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FOOD TECHNOLOGY

Optimization of rheological properties of bread dough with substitution of wheat flour for whole grain flours from germinated Andean pseudocereals

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ABSTRACT: This study optimized the rheological parameters of doughs with partial substitution of wheat flour for blends of whole grain flours from germinated Andean pseudocereals such as quinoa (GQF), kiwicha (GKF), and cañihua (GCF) for bread production. The optimization was conducted through a Simplex-Centroid Mixture Design (SCMD) and Desirability Function (DF). Experiments were formulated using 80 to 90% wheat flour and 5 to 15% germinated pseudocereal blends. The rheological evaluation included farinograph, extensograph, and amylography analyses. Results showed that whole flour from germinated pseudocereals increases the water absorption, consistency, and extensibility of the doughs; and decreases its development time, stability, resistance to extensibility, temperature, and peak viscosity. The GQF-GKF blend developed more extensible and stable doughs, while GCF increased its consistency and was recommended for bread production. The data allowed us to obtain response surface models and the optimal substitution percentages to produce bread using GQF-GKF, GQF-GCF, and GKF-GCF blends.
Key words: sprouted flours, enzymatic activity, Andean grains, dough rheology, whole grain flour.

Otimização das propriedades reológicas das massas de pães com substituição de farinha de trigo por farinhas de grão inteiro de pseudocereais Andinos germinados

RESUMO: Este estudo teve como objetivo otimizar os parâmetros reológicos de massas com substituição parcial de farinha de trigo por blends de farinhas de grãos inteiros germinados de pseudocereais andinos como quinoa (GQF), kiwicha (GKF) e cañihua (GCF) para a produção de pães. A otimização foi realizada através de um Planejamento de Mistura Simplex-Centróide (SCMD) e a Função de Desejabilidade (DF). Os experimentos foram formulados com 80 a 90% da farinha de trigo e 5 a 15% de farinha de pseudocereais germinados. A avaliação reológica incluiu as análises de farinografia, extensografia e amilografia. Os resultados mostraram que a inclusão de farinhas germinadas aumenta a absorção de água, a consistência e a extensibilidade das massas; e diminui seu tempo de desenvolvimento, estabilidade, resistência à extensibilidade, temperatura de gelatinização e viscosidade pico. O blend GQF-GKF desenvolveu massas mais extensíveis e estáveis, enquanto a GCF aumentou sua consistência, por tanto foi recomendada a produção de pães. Os dados nos permitiram obter modelos de superfície de resposta assim como as porcentagens de substituição ótimas para produzir pães usando os blends de GQF-GKF, GQF-GCF e GKF-GCF.
Palavras-chave: farinhas germinadas, atividade enzimática, grãos andinos, reologia de massa, farinha de grão inteiro.

INTRODUCTION

Malnutrition is a problem that affects more than 2.5 billion people worldwide (FAO, 2021). For more than three decades in Peru, the population has been fighting against malnutrition, especially in rural areas. According to the latest report from the Institute of Statistics of Peru-INEI (2021), in 2020, 12.1 % of Peruvian children under five years old suffered from chronic malnutrition. In rural areas, this percentage was 2-fold higher (24.7 %). This problem is mainly due to the low nutritional quality of the food market within the country. For example, bakery products for wide consumption, such as bread and cookies, are formulated using mainly refined wheat flour, which helps meet technological standards (GOESAERT et al., 2005) but has low-quality proteins (CATO, 2020; KUMAR et al., 2011). Therefore, the industrial development of new products from local crops with high nutrients, such as essential amino acids, bioactive compounds, and dietary fibers, is necessary to improve the nutritional quality of the food products offered to the population.

Within the Peruvian crops diversity, Andean pseudocereals have earned the title of

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“Superfoods” since they are rich in essential amino acids such as lysine, isoleucine and tryptophan (REPO-CARRASCO, 2011), minerals, and dietary fibers (MALIK & SINGH, 2022; PIRZADAH & MALIK, 2020; THAKUR et al., 2021). Quinoa, kiwicha (or amaranth), and cañihua are the most produced pseudocereals in the country, whose crops sustain more than 120 thousand families (MIDAGRI, 2019). Some studies have used Andean pseudocereals raw flours to produce bread (BALLESTER-SÁNCHEZ et al., 2019; PASCUAL CHAGMAN & ZAPATA HUAMÁN, 2010; ROSELL et al., 2009; WANG et al., 2021) and cookies (COILA, 2019; SAZESH & GOLI, 2020) obtaining satisfactory results in improving the nutritional and sensory profile of the products.

The growing interest in functional and healthy products has promoted germination to improve the nutritional profile, biodisponibility, and bioaccessibility of the components of grains (BENINCASA et al., 2019; GAN et al., 2019; IKRAM et al., 2021). Germination is a controlled bioprocess of allowing grains to sprout. As a result, amylases, proteases, and other enzymes are mobilized, modifying the components and structure of the grain. Due to their high biological and enzymatic activity, sprouted flours can significantly impact baked goods’ dough rheology and technological properties. GUARDIANELLI et al. (2019), MARTI et al. (2018), MONTEMURRO et al. (2019), and PEÑARANDA et al. (2021) observed that using germinated cereal flour in partial substitution (up to 20 %) of wheat flour reduces water absorption, development time and fermentation time of bread doughs, generating softer products with greater volume. Regarding pseudocereals, PAUCAR-MENACHO et al. (2017, 2018) and LUNA (2015) have already determined the optimal germination time and temperature to maximize the content of bioactive compounds and the antioxidant capacity of quinoa, kiwicha, and cañihua grains. However, no studies have evaluated the impact of the incorporation of whole grain flours from germinated Andean pseudocereals on the rheological properties of doughs.

The dough rheology of bakery products is a set of functional properties that depend on the interaction between the proteins, such as gluten, and the starch of the wheat flour within the food matrix (CAMPBELL & MARTIN, 2012). Knowledge of the impact of incorporating new ingredients on the rheological properties of dough is essential to determine the ideal proportions in which they can be used to make bakery products such as bread, pasta, cakes, and cookies.

In this sense, this study evaluated the impact of the partial substitution of wheat flour by blends of the three main Andean pseudocereals: quinoa, kiwicha, and cañihua, previously germinated, on the rheological properties of the doughs. Using a Simplex-Centroid Mixture Design (SCMD) and Desirability Function (DF), the optimal formulations that allow better dough development for bread production were obtained. This study complements a recent publication by our research group (PAUCAR-MENACHO et al., 2022), where the effect of flours from germinated Andean pseudocereal on the nutritional and bioactive properties of bread was evaluated. Both technological and nutritional results are necessary for developing a new product that achieves good rheological behavior that allows its scalability and provides a better nutrient profile.

MATERIALS AND METHODS

Production of whole grain flours from germinated pseudocereals

They were produced using quinoa (*Pasakalla* variety) and kiwicha (*Centenary* variety) grains, acquired from the Agroindustrial Development Institute of the Universidad Nacional Agraria de la Molina- UNALM (Lima, Peru), and cañihua grains (*Ilpa* variety) sent from the INIA Agricultural Experimental Station (Puno, Peru).

Once received, the seeds were washed and disinfected in a 0.01 % sodium hypochlorite solution for 30 min. The soaking and germination parameters of quinoa, kiwicha, and cañihua were established based on the studies of PAUCAR-MENACHO et al. (2017, 2018) and LUNA (2015), respectively. During soaking, the seeds were immersed in distilled water (1:5 ratio) at room temperature (23 °C) for 6 h (quinoa and kiwicha), and 7 h (cañihua). Then, the seeds were moistened with distilled water and placed in the germination chamber (90 % relative humidity) at 20 °C/48 h (quinoa), 26 °C/63 h (kiwicha), and 24 °C/42 h (cañihua). At the end of the process, the grains were dried in an oven with forced air circulation at 40 °C for 30 h, and then ground using a grinding module model MDNT-60XL (Torrh, Jarcon del Peru S.R.L., Junín, Peru) and passed through a sieve of 0.20 mm pore. Finally, the whole grain flours of quinoa (GQF), kiwicha (GKF), and cañihua (GCF) were packed, vacuum-sealed, and stored in refrigeration (4 °C) until their subsequent application.

Experimental design

The substitution of wheat flour for germinated flour blends of Andean pseudocereals: quinoa-kiwicha (GQF-GKF), quinoa-cañihua (GQF-GCF), and kiwicha-cañihua (GKF-GCF), was carried out using an SCMD with 14 experimental treatments for each blend, plus a pure wheat flour experiment as a control. This type of mixture experiment was chosen because the response surfaces generated help estimate the properties of a multi-component system from a limited number of observations and preselected combinations of components to optimize formulations. The components of the doughs were: wheat flour from 80-90 % and pseudocereal blends from 5 to 15 % (each one). Table 1 shows the values of the experiment matrix of the mixtures made.

Rheological analysis of doughs

It was performed according to the official method of the American Association of Cereal Chemists International (AACCI) with modifications, using farinograph (Brabender, Farinograph-AT 810161, Germany) and extensograph (Brabender, Extensograph-E 860723, Germany). Firstly, our research group published an article using a mixture of wheat flour with germinated pseudocereals flours in breads (PAUCHAR-MENACHO et al., 2022). In the bread-making process, the amount of water was kept constant. Thus, in the present article, we evaluated the behavior of the dough consistency using the same amount of water for a better understanding of the effect of the flour mixture on the dough's rheology. The weight of the flour/flour blend (300g, previously adjusted to 14% moisture) and the amount of water (168 g) were kept constant for all the experiments, to observe the changes generated in adjusted water absorption (WA), development time (DT), stability (S) and consistency of doughs (C), in farinographic units (FU). The extensography (method 54-10.01) analysis determined the resistance to extension of the dough (RE) in Brabender Units (BU) and its extensibility (E) in mm. Since, according to the farinographic results, all the experiments were in the soft flour group, the salt concentration used was 2% for all the trials. The measurements were made at 30, 60, and 90 minutes, for the report the data from minute 90 were considered.

The amylographic analysis of blends was carried out following the instructions of the equipment manufacturer (Brabender, Amylograph-E, Germany), which is based on the AACCI (2010) method 22.10.01, and ISO 7973. The analysis determined the gelatinization temperature (GT) and the peak viscosity (PV) in Amylographic Units (AU).

Table 1 - Matrix of experiments of the germinated flour blends of Andean pseudocereals as a substitute for wheat flour according to Simplex-Centroid Mixture Design (SCMD).

Experiments	-------Quinoa-Kiwicha blend------			-------Quinoa-Cañihua blend------			--------Kiwicha-Cañihua blend------		
	GQF (%)	GKF (%)	WF (%)	GQF (%)	GCF (%)	WF (%)	GKF (%)	GCF (%)	WF (%)
E1	8.33	8.33	83.33	8.33	8.33	83.33	8.33	8.33	83.33
E2	15.00	5.00	80.00	15.00	5.00	80.00	15.00	5.00	80.00
E3	10.00	10.00	80.00	10.00	10.00	80.00	10.00	10.00	80.00
E4	5.00	15.00	80.00	5.00	15.00	80.00	5.00	15.00	80.00
E5	5.00	15.00	80.00	5.00	15.00	80.00	5.00	15.00	80.00
E6	5.00	10.00	85.00	5.00	10.00	85.00	5.00	10.00	85.00
E7	6.67	11.67	81.67	6.67	11.67	81.67	6.67	11.67	81.67
E8	5.00	5.00	90.00	5.00	5.00	90.00	5.00	5.00	90.00
E9	15.00	5.00	80.00	15.00	5.00	80.00	15.00	5.00	80.00
E10	10.00	5.00	85.00	10.00	5.00	85.00	10.00	5.00	85.00
E11	6.67	6.67	86.67	6.67	6.67	86.67	6.67	6.67	86.67
E12	5.00	10.00	85.00	5.00	10.00	85.00	5.00	10.00	85.00
E13	11.67	6.67	81.67	11.67	6.67	81.67	11.67	6.67	81.67
E14	5.00	5.00	90.00	5.00	5.00	90.00	5.00	5.00	90.00
Control	0	0	100	0	0	100	0	0	100

[1]Germinated Quinoa Flour.
[2]Germinated Kiwicha Flour.
[3]Germinated Cañihua Flour.
[4]Wheat Flour.

Statistical analysis

The multiple regression statistical analysis was carried out with the Statistica 6.0 program. Regression models with linear, quadratic, special cubic, and cubic terms were evaluated by analysis of variance (ANOVA). The significant terms of the regression model ($P < 0.05$) and the mathematical models with the best fit ($R^2 > 0.8$) were selected to build the response surfaces and identify the optimal formulation of the dependent variables.

The DF was used in the Design 7.0 software for the multi-response optimization. Each response variable was assigned 0 (if not desirable) or 1 (if desirable). A total function D ($0 < D < 1.0$) equal to the geometric mean of the n individual desired functions was defined for all the desired functions of the different responses. The optimal values were determined from the individual values of the desired functions that maximize D. For the present study, optimization criteria sought to maximize the rheological parameters WA, S, C, GT, PV, RE, and E, and minimize DDT, since these considerations are necessary to achieve doughs with rheological characteristics that suit an industrial-scale process for bread production. A dough with high C can retain the carbon dioxide produced during fermentation and baking; meanwhile, high E helps achieve proper dough shaping and even distribution of crumb in the bread; S is crucial to withstand the handling throughout the production process, while E contributes to achieving desirable bread height and volume (MYERS et al., 2016; VIDOSAVLJEVIĆ et al., 2022).

RESULTS

According to the statistical analysis of the collected data, the most dependent variables presented significant differences ($P < 0.05$) in the rheology parameters analyzed (See supplementary material). In some cases, it was possible to generate a predictive mathematical model to describe their behavior through a response surface and contour plot.

Doughs with quinoa-kiwicha blends

According to farinographic and extensographic results (Supplementary material 1, Supplementary material 2), the doughs presented WA from 60.09 to 65.09 %, DDT from 2.44 to 4.07 min, S from 3.3 to 4.95 min, C from 768 to 860 FU, RE from 733 to 1393 BU, and E from 70 to 92 mm. Incorporating GQF and GKF decreased WA, DDT, S, and RE of doughs but increased their C. E4 and E5 formulated with 15 % GKF presented the greatest drop in DDT, and S; these doughs also obtained the highest C. Conversely, E2 and E9, formulated with 15% GQF, had the highest extensibility of the experiments and the lowest WA. Therefore, incorporating GKF produced stronger doughs, while GQF made them more extensible. Regarding the amylographic results, the experiments presented a GT between 75.7 and 89.2 °C, and PV between 1232 and 1398 AU. Increasing GQF and GKF levels in formulation reduced GT and PV in the experiments up to 13 °C and 120 AU, respectively.

According to the results of the analysis of variance, the rheological parameters best explained by the models ($R^2 > 0.8$ and $P < 0.05$) were WA, DDT, C, RE, E, and PV. For the other parameters, no models with high statistical significance were obtained. AA, DT, E, and PV fit better in the quadratic model (Equation 1, 2, 5, and 6), while C and RE fit better in the cubic one (Equation 3 and 4). Figure 1 shows the contour surface of the models.

$$WA_{GQF\text{-}GKF}=1.266(GQF)+3.863(GKF)+0.795(WF)+0.082(GQF)(GKF)-0.054(GKF)(WF) \quad (1)$$

$$DDT_{GQF\text{-}GKF}=0.075(GQF)-0.188(GKF)+0.062(WF)+0.023(GQF)(GKF) \quad (2)$$

$$C_{GQF\text{-}GKF}=831.929(GQF)+874.429(GKF)+767.92(WF)-145.284(GKF)(WF)+1066.848(GQF)(GKF)(WF)+630.284+630.284(GQF)(GKF)[(GQF)-(GKF)] \quad (3)$$

$$RE_{GQF\text{-}GKF}=838.46(GQF)+918.96(GKF)+1389.96(WF)-685.46(GQF)(WF)-3375.85(GQF)(GKF)[(GQF)-(GKF)]+1484.15(GQF)(WF)[(GQF)-(WF)] \quad (4)$$

$$E_{GQF\text{-}GKF}=2697(GQF)-14.436(GKF)+0.824(WF)-0.364(GQF)(GKF)-0.369(GKF)(WF) \quad (5)$$

$$PV_{GQF\text{-}GKF}=6.641(GQF)+20.515(GKF)+6.152(WF)-0.459(GQF)(GKF)-0.337(GKF)(WF) \quad (6)$$

Dough with quinoa-cañihua blends

The experiments presented WA between 62.6 and 65.3 %, DDT between 2.8 and 4.52 min, S between 3.45 and 5.42 min, C between 764 and 872 FE, RE between 823 and 1431 BU, and E between 68 and 86 mm. Incorporating GQF and GCF increased the WA and C of doughs and decreased their DT, S, RE, and E values. However, analyzed separately, the increase of GQF produced doughs with greater S and E. In contrast, incorporating GCF made doughs more resistant to extension (ER) and with lower E. Regarding the amylographic results, the increase

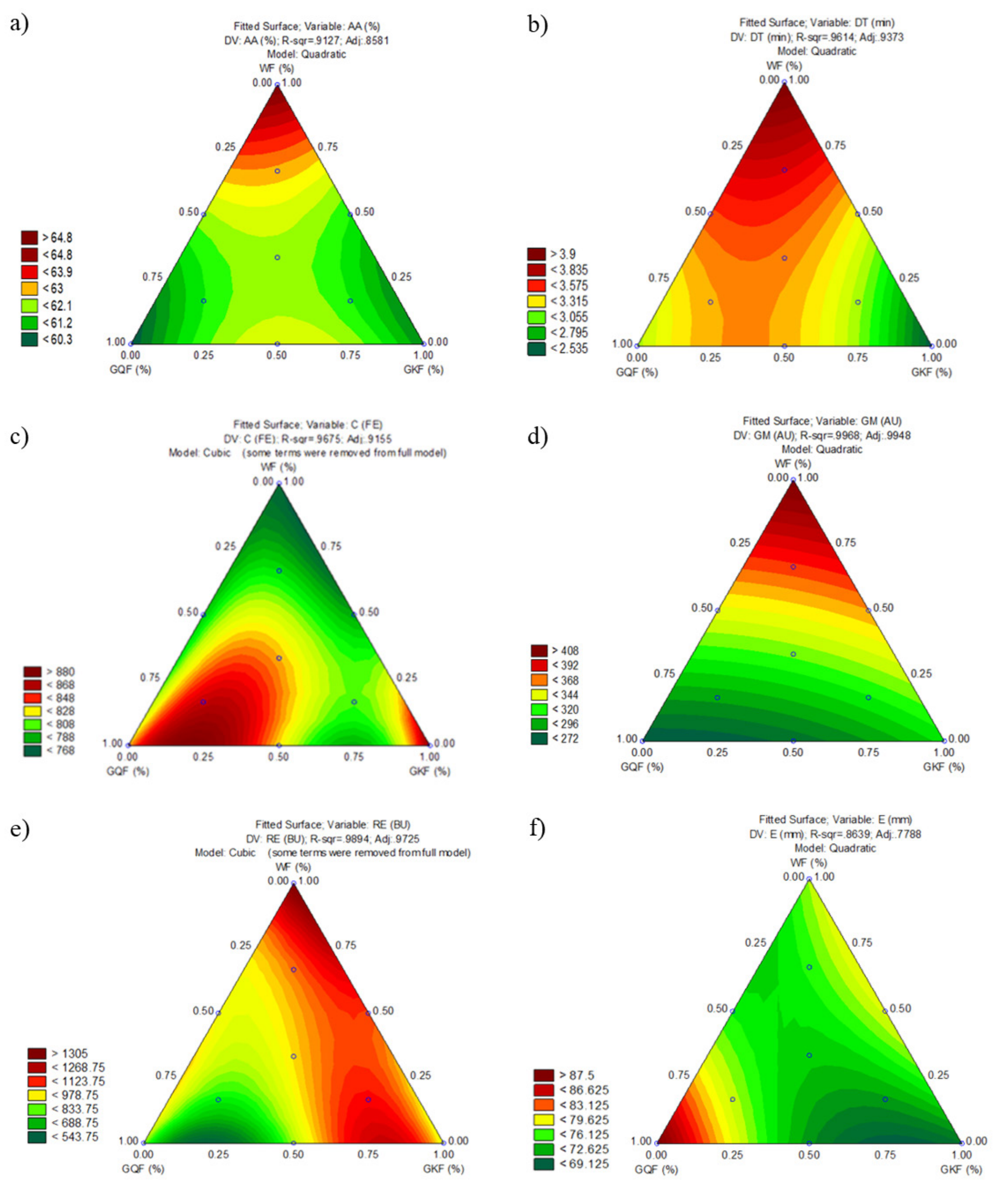

Figure 1 - Contour surfaces of the rheological properties: (a) WA, (b) DDT, (c) C, (d) RE, (e) E, and (f) PV of flour mixture wheat (WF) and germinated flours of quinoa (GQF) and kiwicha (GKF).

of GQF and GCF decreased GT and PV of the experiments. GQF led to a greater drop in GT and PV since E2 and E9, formulated with 15 % GQF, presented the lowest values of these parameters.

According to the ANOVA results for each response variable, the best-explained rheological parameters ($R^2 > 0.8$ and $P < 0.05$) were S, GT, and PV. It was not possible to obtain models with high statistical significance for the other parameters. S, GT, and PV fit better with the quadratic model (Equation 7, Equation 8, and Equation 9). Figure 2 shows the contour surface of the models.

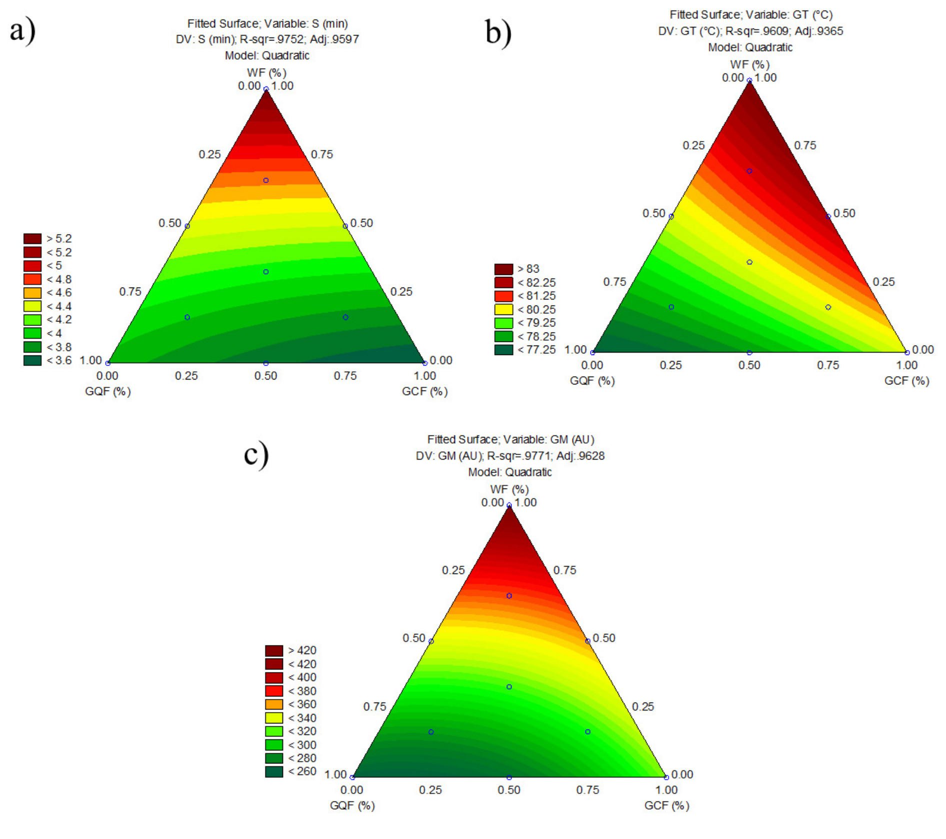

Figure 2 - Contour surfaces of the rheological properties: (a) S, (b) GT, and (c) PV of flour mixture wheat (WF) and germinated flours of quinoa (GQF) and cañihua (GCF).

$$S_{GQF-GCF}=0.677(GQF)+0.286(GCF)+0.086(WF)-0.002(GQF)(GCF)-0.010(GQF)(WF)-0.006(GCF)(WF) \quad (7)$$

$$GT_{GQF-GCF}=1.501(GQF)-1.241(GCF)+0.861(WF)-0.019(GQF)(GCF)-0.013(GQF)(WF)+0.024(GCF)(WF) \quad (8)$$

$$PV_{GQF-GCF}=12.690(GQF)+59.296(GCF)+6.604(WF)-0.856(GQF)(GCF)-0.305(GQF)(WF)-0.811(GCF)(WF) \quad (9)$$

Dough with kiwicha-cañihua blends

Experiments presented AA between 61.1 and 63.8%, DT between 2.67 and 4.3 min, S between 3.55 and 5.2 min, C between 764 and 872 FE, RE between 723 and 1388, and E between 72 and 95 mm. Like the previous experiments, incorporating GKF and GCF decreased the values of AA, DT, S, and RE, and increased the C and E of doughs. In particular, GCF had a greater impact on the rheological properties of the doughs since E4 and E5 were stronger and presented less stability and extensibility. In contrast, those formulated with a greater GKF (up to 15%) were more stable and extensible. Regarding the amylographic properties, the experiments presented a GT between 76.1 and 85.6 °C, and PV between 258 and 437 AU. Increasing GKF and GCF decreased GT and PV values of experiments to 10 °C and 80 U, respectively, especially in the formulations with higher GKF.

In this case, when performing the ANOVA results for each response variable, the best explained rheological parameters ($R^2 > 0.8$ and $P < 0.05$) were S, RE, and PV, whose coefficients were 0.852, 0.8453, and 0.9475, respectively. It was not possible to obtain models with high statistical significance for the other parameters. S and PV fit better with the linear model (Equation 10 and Equation 11), while RE fit better with the cubic model (Equation 12). Figure 3 shows the contour surface of the models.

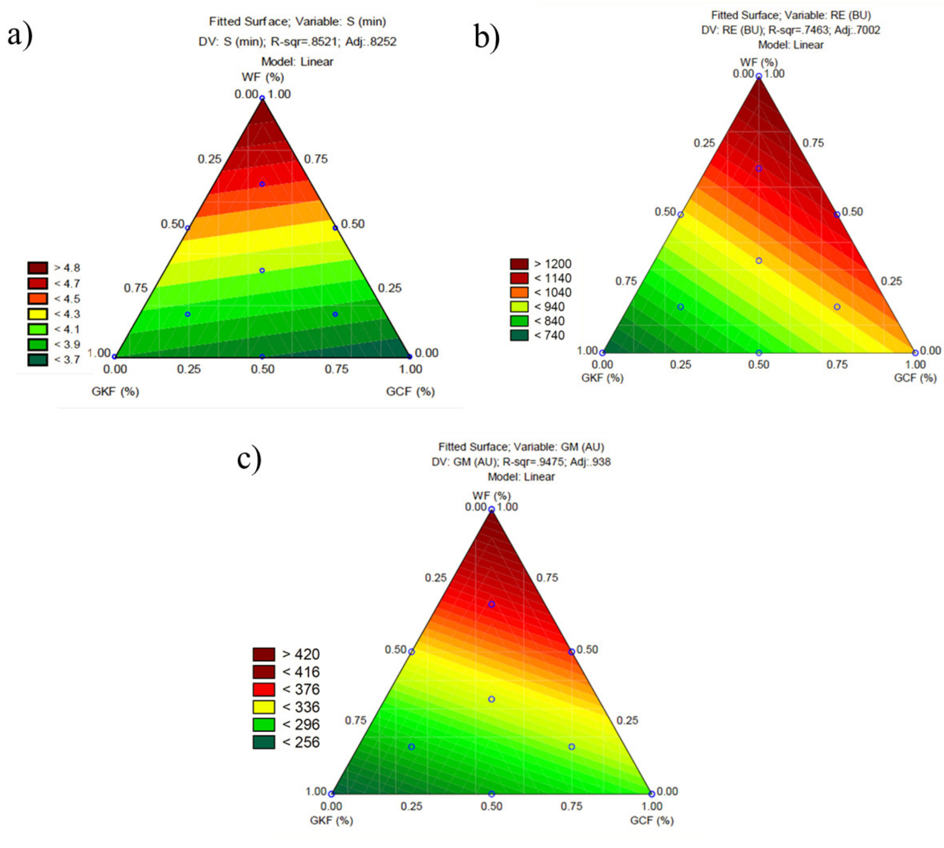

Figure 3 - Contour surfaces of the rheological properties: (a) S, (b) RE, and (c) PV of flour mixture wheat (WF) and germinated flours of kiwicha (GKF) and cañihua (GCF).

$$S_{GKF\text{-}GCF}=12.58(GKF)+12.36(GCF)+13.93(WF) \quad (10)$$

$$RE_{GKF\text{-}GCF}=821.16(GKF)+944.72(GCF)+1377.15(WF)-759.25(GKF)(WF) \quad (11)$$

$$PV_{GKF\text{-}GCF}=264.91(GKF)+307.22(GCF)+428.60(WF)-45.95(GKF)(GCF)-33.72(GCF)(WF) \quad (12)$$

Mix optimization

The optimization of blends (quinua-kiwicha, quinua-cañihua, kiwicha-cañihua) included the response variables analyzed in the dough rheology: WA, DDT, S, C, GT, PV, RE, and E. Following the considerations described in the methodology, the software indicated the optimal formulas for each mixture of wheat flour with whole flours from germinated pseudocereals (Table 2). When projecting the rheological responses and analyzing the FD value, the formulations finally selected were: (I) for the mixture of wheat flour with GQF and GKF, (II) for the mixture of wheat flour with GQF and GCF, and (III) for the mixture of wheat flour with GKF and GCF, with 0.694, 0.748, and 0.48 values respectively.

DISCUSSION

The impact of GQF, GKF, and GCF on the rheological characteristics of doughs may be attributed to the gluten dilution in the food matrix and the increase of fibers. The gluten dilution results from the substitution of wheat flour with gluten-free raw material flours, which diminishes the dough's strength. Moreover, an increase in fiber concentration weakens the dough and impedes its development.

Incorporating the Andean pseudocereal germinated flours increased the WA of doughs up to 2 %. One contributing factor to this observation could be the higher fiber content in the germinated flours, as fibers are known to absorb water effectively (LIMA et al., 2023). In a previous study, our team

Table 2 - Optimization of blends and projection of rheological parameters of the doughs formulated with wheat flour (WF) and germinated flours of quinoa (GQF), kiwicha (GKF) and cañihua (GCF).

Optimal points		I			II			III	
	GQF	GKF	WF	GQF	GCF	WF	GKF	GCF	WF
Flour (%)	8.09	8.45	83.5	5.00	5.00	90	5.0	8.95	86
WA		61.90						62.71	
DDT		3.40						3.67	
S		3.80			5.38			4.40	
C		810.73						796.64	
RE		1324.78						1125.65	
E		80.89						78.46	
GT		95.68			83.04			81.24	
PV		73.41			431.07			377.50	
FD		0.694			0.748			0.480	

WA= Adjusted water Absorption; DDT= dough development time; S=stability; C= consistency; GT= gelatinization temperature; PV= peak viscosity, RE= resistance to extension; E= extensibility.

reported that the fiber content in germinated flours ranged from 22 to 23 g/100g, which is more than double the fiber content in wheat flour (8.5 g/100g) (PAUCAR-MENACHO et al., 2022). Conversely, PARASKEVOPOULOU et al. (2010) also recommend analyzing the raw materials' composition since proteins absorb more water than starch and other carbohydrates. GQF, GKF, and GCF flours had 13.52 %, 15.38 %, and 19.11 % protein, respectively, while WF had 12.5 %, so protein concentration may have been an influential factor in WA. Compared with other authors, the values observed in our study were higher than those of ATUDOREI et al. (2021), MARTI et al. (2018), and SAPIRSTEIN et al. (2018), whose WA of doughs was between 51 and 57 %.

The decrease of DDT and S of doughs with whole grain flours from germinated pseudocereal may be related to the gluten dilution and the gluten network weakening due to the high enzymatic activity. According to KOEHLER et al. (2007), germination promotes the hydrolysis of gluten-forming proteins by proteases and the formation of soluble peptides, then using germinated flours can cause doughs with less stability. MARTI et al. (2018) had similar results when using germinated wheat flour in breadmaking; as a result, they obtained more porous and soft products. Therefore, good quality products can be obtained by taking the necessary care. The lowest S were observed in the doughs with the highest amount of GCF, which could be associated with the higher enzymatic activity of α-amylase and α-glucosidase (CORONADO-OLANO et al., 2021).

The increased consistency (C) of doughs resulting from the addition of germinated pseudocereal flours may primarily be attributed to the higher fiber content in the blends, specifically whole grain fibers. According to Marti et al. (2014), the presence of fibers, particularly those subjected to prior enzymatic processing, enhances WA; and consequently, improves dough consistency and development time. It's important to note that whole grain flours generally require more water to achieve equivalent torque values compared to refined flours. This is due to the hydrophilic nature of whole grain fibers (GALLAGHER et al., 2004). If the full water requirement is not met for doughs containing whole grain flours, greater torque values, indicating higher dough consistency, are observed. This finding also opens the possibility of using germinated pseudocereal flours to produce bakery products, where structural ingredients are needed since bread doughs with high hydration levels are a tendency in the food industry.

As in the previous parameters, the variation of RE and E in doughs could have been influenced by the gluten dilution and the fibers' presence. Of the three germinated pseudocereal flours used, GQF was the one that decreased RE by up to 30 % and increased E by 20 %; therefore, GQF allowed for obtaining more extensible doughs. These results coincided with the observations made by TAMBA-BEREHOIU et al. (2019), who evaluated the effect of the addition of different varieties of quinoa on the rheology of bread doughs. The extensible doughs are ideal for elaborating cookies and products that do not need to develop volume; however, considering the values established in the AACCI (2010) to evaluate the quality of the flour, doughs with E < 120 mm are still suitable for their application. Adding up to 15 % of GQF, GKF and GCF would not affect this attribute in bread production.

Regarding the amylographic results, GT and PV decreased due to GQF, GKF, and GCF increases can be related to the morphological and techno-functional characteristics of the starch granule of the raw materials. Small starch granules are more easily leached than larger ones (PUNCHA-ARNON et al., 2008). Wheat starch granules are bimodal and have an average diameter of 25 µm, while pseudocereals such as quinoa and amaranth have 1 to 2 µm (LI & ZHU, 2018; ZHU, 2016) and those of cañihua from 0.5 to 1.5 µm. (FUENTES et al., 2019). According to these authors, the starch gelatinization temperature of these pseudocereals is between 50 and 54 °C, which would explain the GT drop in the experiments. In addition, the germination process hydrolyzed starch granules, which are more exposed to hydration and increase their solubility in water (LI et al., 2020). Reducing GT is desirable for products like bread to ensure the center reaches a temperature of 95 °C, guaranteeing complete cooking. However, this decrease must be carefully controlled, as it can impact the crumb consistency and difficulting of the product cutting.

The optimal formulations obtained in each blend of GQF-GKF, GQF-GCF, and GKF-GCF with wheat flour, were selected considering the desirable attributes for bread-baking such as higher WA, S, C, GT, PV, RE, and E and lower DT, guarantees a scalability of the product for a possible industrial application.

CONCLUSION

Incorporating GQF, GKF, and GCF significantly affected the doughs' rheological properties, increasing their water absorption, consistency, and extensibility, decreasing their dough development time, stability, resistance to extension, the temperature of gelatinization, and peak viscosity. The answers obtained allowed the establishment of mathematical models to describe the behavior of some variables, and likewise, they made it possible to determine the optimal formulation in each case. The mixture of wheat flour with GQF-GKF allowed the development of more extensible doughs with good stability so that the optimized formula could be used to produce bread and cookies. While incorporating GCF allowed us to obtain more consistent doughs and a lower gelatinization temperature, the optimal formulations of GQF-GCF and GKF-GCF with wheat flour would be ideal for their application in bread making.

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DECLARATION OF CONFLICT OF INTEREST

We have no conflict of interest to declare.

AUTHORS' CONTRIBUTIONS

All authors contributed equally to the conception and writing of the manuscript. All authors critically revised the manuscript and approved the final version.

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