protein chemistry In Wrigley, C., Corke, H., & Walker, C. E. (Eds.). *Encyclopedia of grain science* (pp. 254-262). Elsevier.

Bouasla, A., Wójtowicz, A., & Zidoune, M. N. (2017). Gluten-free precooked rice pasta enriched with legumes flours: Physical properties, texture, sensory attributes and microstructure. *LWT - Food Science and Technology*, *75*, 569–577. https://doi.org/10.1016/j.lwt.2016.10.005

Ciantelli, G. L., Brabo, A. M., Minata, M., Munhoz, M. M., Martins, R. B., & Borghesi, R. A. (2012). Novos aspectos diagnósticos da doença celíaca. *Revista da Faculdade de Ciências Médicas de Sorocaba*, *14*(2), 47-50.

Damodaran, S., & Parkin, K. L. (Eds.). (2017). *Fennema´s food chemistry* (5th ed.). CRC Press.

Figueira, F. D. S., Crizel, T. D. M., Silva, C. R., & Salas-Mellado, M. D. L. M. (2011). Pão sem glúten enriquecido com a microalga Spirulina platensis. *Brazilian Journal of Food Technology*, *14*(4), 308-316. https://doi.org/10.4260/BJFT2011140400037

Kaushal, P., Kumar, V., & Sharma, H. K. (2012). Comparative study of physicochemical, functional, antinutritional and pasting properties of taro (*Colocasia esculenta*), rice (*Oryza sativa*) flour, pigeonpea (*Cajanus cajan*) flour and their blends. *LWT - Food Science and Technology*, *48*(1), 59-68. https://doi.org/10.1016/j.lwt.2012.02.028

Katekhong, W., & Charoenrein, S. (2017). Color and gelling properties of dried egg white: effect of drying methods and storage conditions. *International Journal of Food Properties*, *20*(9), 2157–2168. http://dx.doi.org/10.1080/10942912.2016.1233429

Kaushal, P., Kumar, V., & Sharma, H. K. (2015). Utilization of taro (*Colocasia esculenta*): a review. *Journal of Food Science and Technology*, *52*(1), 27–40. https://doi.org/10.1007/s13197-013-0933-y

Konica Minolta (2015). *Precise color communication*: *Color control from perception to instrumentation*. Konica Minolta, Inc.

Larrosa, V., Lorenzo, G., Zaritzky, N., & Califano, A. (2016). Improvement of the texture and quality of cooked gluten-free pasta. *LWT - Food Science and Technology*, *70*, 96-103. https://doi.org/10.1016/j.lwt.2016.02.039

Lawton, J. W. (2004). Starch: uses of native starch In Wrigley, C., Corke, H., & Walker, C. E. (Eds.). *Encyclopedia of grain science* (pp. 195-202). Elsevier.

Marti, A., Barbiroli, A., Marengo, M., Fongaro, L., Iametti, S., & Pagani, M. A. (2014). Structuring and texturing gluten-free pasta: egg albumen or whey proteins? *European Food Research and Technology*, *238*(2), 217-224. https://doi.org/10.1007/s00217-013-2097-4

Mine, Y. (Ed.). (2008). *Egg bioscience and biotechnology*. Wiley.

Mühlenchemie (2013). *Information: Alphamalt PT21006 coated microbial transglutaminase*. Mühlenchemie (pp. 1-2).

Njintang, N. Y., Boudjeko, T., Tatsadjieu, L. N., Nguema-Ona, E., Scher, J., Mbofung, C. M. F. (2014). Compositional, spectroscopic and rheological analyses of mucilage isolated from taro (*Colocasia esculenta* L. Schott) corms. *Journal of Food Science and Technology*, *51*(5), 900-907. https://doi.org/10.1007/s13197-011-0580-0

O'Bryan, T., Ford, R., & Kupper, C. (2012). Celiac disease and non-celiac gluten sensitivity In I. Kohlstadt (Ed.). *Advancing medicine with food and nutrients* (2nd ed., pp. 305–330). CRC Press.

Oikonomou, N. A., & Krokida, M. K. (2011). Literature data compilation of WAI and WSI of extrudate food products. *International Journal of Food Properties*, *14*(1), 199-240. https://doi.org/10.1080/10942910903160422

Onyango, C., Mutungi, C., Unbehend, G., & Lindhauer, M. G. (2010). Rheological and baking characteristics of batter and bread prepared from pregelatinised cassava starch and sorghum and modified using microbial transglutaminase. *Journal of Food Engineering*, *97*(4), 465-470. https://doi.org/10.1016/j.jfoodeng.2009.11.002

Peng, N., Gu, L., Li, J., Chang, C., Li, X., Su, Y., & Yang, Y. (2017). Films based on egg white protein and succinylated casein cross-linked with transglutaminase. *Food and Bioprocess Technology*, *10*(8), 1422-1430. https://doi.org/10.1007/s11947-017-1901-8

Pereira, A. S., Shitsuka, D. M., Parreira, F. J., & Shitsuka, R. (2018). *Metodologia da pesquisa científica*. Santa Maria: UAB/NTE/UFSM.

Rodríguez-Miranda, J., Ruiz-López, I. I., Herman-Lara, E., Martínez-Sánchez, C. E., Delgado-Licon, E., & Vivar-Vera, M. A. (2011). Development of extruded snacks using taro (*Colocasia esculenta*) and nixtamalized maize (*Zea mays*) flour blends. *LWT - Food Science and Technology*, *44*(3), 673-680. https://doi.org/10.1016/j.lwt.2010.06.036

Rosarlo, M. D., Vinas, A., & Lorenz, K. (1999). Pasta products containing taro (*Colocacia esculenta* L. Schott) and chaya (Cnidoscolus chayamansa L. Mcvaugh). *Journal of Food Processing Preservation*, *23*(1), 1-20. https://doi.org/10.1111/j.1745-4549.1999.tb00366.x

Sakamoto, H., Kumazawa, Y., & Motoki, M. (1994). Strength of protein gels prepared with microbial transglutaminase as related to reaction conditions. *Journal of Food Science*, *59*(4), 866-871. https://doi.org/10.1111/j.1365-2621.1994.tb08146.x

Seuss-Baum, I., & Nau, F. (2011). The nutritional quality of eggs. In Y. Nys, M. Bain, & F. Van Immerseel (Eds.). *Improving the safety and quality of eggs and egg products*: *Egg chemistry, production and consumption*. (pp. 201-236). Elsevier. https://doi.org/10.1533/9780857093929.3.201

Sicignano, A., Di Monaco, R., Masi, P., & Cavella, S. (2015). From raw material to dish: pasta quality step by step. *Journal of the Science of Food and Agriculture*, *95*(13), 2579-2587. https://doi.org/10.1002/jsfa.7176

Smerdel, B., Pollak, L., Novotni, D., Čukelj, N., Benković, M., Lušić, D., & Ćurić, D. (2012). Improvement of gluten-free bread quality using transglutaminase, various extruded flours and protein isolates. *Journal of Food and Nutrition Research*, *51*(4), 242-253.

Stadelman, W. J., & Cotterill, O. J. (Eds.). (2013). Egg science and technology (4th ed.). Taylor & Francis.

Stantiall, S. E., & Serventi, L. (2018). Nutritional and sensory challenges of gluten-free bakery products: a review. *International Journal of Food Sciences and Nutrition*, *69*(4), 427-436. https://doi.org/10.1080/09637486.2017.1378626

Steffen, W., Ko, F. C., Patel, J., Lyamichev, V., Albert, T., Benz, J., Rudolph, M. G., Bergmann, F., Streidl, T., Kratzsch, P., Boenitz-Dulat, M., Oelschlaegel, T., & SchraemL, M. (2017). Discovery of a microbial transglutaminase enabling highly site-specific labeling of proteins. *Journal of Biological Chemistry*, *292*(38), 15622-15635. https://doi.org/10.1074/jbc.M117.797811

Strixner, T., & Kulozik, U. (2011). Egg proteins. In G. O. Phillips, & P. A. Williams (Eds.). *Handbook of food proteins* (pp. 150-209). Elsevier.

Susanna, S., & Prabhasankar, P. (2015). Effect of different enzymes on immunogenicity of pasta. *Food and Agricultural Immunology*, *26*(2), 231-247. https://doi.org/10.1080/09540105.2014.893999

Tomicki, L., Rigo, A. A., Durigon, A., Gutkoski, L. C., Zeni, J., Valduga, E., Steffens, C., & Toniazzo, G. (2015). Elaboração e avaliação da qualidade de macarrão isento de glúten. *Ciência Rural*, *45*(7), 1311-1318. http://dx.doi.org/10.1590/0103-8478cr20140977

Wang, F., Huang, W., Kim, Y., Liu, R., & Tilley, M. (2011). Effects of transglutaminase on the rheological and noodle-making characteristics of oat dough containing vital wheat gluten or egg albumin. *Journal of Cereal Science*, *54*(1), 53-59. https://doi.org/10.1016/j.jcs.2011.02.010

Yao, M., Li, M., Dhital, S., Tian, Y., & Guo, B. (2020). Texture and digestion of noodles with varied gluten contents and cooking time: the view from protein matrix and inner structure. *Food Chemistry*, *315*, 126230. https://doi.org/10.1016/j.foodchem.2020.126230