



Comparative Evaluation of the Thickening Power of Starches from Diverse Flour Sources, in Bechamel and Velouté Sauces

Fabiana Mortimer Amaral ^{1*}
Julyetty Crystyne da Silva ¹

¹Gastronomy Department, Instituto Federal de Educação Ciência e Tecnologia de Santa Catarina,
Rua 14 de Julho, 150 - Coqueiros, Florianópolis, SC, CEP 88075-010; Brazil

Abstract

In this work the thickening power of starches from rice (FAR), coconut (FCO), white bean (FFB), chickpea (FGB), cassava (FMA), wheat (FTR), pinion (FPI), corn (AMI), arrowroot (ARA), potato (FBT) and sweet manioc (PDO), in the production of *Béchamel* and *Velouté* sauces was studied. From the studies of specific viscosity were drawn exponential graphs of viscosity versus concentration of *Roux* allowing to obtain relations of percentages between *Roux* produced with flour of wheat starche and other sources studied. The sensorial analysis of acceptability carried out on *Béchamel* and *Velouté* sauces produced with wheat, arrowroot, rice, potato and sweet manioc starches showed that potato starch and arrowroot are good substituents in the production of *Béchamel* sauce and rice starch is a good substitute in the production of *Roux Velouté* sauce.

Keywords

Béchamel sauce; *Velouté* sauce; Starch; *Roux*; Specific Viscosity; Sensory Analysis

Introduction

The main functions of a sauce in gastronomic productions are to introduce contrast or complementary flavors, to add moisture or juiciness in the preparation, to assist the visual interest and texture of the dish [1]. In gastronomy, the sauces can be divided into several groups, the main ones are the base sauces, also called mother sauces. In the 19th century Carême, one of the chefs responsible for creating French haute cuisine, described the mother sauces in four different types, *Bechamel*, *Velouté*, spanish and *allemande*. In the 20th century, Escoffier, chef and writer responsible for popularizing and renewing methods in French cuisine, included *hollandaise* and tomato sauce among the mother sauces and classified *allemande* sauce as derived from *Velouté* sauce [2,3]. A sauce consists of a liquid, a thickener and flavoring. *Bechamel* sauce is produced with milk as liquid, light *Roux* as thickener and flavorings such as onion, cloves, salt, bay leaf and nutmeg. The classic *Velouté* sauce is prepared with a light stock (chicken, veal, fish or vegetables) and light or yellow *Roux* [1].

Roux is a essential ingredient in some classic gastronomic preparations, such as sauces already mentioned. A predominant function is thicken of sauces, soups and stews, which is made possible by the presence of wheat flour, a source of starch, in its constitution.

Usually the *Roux* is made up of equal parts of flour and butter, this mixture is cooked and 4 types of *Roux* can be obtained according to the cooking time of the mixture, the light, yellow, brown and dark. Due to the caramelization and millard chemical reactions of starch that occur during cooking, the darker is the *Roux*, the less it will thicken [1,4,3]. In addition to the starch source, a wheat flour is also rich in protein, the main ones being gliadin and gluten, which constitutes, respectively, 33% and 16% of wheat flour proteins. The union of these two proteins forms a complex known as gluten. The presence of gluten in flours is of great importance for various areas of gastronomy, such as baking and pastry [1,5]. There are currently several pathologies related to the effect of gluten on the human body, they are treated as "gluten-related disorders", some are: non-celiac gluten sensitivity, dermatitis herpetiformis, gluten ataxia, wheat allergy and celiac disease. People who suffer from any of these syndromes, in general, should remove any source of gluten from their diet, such as wheat, rye, oats, barley, among others [6,7]. The current gastronomy plays an essential role in the development of gluten-free products to meet the increasing demand of people with gluten-related disorders.

Within this perspective, in order to maintain the sensory attractions of a sauce-based gastronomic production, which, in most cases, are derived from a mother sauce that has wheat flour as its thickening element, it is essential to look for substitutes for wheat flour present in the *Roux* by some starch-rich ingredient which does not contain gluten, such as rice flour, cornstarch or potato starch, but which allows for increased viscosity due to heating, thanks to starch functional characteristics.

Article Information

DOI: 10.31021/fnoa.20203119
Article Type: Research
Journal Type: Open Access
Volume: 3 **Issue:** 1
Manuscript ID: FNOA-3-119
Publisher: Boffin Access Limited

Received Date: 13 February 2020
Accepted Date: 28 February 2020
Published Date: 29 February 2020

*Corresponding author:

Fabiana Mortimer Amaral
Instituto Federal de Educação Ciência e
Tecnologia de Santa Catarina, Brazil
E-mail: fabiana@ifsc.edu.br

Citation: Amaral FM, da Silva JC. Comparative Evaluation of the Thickening Power of Starches from Diverse Flour Sources, in *Bechamel* and *Velouté* Sauces. Food Nutr OA. 2020Feb;3(1):119

Copyright: © 2020 Amaral FM, et al. This is an open-access article distributed under the terms of the Creative Commons Attribution 4.0 international License, which permits unrestricted use, distribution and reproduction in any medium, provided the original author and source are credited.

Molecular gastronomy is a science that aims primarily at understanding the basic physical chemical mechanisms that occur during the cooking process. Its main objectives are the scientific exploration of the artistic and social aspects of cooking; Addition of techniques to recipes aiming at greater precision in the reproduction and scientific exploration of culinary definitions, thus making, in particular, the chemical and physical phenomena involved in the processes present in the kitchen gain a scientific explanation [8-10]. One of the main parameters evaluated for the quality of a food is its texture, it is the response of the tactile senses to the physical stimuli that result from the contact between the food and the mouth. Molecular gastronomy has introduced the use of viscosity measurement technique in the kitchen. It can be defined as the internal resistance of a substance to flow when subjected to stress. This measure is important for gastronomy as it can be used for product development and control, from appearance to perception [8-10]. Flours are products obtained by grinding and sieving of various ingredients such as grain, seeds, roots, tubers and fruits. They usually contain polysaccharides such as starch, sugar, proteins, lipids and inorganic materials. The quantity of these components varies according to flour source [11,12].

Starch present in flour is the main source of calories in the human diet and the main reserve of polysaccharide in higher plants. It comes in the form of granules of varying size and shape. It is a heterogeneous polysaccharide composed essentially of two α -D-glucose polymers in varying proportions, amylose and amylopectin, and as minor components lipids and proteins. The ratio between amylose and amylopectin is dependent on the plant species and the degree of maturity of plants from the same species [13-15].

In cold, the starch structure remains unchanged and insoluble in water. However, when heated in the presence of water, this mixture undergoes a process known as gelatinization, this is an irreversible transformation of granular starch into a viscoelastic paste, where destruction of the semicrystalline granular structure of starch by disruption of the hydrogen bonds that held its integrity.

This destruction results in a homogeneous and amorphous polymeric matrix. This power of swelling, solubility and gelatinization vary by starch source and are mainly controlled by amylopectin (chain length, branch length and molecular mass), starch composition (amylose to amylopectin ratio) and granular architecture. (proportion of crystalline and amorphous regions) [15,16].

Both the gelatinization process, which occurs during heating, and the retrogradation that occurs when cooling starch solutions, play an important role in gastronomy, they are mainly related to the increase in the viscosity of solutions, as in sauces contains **Roux**. In gelatinization the increase in viscosity is related to granular swelling and in retrogradation with the formation of a partially swollen granular starch network. Still, with the cooling of the formed solution or gel, it tends to release water, a process known as synergistic, an extension of this process depends on the characteristics of the starch and is of great importance, mainly by changing the texture and showing the sauces formed with **Roux** [15,16]. In this context, the research aimed to evaluate the thickener power of various starch sources in mother sauces (**Bechamel** and **Velouté**), from the specific viscosity create percentage relationships between wheat flour and other starch sources and to sensorially analyze the products obtained.

Materials and Methods

Materials

Twelve types of starches from different flour sources were used in these study: Rice (FAR), Banana (FBA), Coconut (FCO), White Bean (FFB), Chickpeas (FGB), Cassava (FMA), Wheat (FTR), Corn (AMI), Arrowroot (ARA), Potato (FBT) and Sweet Cassava (PDO). All starches were purchased as a flour in the local markets. Pinion flour (FPI) was produced on our own in the Center of Gastronomy Studies (NEG-IFSC).

Preparation of **Bechamel** and **Velouté** Sauce

All the **Roux** was prepared using the same amount of starch as a flour and clarified butter. The flour concentration ranging from 0% to 10% in relation to the total liquid used [3]. For all sauces sample, the **Roux** was made by mixing the flour of different starches in the melted butter and cooked at 90°C for 30 seconds. For **Bechamel** sauce 100 ml of milk was added to butter/flour mixture, however for the **Velouté** sauce 100 ml of vegetable stock solution was added to the butter/flour mixture. All experiments were heated to 90 °C with stirring for 5 minutes.

The specific viscosity was measured for all sauces, in order to obtain a specific viscosity graph versus the percentage of **Roux** in the sauce samples. All samples were performed in triplicate.

For the sensory analysis of the sauces, the **Roux** concentrations used, were determined by the formula obtained in the relative specific viscosity graphs.

Specific viscosity measure

Viscosity analyzes were made from a Canon-Fenske viscometer. The Canon-Fenske Viscometer allows simple determination of the viscosity coefficient as long as its constant is known, however, when the constant is unknown, viscosity measurements are made by comparing the flow time of whose viscosity is to be determined and a liquid of known viscosity. At the same temperature and in the same device [17].

All analyzes were performed at a constant temperature of 70°C and in triplicate, calculated as mean and standard deviation.

The specific viscosity was calculated using equation 1, where pure milk or vegetable stock solution was considered as a solvent and the different sauces prepared as solutions [18].

$$\eta_{sp} = \frac{\eta_{sol}}{\eta_0} - 1 = \frac{t_{sol}}{t_0} - 1 \quad (1)$$

Where: η_{sp} = specific viscosity, η_{sol} = solution viscosity, t_{sol} = solution flow rate, η_0 = solvent viscosity and t_0 = solvent flow rate.

Sensory acceptability analysis

The **Bechamel** and **Velouté** sauces sensory acceptability was carried out with sauces made with flour from arrowroot, wheat (reference), rice, potato and sweet cassava. A reference hedonic scale was used. The scale is structured in 9 points, from -4 to +4, where -4 corresponds to liked it a lot less than the reference and +4 corresponds to liked it a lot more than the reference [19,20].

Participated in the test 39 untrained consumers (18 men and 21 women) aged 18 to 55 years. Prior to testing, consumers were warned of possible allergic reactions due to ingestion of the product. The test was performed under controlled conditions. Each taster received 20 mL of each sample at room temperature encoded with random three-digit numbers and a reference sample. The reference sample of **Bechamel** and **Velouté** sauce was made from wheat flour and was also added as a coded sample for comparing assigned values.

Acceptance test results were analyzed by analysis of variance (ANOVA) with significance of 5% and Tukey test for comparison between means.

Results and Discussion

Specific viscosity

Bechamel Sauce: In order to obtain a relationship between the amount of **Roux** and the specific viscosity of the sauces, **Bechamel** sauce samples were prepared with starches from diverse flour source, in different concentrations. **Figure 1** presents the results of specific viscosity versus **Roux** concentration with the flours from: wheat, chickpeas, white beans, coconut, banana and pinion.

The **Figure 1** shows that the relationship between *Bechamel* sauce specific viscosity versus *Roux* concentration is an increasing exponential curve, where from the inflection point there is a large increase in viscosity as the *Roux* concentration increases. That is, they are growing very fast.

It can be seen in the graph that in the sauces prepared with coconut (FCO) and pinion (FPI) there was no significant variation in relative viscosity as a function of *Roux* concentration, suggesting little thickening effect of these two ingredients when applied as wheat flour substitutes in the production of *Bechamel*.

This fact can be explained because coconut flour is made from crushed coconut that does not have a significant starch content.

In the case of pinion flour, even though it is a starch-rich seed [21], the little thickening effect may be associated with the method of obtaining the flour, produced from roasted and crushed pinion, whose process has possibly degraded starch preventing thickening. One solution would be to extract pinion starch or flour production without the heating processes, but as these products are not commercially available, the use of pinion flour, as well as coconut, was considered unfeasible to thicken sauces in these study.

Banana flour (FBA), in general, is produced with green fruit, presenting a high content of resistant starch, dietary fiber and potassium, as well as antioxidant activity and ability to reduce glycemic index, so it has been widely applied to the production of bread, cookies and pasta [22]. When used as a thickener in *Bechamel* sauce it can be observed that banana flour has this capacity and has a weaker thickener power than wheat flour. However, it was noted that in the production of the sauce, banana flour changes its color to a much darker shade than desired. Thus, it was also considered unsuitable for the production of *Bechamel* sauce and *Velouté*, which have as sensory attributes the color white and light beige respectively. Being able to be applied for the preparation of a Spanish base sauce or for other darker preparations where color has no influence on the final product.

Like banana flour, white bean (FFB) and chickpea (FGB) flours are also produced with raw ingredients. Both vegetables are good sources of protein, fiber, minerals, vitamins and starch [23,24]. In the production of *Bechamel* sauce with white bean and chickpea flour, a lower thickener power was found than wheat flour. However the sauces produced showed strong residual taste of the ingredients used. Thus, white bean and chickpea flours were also considered unsuitable for the production of *Bechamel* and *Velouté* sauce, as they considerably alter the characteristic taste of these base sauces. However, both can be applied as a thickener in preparations with a more intense flavor, which is desired for the characteristic taste of vegetables or even longer cooking time, aiming to reduce the residual taste of the flours.

Figure 2 presents the relationship between the specific viscosity and *Roux* percentage in *Bechamel* sauce prepared using different starch sources obtained by the use of flour from corn, arrowroot, rice, cassava, potato and sweet cassava.

Corn starch (AMA), according to tests, is a great thickener for milk-based sauces, with an exponential growth of between 5 and 6%, and from 6% on the solution became too thick to measure its flow rate on the Canon-Fenske viscometer. However, it was observed that cooling the solution at room temperature caused a thick film to form on the surface of the solution, which was considered detrimental to the appearance of the sauce when served in gastronomic preparations.

Another noteworthy factor is the fact that it is difficult to control the process of thickening of sauces, since as observed in the graph, small variations in *Roux* concentration cause large variations in viscosity, making it difficult to apply. For this reason the corn starch sauce was also excluded from further sensory testing.

Arrowroot (ARA) [25] is a plant found in rainforests. Economically, arrowroot rhizome has been used for starch extraction, which has

excellent digestibility, gelling capacity and special physicochemical characteristics such as high amylose content, [25].

When preparing the *Bechamel* sauce with arrowroot can observe a high thickening power. The maximum concentration possible to be measured by the method used in the study was 5% *Roux*, due to the exponential growth of the curve at 4% concentration. The sauce did not present any marked alteration of its sensory attributes, being chosen for the subsequent sensorial tests.

Flour from cassava (FMA) and potato (FBT) have a thickening power very similar to that of araruta. They presented the beginning of exponential growth between 3 and 4% and it was not possible to measure the flow rate from 5%. However, cassava flour forms lumps in the sauce, compromising its sensorially, being eliminated from further tests. In the potato starch sauce it was not possible to observe macroscopic changes, being this product selected for the sensory analysis test.

Among the thickeners tested, flour from rice (FAR) was the one that presented the closest curve to wheat flour, with the lowest exponential growth of viscosity. It was not possible to observe macroscopic changes in the sauce compared to wheat flour; however, there was a poor residual taste of rice flour, which did not seem to have a great sensory impact, being applied sensory analysis tests in this sauce.

Sweet cassava flour presented the highest thickening power, reaching a specific viscosity of ~ 30 when 4% *Roux* was used. The exponential increase in viscosity was observed between 2 and 3%, with its maximum measurable at a concentration of 4% *Roux*. Although sweet starch also came from cassava (cassava starch), it was not possible to observe clumps or any macroscopic changes, and it was also chosen for further testing.

Still, with the graphs obtained from each flour it was possible to calculate the coefficient of determination (r^2) for all curves. With the exception of coconut and pinion flour all the graphs presented an r^2 higher than 0.95. The r^2 is a statistical measure that indicates how much the model can explain the observed values. These values of r^2 show that the exponential equation model $y=a.e^{(b.x)}$ can explain more than 95% of the results obtained.

In addition, the formula $y=a.e^{(b.x)}$ made it possible to calculate the ratio of equivalent percentages for each flour to wheat flour.

In the exponential equation obtained for each curve were used the specific viscosity values (y) obtained in the production of *Bechamel* sauce with wheat flour, where a and b are the coefficients greater than zero and x is the percentage of *Roux* to be calculated for each type of flour. **Table 1** presents the results obtained for x for the different types of flour used in the preparation of *Roux*.

The theoretical relationship allows the elaboration of a *Roux* with different types of starches from different source of flour, obtaining viscosities similar to the gastronomic standard of *Bechamel*, which is made with wheat flour. It should be noted in **Table 1** that the flour concentration in each *Roux* varies depending on the starch source used to obtain a sauce with the same specific viscosity. For example, a *Roux* sauce made with 10% of wheat flour has a viscosity equivalent to a *Roux* sauce made with 7% of corn flour.

The preliminary analysis allowed to observe that *Roux* made with flour from arrowroot, rice, wheat, potato and sweet cassava can be a good ingredient for *Bechamel* sauce production. The sauce made with these ingredient were subjected to acceptability sensory analysis, to verify the real possibilities of *Bechamel* sauce production when compared with the sauce production with a *Roux* made with wheat flour, which is the classical ingredient in *Bechamel* sauce.

Velouté sauce: As the starches from arrowroot, rice, potato, and sweet cassava seem to be a good alternative for the production of *Bechamel* sauce, the flours made with these source of starches were tested for the *Velouté* sauce production and the results for the specific viscosity in relation to the percentage of *Roux* are provided in **Figure 3**.

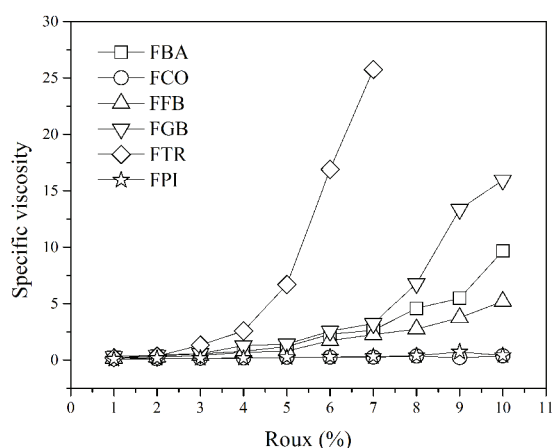


Figure 1: Specific viscosity variation as a function of **Roux** concentration in **Bechamel** sauce.

*FBA – Banana, FCO – Coconut, FFB – White Bean, FGB – Chickpeas, FTR – Wheat, FPI – Pinion

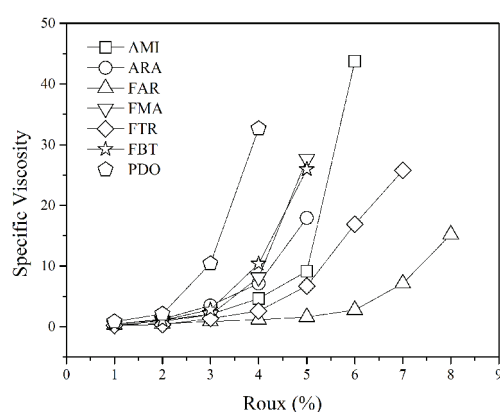


Figure 2: Specific viscosity variation as a function of **Roux** concentration in **Bechamel** sauce.

*AMI – Corn, ARA – Arrowroot, FAR – Rice, FMA – Cassava, FTR – Wheat, FBT – Potato, PDO – Sweet Cassava

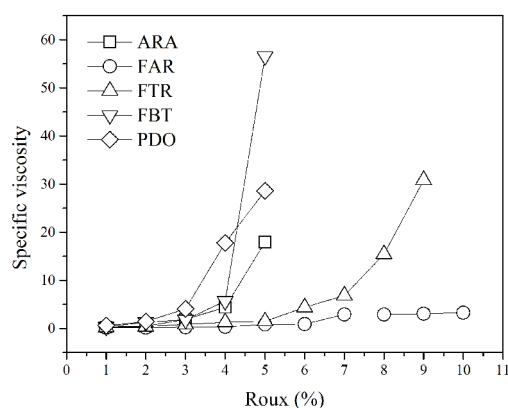


Figure 3: Specific viscosity variation as a function of **Roux** concentration in **Velouté** sauce.

*ARA – Arrowroot, FAR – Ric, FTR – Wheat, FBT – Potato, PDO – Sweet Cassava

As the analyzes made for **Bechamel**sauce, the relationship between specific viscosity and **Roux** concentration in all samples tested were exponential. However, there is a different behavioral pattern to **Bechamel** sauce, these changes may be related to the difference in macronutrient composition, suggesting different interactions between starch and milk from that observed for starch and vegetable stock solution.

Arrowroot and potato starches showed exponential growth between 4 and 5%, and potato starch was the thickener with the highest viscosity, ~ 50 with 5% **Roux**. The two flours showed no change in sensory attributes.

Rice flour presented the lowest relationship between specific viscosity and **Roux** concentration among **Velouté** sauces tested, this is expected since all other thickeners, except wheat flour, consist of pure starches. It is also possible to observe the rice flour graph has two growth points, one between 4 and 5% and another between 6 and 7% and although it had the lowest growth was the most similar with wheat flour.

Sweet cassava starch presented the fastest exponential growth, between 3 and 4% and as potato starch and arrowroot it was only possible to measure the viscosity of the sauce by the chosen method until the concentration of 5% **Roux**. In addition, sweet cassava starch did not show any macroscopic or sensory alterations.

Among the graphs, rice flour presented the lowest $r^2(0.81)$, all other flours tested presented $r^2 > 0.95$, showing, as in **Bechamel** sauce, that the exponential equation model $y = a.e^{(b.x)}$ can explain more than 95% of the results obtained.

The equivalent percentages for each flour in relation to wheat flour were then calculated. This was done from the exponential equation obtained for each curve and the specific viscosity values obtained in the production of **Velouté** sauce with wheat flour as reference. **Table 2** presents the results obtained.

As expected, the relationship shows that a lower concentration of arrowroot, potato starch, and sweet cassava starch **Roux** is required to achieve a viscosity equivalent to that of wheat flour **Roux** and a higher concentration of rice flour **Roux**. to the same equivalence.

Aiming to prove similarity with the classic **Velouté** sauce, for possible substitutions in gastronomic productions, a sensorial analysis of acceptability of the sauces produced was performed.

Sensory acceptability analysis

Bechamel Sauce: The **Bechamel** sauces were prepared using the relationship between the percentages of **Roux** produced with wheat flour and other starches sources obtained in the specific viscosity tests. **Table 3** shows the percentages of **Roux** used in the production of **Bechamel** and **Velouté** sauces for acceptability analysis.

Analysis of variance (ANOVA) showed that the mean values obtained in the study of **Bechamel** sauce produced with different flours differed from each other at 5% ($p < 0.05$) level of significance (calculated $F = 5.89$ and critical $F = 2.42$), the Tukey's test was then performed to verify the difference between each sample in relation to the reference. The results obtained are presented in **Table 4**.

The acceptability test showed that, among the coded samples, the most accepted sauce was the reference itself (0.15), showing the evaluators were able to identify the difference between the samples and conferring a certain degree of quality of the judges.

Among the sauces prepared with different starch sources, excluding the reference, the most accepted was the one produced with potato starch (-0.64), followed by the one produced with arrowroot (-0.67), sweet cassava starch (-1.21).) and rice flour (-1.82). The sweet cassava starch presented different texture from the standard and the rice flour different texture and residual taste.

When analyzing the p values it can be observed that the sauces produced with potato and arrowroot starch did not differ from the

reference of level 5% of significance, proving that besides being more accepted these flours were also the most similar to the reference. While in rice flour and sweet cassava starch it was possible to notice a difference in a level of 5% of significance.

Indicating a high degree of possibility of substitution of wheat flour by potato starch or arrowroot in the production of *Bechamel* sauces. Always remembering the need to make the concentration adaptations to the desired viscosity.

Velouté Sauce: For *Velouté* sauce, the concentration of each *Roux* produced for analysis is listed in **Table 3**. An analysis of variance (ANOVA) showed that the media values detected in the sauces used by the different flours differ between the 5% ($p < 0.05$) significance levels (calculated $F = 27.63$ and critical $F = 2, 42$), the Tukey's test was then performed to verify the difference between each sample in relation to the reference. The results presented are presented in **Table 4**.

The acceptability test showed that, among the coded samples,

the most accepted sauce when evaluated in relation to the reference was rice flour (0.41), which shows the possibility of obtaining a more pleasant sauce than the classic *Velouté*. replacing wheat flour with rice flour.

The second most accepted was the reference (-0.22), followed by the sauce produced with potato starch (-1.62), arrowroot (-1.89) and sweet cassava starch (-2.70), with the last presented texture different from the pattern.

By analyzing the p values it can be observed that only the sauce produced with rice flour does not differ from the reference level of 5% of significance, showing that besides accepting rice flour more closely resembles wheat flour.

Analysis results show that changing wheat flour in water-based sauces such as *Velouté* presents a greater difficulty for the public to accept compared to milk-based sauces such as *Bechamel*. However rice flour is a substitute that can be applied efficiently.

Starch Source	Roux amount (%) *									
Wheat flour	1,0	2,0	3,0	4,0	5,0	6,0	7,0	8,0	9,0	10,0
Corn starch	0,0	1,4	2,6	4,0	4,7	5,3	5,6	6,1	6,6	7,0
Arrowroot	0,2	0,7	2,0	2,7	3,6	4,5	5,0	5,6	6,3	6,9
Rice flour	2,4	3,1	4,8	5,7	6,9	8,1	8,7	9,6	10,4	11,2
Banana flour	0,6	1,9	5,2	6,8	9,2	11,5	12,5	14,2	15,8	17,4
White bean flour	0,0	1,6	5,7	7,8	10,8	13,7	15,0	17,1	19,1	21,1
Chickpea flour	0,2	1,3	4,3	5,8	7,9	10	10,9	12,4	13,9	15,3
Cassava flour	0,9	1,4	2,7	3,4	4,3	5,3	5,7	6,3	7,0	7,6
Potato starch	0,2	0,7	2,0	2,7	3,6	4,6	5,0	5,7	6,3	7,0
Sweet cassava starch	0,0	0,2	1,3	1,9	2,7	3,4	3,8	4,4	4,9	5,4

Table 1: Relationship between % of wheat flour and other flour in *Bechamel* sauce *Roux* production.

* % *Roux* value equals 50% flour.

Starch Source	Roux amount (%) *									
Wheat flour	1,0	2,0	3,0	4,0	5,0	6,0	7,0	8,0	9,0	10,0
Arrowroot	1,2	1,8	2,7	3,1	3,2	4,3	4,8	5,6	6,3	7,0
Rice flour	3,2	3,9	4,8	5,1	5,2	6,4	6,8	7,6	8,3	9,0
Potato starch	1,5	2,2	3,1	3,4	3,6	4,7	5,1	5,9	6,6	7,3
Sweet cassava starch	0,0	0,0	0,5	0,7	0,9	2,0	2,4	3,2	3,9	4,6

Table 2: Relationship between % of *Roux* in *Velouté* sauce production

* % *Roux* value are equals to 50% flour from different starch source and 50% of butter

Starch Source	% of <i>Roux</i> <i>Bechamel</i>	% of <i>Roux</i> <i>Velouté</i>
Arrowroot	6,9	7,0
Rice flour	11,2	9,0
Wheat flour	10,0	10,0
Potato starch	7,0	7,3
Sweet cassava starch	5,4	4,6

Table 3: Ratio of *Roux* with different starch sources to 1 liter of *Bechamel* and *Velouté* sauces.

STARCH SOURCE	<i>Bechamel</i>		<i>Velouté</i>	
	Mean values	p	Mean values	p
Arrowroot	-0,67 *	0,310	-1,89	$2,07 \times 10^{-5}$
Rice flour	-1,82	$6,899 \times 10^{-5}$	0,41 *	0,37
Wheat flour	0,15	-	-0,22	-
Potato starch	-0,64 *	0,343	-1,62	$5,67 \times 10^{-4}$
Sweet cassava starch	-1,21	0,015	-2,70	0

Table 4: Values of the evaluation means and p for different flours in relation to wheat flour in *Bechamel* and *Velouté* sauce production.

* samples that do not differ at 5% significance level of wheat flour.

** p – the p -value is defined as the probability of observe a value of the statistic test greater or same as found ($p < 0,05$ for samples that show no differences between them)

Conclusion

The construction of specific viscosity versus **Roux** concentration graphs using different starch sources in the production of **Bechamel** and **Velouté** sauces proved to be effective, obtaining an r^2 greater than 0.95, for an exponential equation $y = a.e^{(b \cdot x)}$, in almost all samples.

The equation made it possible to obtain percentages and equivalence between flour and wheat flour for the sauces studied, indicating that the use of scientific knowledge of the exact sciences (chemistry, physics and mathematics) help in the processes of culinary production allowing greater efficiency and effectiveness in product development to meet the current demands of society.

The acceptability sensory analysis was performed with the arrowroot, rice, potato starch and sweet cassava starch, which did not present significant macroscopic alteration during the preparation of the sauces. The analysis showed that for **Bechamel** sauce the best wheat flour substitutes in **Roux** were potato starch and arrow root, having acceptability of -0.64 and -0.67, respectively. Moreover, the two samples were not different from the reference when applying the Tukey's test.

The **Velouté** sauce acceptability test showed that rice flour is a great substitute for **Roux** wheat flour having an acceptability of 0.41, higher than the acceptability of the reference, and not differing from it, according to Tukey's test.

The study showed that it is possible to obtain base sauces with the same characteristics as classic base sauces by replacing wheat flour with other thickeners, provided that a graph is used to obtain the formula to calculate the **Roux** concentration for the desired viscosity. This is of great interest as these sauces can be used in preparations that now cover an ever-growing market of people with gluten-related disorders or other restrictions on wheat intake.

As already mentioned some thickeners may change the color, such as banana flour, or taste, such as chickpea flour, however depending on the gastronomic preparation may be applied.

The study shows the importance of interdisciplinarity in the area of gastronomy, as well as demonstrating that empirical procedures can lead to error in culinary processes. For if the replacement of the studied flours were performed with the same concentration of **Roux** based on wheat flour, it would certainly be considered inadequate to the substitution process. Noting that basic scientific studies, such as viscosity measurement, lead to results of great culinary impact [26,27].

Acknowledgments

To Instituto Federal de Educação Ciência e Tecnologia Santa Catarina and Fundação de Amparo à Pesquisa e Inovação do Estado de Santa Catarina (FAPESC) for the financial support.

References

1. Instituto americano de culinária. Chef profissional, 4th ed. Senac São Paulo.
2. Burton J. The five french mother sauces: the mother of all resources. 2011 May.
3. Escoffier A. Le guide culinaire: aide-mémoire de cuisine pratique. Flammarion, Paris. 2009.
4. Alvarez-Ramirez, J, Vernon-Carter E.J, Carrillo-Navas H, Meraz M. Effects of cooking temperature and time on the color, morphology, crystallinity, thermal properties, starch-lipid complexes formation and rheological properties of roux. LWT. 2018 May;91:203-212.
5. Finnie S. Wheat flour, 2nd edition. ed. AACC International, St. Paul, MN. 2016 Sep.
6. Di Cairano M, Galgano, F, Tolve R, Caruso MC, Condelli N. Focus on gluten free biscuits: ingredients and issues. Trends Food Sci. Technol. 2018 Nov;81:203-212.
7. Hera E de la, Martinez M, Gómez M. Influence of flour particle size on quality of gluten-free rice bread. LWT - Food Sci. Technol. 2013 Nov;54:199-206.
8. Amaral FM, Southgate A, Nogueira Novaes. Aplicação de hidrocolóides na elaboração de panna cotta. Arq Bras Aliment. 2017 Oct;3(1):2-10.
9. Bourne MC. Food texture and viscosity: concept and measurement. Food science and technology. 2002. Academic Press, New York.
10. McKenna B.M, Lyng J.G. Principles of food viscosity analysis, in: Instrumental Assessment of Food Sensory Quality. 2013;129-162.
11. Anvisa. Resolução - CNNPA nº 12, de 1978.
12. Pancha-armon S, Uttapap D. Rice starch vs. rice flour: Differences in their properties when modified by heat-moisture treatment. Carbohydr. Polym. 2013 Jan;91(1):85-91.
13. Halley PJ, Avérous L. Starch polymers: from genetic engineering to green applications, First edition. ed. Elsevier, Amsterdam; Boston. 2014 Apr.
14. Klaohanpong N, Puttanlek C, Rungsardthong V, Pancha-armon S, Uttapap D. Physicochemical and structural properties of debranched waxy rice, waxy corn and waxy potato starches. Food Hydrocoll. 2015 Mar;45:218-226.
15. Luchese CL, Spada JC, Tessaro IC. Starch content affects physicochemical properties of corn and cassava starch-based films. Ind. Crops Prod. 2017 Dec;109:619-626.
16. Denardin CC, Silva LP da. Estrutura dos grânulos de amido e sua relação com propriedades físico-químicas. Ciênc. 2009 Jun;39(1):945-954.
17. Reolon TN. Determinação da viscosidade do biopolímero produzido pelo fungo nativo Botryosphaeria rhodina MMPI. Universidade tecnológica do Paraná, Pato Branco - PR. 2011.
18. Rocha TS, Demiate IM, Franco Célia M Landi. Características estruturais e físico-químicas de amidos de mandioca-salsa (Arracacia xanthorrhiza). Ciênc. E Tecnol. Aliment. 2008;28(3):620-628.
19. Bergara-Almeida S, Aparecida M, da Silva AP. Hedonic scale with reference: performance in obtaining predictive models. Food Qual. Prefer. 2002 Jan;13(1):57-64.
20. Campuzano A, Rosell CM, Cornejo F. Physicochemical and nutritional characteristics of banana flour during ripening. Food Chem. 2018 Aug;256:11-17.
21. Henríquez C, Escobar B, Figuerola F, Chiffelle I, Speisky H, Estévez A.M. Characterization of piñon seed (Araucaria araucana (Mol) K. Koch) and the isolated starch from the seed. Food Chem. 2008 Mar;107(2):592-601.
22. Campuzano A, Rosell CM, Cornejo F. Physicochemical and nutritional characteristics of banana flour during ripening. Food Chem. 2018 Aug;256:11-17.
23. Kaur M, Singh N. Studies on functional, thermal and pasting properties of flours from different chickpea (Cicer arietinum L.) cultivars. Food Chem. 2005 Jul;91(3):403-411.
24. Siddiq M, Ravi R, Harte JB, Dolan KD. Physical and functional characteristics of selected dry bean (Phaseolus vulgaris L.) flours. LWT - Food Sci. Technol. 2010 Mar;43(2):232-237.
25. Nogueira GF, Fakhouri FM, de Oliveira RA. Extraction and characterization of arrowroot (Maranta arundinacea L.) starch and its application in edible films. Carbohydr. Polym. 2018 Apr;186:64-72.
26. Sarioğlu M. New Orientations in Gastronomy Education: Molecular Gastronomy. Procedia - Soc. Behav. Sci. 2014 Aug;143:320-324.
27. Siddiq M, Ravi R, Harte JB, Dolan KD. Physical and functional characteristics of selected dry bean (Phaseolus vulgaris L.) flours. LWT - Food Sci. Technol. 2010 Mar;43(2):232-237.