Brazilian Journal of Development

Influence of cooking and drying in structural quality and shelf life of quinoa (*chenopodium quinoa*) negra ayrampo

Influência do cozimento e secagem na qualidade estrutural e na vida útil da quinoa (*chenopodium quinoa*) negra ayrampo

DOI:10.34117/bjdv6n2-064

Recebimento dos originais: 30/12/2019
Aceitação para publicação: 06/02/2020

Huamani Huamani Alberto Luis
Doctor en Ciencias de los Alimentos, Universidad Nacional Federico Villarreal-Perú.
E-mail: alberto.huamani@unsch.edu.pe

Ponce Ramírez Juan Carlos
Doctor en Ciencias de los Alimentos, Universidad Nacional Federico Villarreal-Perú.
E-mail: juan.ponce@unsch.edu.pe

Agustín Julián Portuguez Maurtua
Doctor en Ciencias de los Alimentos, Universidad Nacional Federico Villarreal-Perú.
E-mail: agustin.portuguez@unsch.edu.pe

Jack Edson Hernandez Mavila
Ingeniero, Universidad Nacional de san Cristóbal de Huamanga.
E-mail: jack.hernandez@unsch.edu.pe

Wiler Hugo De La Cruz Quispe
Magister Scientiae en Tecnología de Alimentos, Universidad nacional Agraria la Molina.
E-mail: wiler.delacruz@unsch.edu.pe

Abrahán Trejo Espinoza
Maestro en química, Universidad Alas Peruanas.
E-mail: abrahan.trejo@unsch.edu.pe

Fredy Rober Pariona Escalante
Maestro en Gestión Empresarial, Universidad Nacional de san Cristóbal de Huamanga.
E-mail: frpe_01@hotmail.com

ABSTRACT
Quinoa (Chenopodium quinoa Willd) is a pseudocereal native to the Andean regions of South America. If compared with most cereals, quinoa seeds have a higher nutritional value (Matiacevich et al., 2006) with a protein content that ranges between 12% and 23% (Abugoch et al., 2008; Ando et al., 2002; Jancurová et al., 2009; Koziol, 1992; Ruales and Nair, 1992). The objective of this study was to optimize cooking with saturated steam and high temperature dehydration of quinoa (Chenopodium quinoa). The multiple response surface optimization methodology was applied with independent variables (saturated vapor pressure and cooking time) and as a response variable (gelatinization, water adsorption index and cotyledon detachment). A vertical cooker with steam generator was used (Item: HL-340, Serial No. 806727, Gemmy Industrial Corp. U.S.A.). The results and conclusion of cooking were: The results of cooking and dehydration, are due to the behavior of starch due to the effect of saturated steam pressure and cooking process time. In gelatinization the

internal starch hydrogen bonds are replaced by starch-water bonds (Pardhi et al., 2016), it is an irreversible process, it consists of granular swelling, native crystalline fusion, birefringence loss and starch solubilization (Ji et al., 2017). The solubility index indicates the degree of association (intragranular bonds) between starch polymers (amylose and amylopectin) (Araujo et al., 2004). The optimum cooking values were, vapor pressure was 1,55 kgf cm-2, time of 10 minutes and dehydration temperature 82 ° C, gave good results in keeping the whole grain of instant quinoa with a gelatinization of starch in 93,82% and a 2,54 minutes rehydration.

Keywords: *Chenopodium quinoa* Willd, steam pressure cooking, high temperature dehydration.

RESUMO

A quinoa (Chenopodium quinoa Willd) é um nativo pseudocereal das regiões andinas da América do Sul. Se comparadas à maioria dos cereais, as sementes de quinoa têm um valor nutricional mais alto (Matiacevich et al., 2006), com um teor de proteína que varia entre 12% e 23% (Abugoch et al., 2008; Ando et al., 2002; Jancurová et al., 2009; Koziol, 1992; Ruales e Nair, 1992). O objetivo deste estudo foi otimizar o cozimento com vapor saturado e desidratação a alta temperatura da quinoa (Chenopodium quinoa). A metodologia de otimização da superfície de resposta múltipla foi aplicada com variáveis independentes (pressão de vapor saturado e tempo de cozimento) e como variável de resposta (gelatinização, índice de adsorção de água e descolamento de cotilédones). Foi utilizado um fogão vertical com gerador de vapor (Item: HL-340, Nº de série 806727, Gemmy Industrial Corp. EUA). Os resultados e conclusão do cozimento foram: Os resultados do cozimento e desidratação, são devidos ao comportamento do amido devido ao efeito da pressão do vapor saturado e do tempo do processo de cozimento. Na gelatinização, as ligações internas de hidrogênio do amido são substituídas por ligações amido-água (Pardhi et al., 2016), é um processo irreversível, consiste em edema granular, fusão cristalina nativa, perda de birrefringência e solubilização do amido (Ji et al., 2017). O índice de solubilidade indica o grau de associação (ligações intragranulares) entre polímeros de amido (amilose e amilopectina) (Araujo et al., 2004). Os valores ótimos de cozimento foram: pressão de vapor de 1,55 kgf cm-2, tempo de 10 minutos e temperatura de desidratação de 82 ° C, proporcionaram bons resultados na manutenção de todo o grão de quinoa instantânea com uma gelatinização de amido em 93,82% e uma reidratação de 2,54 minutos.

Palavras-chave: *Quinoa Chenopodium* Willd, cozimento sob pressão a vapor, desidratação a alta temperatura.

1 INTRODUCTION

Quinoa (*Chenopodium quinoa Willd*.) Is a pseudocereal traditionally consumed by Andean cultures that is attracting worldwide attention as a functional food. Because of its high content of proteins, lipids, fiber, vitamins and minerals, and its excellent balance of essential amino acids, it has been found that quinoa contains numerous phytochemicals that include saponins, phytosterols, phytoecteresteroids, phenolic compounds and bioactive peptides. These compounds can have beneficial effects on metabolic, cardiovascular and gastrointestinal health (Vilcacundo & Hernández-Ledesma, 2017). It is an important source of minerals and vitamins, and it has also been found to contain compounds such as polyphenols, phytosterols and flavonoids with possible nutraceutical benefits (Abugoch James, 2009).

Compared to most quinoa seed cereals, they have a higher nutritional value that is relatively rich in protein, with a content that ranges between 12% and 23%. 11S globulin and 2S albumin are the largest fraction of quinoa proteins, representing approximately 37% and 35% of the total grain protein, respectively. The molar mass of 2S albumin is 8-9 kDa, 11S globulin is 22-23 kDa, for the basic subunit of 32-39 kDa and for the acid subunit (Kaspchak *et al*., 2017).

Leite *et al.* (2017), developed the research "High pressure processing (HPP) of pea starch: Effect on gelatinization properties". (Mota *et al.*, 2016) investigated the effect of cooking methods on the mineral content of quinoa (Chenopodium quinoa), amaranth (Amaranthus sp.) And buckwheat (Fagopyrum esculentum), concluded that steam cooking demonstrated be more appropriate than boiling with respect to all foods under study.

The response surface methodology (RSM) is a statistical procedure commonly applied for optimization studies in general and especially in food processing (Mestry *et al.*, 2011; Pérez-Francisco *et al.*,2008).

The response surface methodology (RSM) as a statistical method optimizes the dependent variable. Each response (dependent variable) is affected by different independent variables (control factors). In addition, RSM is powerful in defining the correlation between the response variables and the independent variables (Kaur *et al.*, 2009; Kumar *et al*., 2014). Each response variable in RSM has a mathematical relationship with the experimental parameters through a non-linear polynomial equation with square terms, two-factor interaction terms, linear terms and a constant term. This equation can be expressed as (Montgomery, 2017):

$$y_i = \beta_0 + \sum_{i=1}^{\infty} \beta_i x_i + \sum_{i=1}^{\infty} \beta_{ii} x_i^2 + \sum_{i=1}^{\infty} \sum_{i=1}^{\infty} \beta_{ij} x_i x_j \tag{1}$$

Where "Yi" are the response variables. βo, βi, βij where i = j, and βij where i ≠ j are the coefficients to intercept, linear, quadratic and interactive effects respectively. In this study, ec. (1) It is organized by the RSM quadratic model and is a mathematical relationship between the control factors. A quadratic model is useful to approximate the true response surface with a parabolic curvature. The quadratic model has a set of all terms in the first order model, plus all second order terms and all cross-product terms. In addition, the quadratic model is a flexible model, since it employs a variety of functional forms and determines the response surface locally. Consequently, this is an excellent model to assess the true response surface (Majdi *et al*., 2019).

Multiple responses can be estimated through the desirability function (D (x)) (Derringer, 1980; Giri and Prasad, 2007; Myers *et al*., 2016) by applying the equation (2).

$$D(x) = (Y_1 * Y_2, Y_3, \dots. Y_n)^{1/n} \tag{2}$$

where Yi (i = 1, 2 ... n) are the dependent variables and "n" is the total number of responses evaluated. The value of "D" varies from zero to one. "D" is the desirability function that represents the way in which the dependent variables are at a selected level of independent variables. The method consists in obtaining a function that converts a multiple response problem into a single response (Martinez Delfa, Olivieri, & Boschetti, 2009). A high value of D (x) indicates the best combinations of factors, which is considered the optimal system solution. The optimal values for each factor are determined from the values of the individual convenience functions that maximize the global function D (x) (Corzo & Gomez, 2004).

Quinoa grains are composed of a single seed enclosed by an outer pericarp. Quinoa seed contains a central perisperm where carbohydrate stores are located, surrounded by the lipid-rich and protein-rich embryo, the endosperm and the seed layer, the quinoa pericarp is rich in bitter saponins (Graf *et al.*, 2015). During the immersion cooking of quinoa in water, problems of excessive detachment of the cotyledon from the grain are generated and as a consequence of this release of the starch, as a consequence of this during the dehydration a problem is also generated such as the excess of drying time, rehydration prolonged To keep the grains cooked and whole, it proposes as an alternative a technology of pressure cooking of saturated steam and high temperature dehydration. As a study objective, the optimization of high temperature cooking and dehydration of quinoa (Chenopodium quinoa Willd) variety Ayrampo Negra is proposed.

2 MATERIALS AND METHODS

2.1 MATERIAL

The samples used in this investigation were whole grains of quinoa (*Chenopodium quinoa Willd*) Ayrampo black variety. All were harvested in the region of Ayacucho-Peru. The moisture content was determined in triplicate using method 925.10, as described by (AOAC, 1990).

2.2 METHODOLOGICAL COOKING PROCEDURE

For cooking the quinoa previously, it was soaked for 24 hours and then washed with water from the net to remove the bitter taste and saponins and then drained into a mesh. The cooking was done in a vertical cooker with steam generator (Vertical Type Sterilizer, Item: HL-340, Serial No. 806727, Gemmy Industrial Corp. USA) was programmed with the addition of 2 liters of distilled water for steam generation , the pressure and cooking time according to the experimental design proposed, the response surface methodology, the central composite design was used, as shown in Table 1. The samples were placed in a stainless-steel basket in an amount of 250 g, then they were cooked. The conditions of the convection air dehydrator were, the relative humidity measured was 12 ± 2.0%, dry bulb temperature 90 ° C, incorporated with a digital balance with an accuracy of ±

0.01 g., Connected to a personal computer that records the weight loss at intervals of 10 seconds, until reaching a constant weight.

Table 1

Level of control factors

Control variables	Unit	Symbol	Minimum level	Medium level	Maximum level
Cooking steam pressure	kgf cm^{-2}	P	1	1,5	2
Cooking time	min	t	2	6	10

2.3 METHODOLOGICAL COOKING-DEHYDRATION PROCEDURE

Once the cooking was done, the product was immediately removed from the cooker (T = 100 ° C), placed in stainless steel fine mesh trays and placed inside the air dryer by preconditioning conditioned its temperature and speed control system air. In the dryer the samples were placed in a stainless-steel fine mesh base tray that hangs on a digital scale with an accuracy of ± 0,01 g. Digital balance connected to a personal computer that records weight loss at 10 second intervals, until a constant weight is reached. The tests were carried out according to the design proposed in Table 2. Pressure values of 1 to 2 kgf cm^{-2}, these values were assigned based on preliminary tests, the values of 60 and 100 ° C chosen for the Dehydration temperature were chosen based on the outlet temperature after the opening of the cooker and the minimum temperature based on the temperature of possible cooling during handling. The relative humidity of the air was measured digitally by a humidity sensor (Traceable # Grainger: 3LYW2, Mexico) that was located in the dryer cabin. Under drying conditions, the measured relative humidity was 12 ± 2,0 %, dry bulb temperature 90 ° C, at an altitude of 2761 m.a.s.l. The initial moisture content of cooked quinoa was 83,3 % on a wet basis (w.b.) determined by the stove method at atmospheric pressure at 105 ° C for 24 h (Helrick, 1990). Dehydration of the samples continued until their equilibrium moisture content was reached in each test condition. The equilibrium moisture content (0,136 g of water / g of dry matter on dry basis) was determined through the interpolation of Newton's finite differences of numerical methods using the adsorption isotherm model of Guggenheim-Anderson-de Boer a the drying temperature (70 - 90 ° C), similar to that used by (Golestani *et al*., 2013).

Table 2

Level of control factors

Control variables	Unit	Symbol	Minimum level	Medium level	Maximum level
Cooking steam pressure	kgf cm^{-2}	P	1	1,5	2
Dehydrated temperature	°C	T	60	80	100

2.4 STATISTICAL EVALUATION

To evaluate the influence of the variables in the research, the response surface methodology, of the central composite design factorial design at a level of significance of $\alpha = 0{,}05$ was used. To assess the correlation of multiple responses, the desirability function of the response surface methodology was used.

2.5 ANALYSIS OF RESPONSE VARIABLES

The response variables that were analyzed were:

Water absorption index (IAA) and water solubility index (ISA) (Jafari *et al.*, 2017): The IAA and ISA were determined according to the method developed by (Pardhi *et al.*, 2016).

Degree of starch gelatinization: A spectophotometric method used by (Birch & Priestley, 1973), based on the formation of the amylose-iodine complex.

Cotyledon detachment (%): It was determined by percentage of grains with cotyledons completely detached as a result of cooking.

Rehydration: For rehydration the methodology used by (Jiao *et al.*, 2014) was used.

3 RESULTS AND DISCUSSIONS

3.1 COOKING

Figure 1 shows the 3D response graphs obtained from the results of maximization of water absorption index, minimization of cotyledon shedding and maximization of gelatinization during cooking of Ayrampo variety black quinoa.

The correlation coefficients of the polynomial adjustment was evaluated through the analysis of variance (ANVA) as observed in Table 2, the results show a significance of p-value less than the alpha value (5%) or a 95% confidence level , confirms the existence of the correlation of the dependent variables with the independent ones according to the stated objective. In addition, observing the results of the coefficients presents a statistical model of quadratic type with 6 coefficients for each response consisting of: water absorption index, release of cotyledon and gelatinization of cooked quinoa starch as a function of cooking vapor pressure (X1) and cooking time (X2).

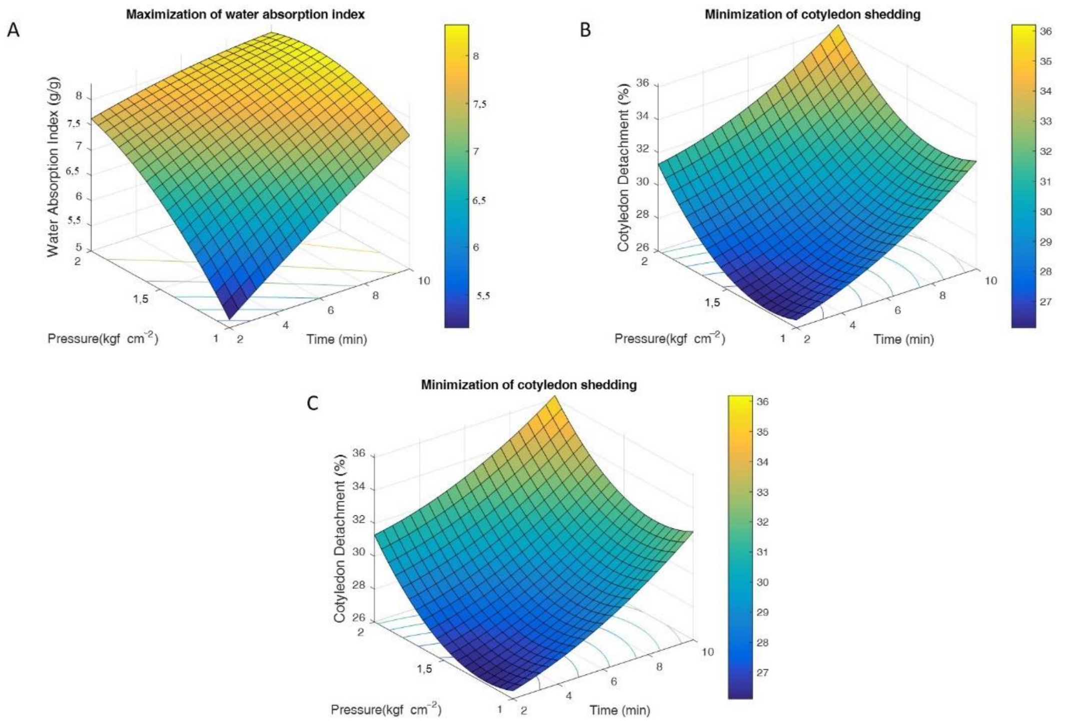

Figure 1. Response surface of: A-Maximization of water absorption index; B- minimization of cotyledon shedding; C- Maximization of gelatinization, during the cooking of quinoa with saturated steam.

Table 3

Analysis of the variance of the polynomial predictive models for the responses during cooking during Ayrampo black quinoa.

Factors		Water absorption index (g / g)		Detached cotyledons (%)		Gelatinization (%)	
		coefficient	p-value	coefficient	p-value	coefficient	p-value
Constant	β_0	-1,40656		37,1239		0,576562	
x_1(Pressure)	β_1	7,27917	0,0002	- 19,4092	0,0007	63,2983	0,0001

x_2(Time)	β_2	0,619896	0,0002	0,345729	0,0002	2,29698	0,0000
x_1^2	β_{11}	- 1,445	0,0450	8,175	0,0066	- 18,575	0,0022
x_2^2	β_{22}	- 0,005703	0,5473	0,04711	0,1848	0,05789	0,3492
x_1x_2	β_{12}	- 0,24125	0,0062	- 0,14875	0,4962	0,71	0,1053
R^2		0,9611	3,7e-04	0,9569	5,0e-04	0,9929	2,36e-06

The p-value of the model less than 0,05, which indicates that the terms of the model are significant. In this case, pressure, time and pressure 2 are significant terms of the model. P values greater than 0,05 indicate that the terms of the model are not significant. In this case, time 2 and pressure * time are insignificant model terms. The mathematical model obtained was quadratic obtained from the regression analysis for the dependent variables in terms of the independent variables as shown in Fig. 1A, B and C respectively and is expressed through the following equations 3-5:

IIA = -1,40656 + 7,27917* Pressure + 0,619896*Time - 1,445* Pressure^2 - 0,24125* Pressure *Time - 0,00570313*Time^2 (3)

Gelatinization = 0,576562 + 63,2983* Pressure + 2,29698*Time - 18,575* Pressure ^2 + 0,71* Pressure *Time + 0,0578906*Time^2 (4)

Cotyledon Detachment = 37,1239 - 19,4092* Pressure + 0,345729*Time + 8,175* Pressure ^2 - 0,14875* Pressure *Time + 0,0471094*Time^2 (5)

Optimization analysis of steam pressure cooking

From the results of Fig. 1 A, B and C, the optimization of multiple responses was estimated through the desirability function (D (x)) (Derringer, 1980; Giri and Prasad, 2007; Myers *et al* ., 2009), for cooking Ayrampo black variety quinoa, according to the following criteria of: maximizing the water absorption rate (g / g), minimizing the release of cotyledons (%) and maximizing gelatinization (%), which were also applied in other foods by, Ahmed, Qazi, and Jamal (2016), (Corzo, Bracho, Vásquez, & Pereira, 2008; Corzo & Gomez, 2004), as we can see the results in Table 3 and Fig. 2 respectively.

Table 4

Optimum operating conditions for pressure cooking of quinoa vapor black variety ayrampo.

Product	**Optimal conditions**		**Optimized Answers**			DT max
	Pressure (kgf cm^{-2})	Time (min)	IAA(g/g)	Detached cotyledons (%)	Gelatinization (%)	
Objective	-	-	Max.	Min.	Max.	
Quinoa	1,550	10	8,2954	32,5412	93,8261	0,8414

During cooking the physical changes suffered by quinoa grains are the shedding of cotyledons. The morphological structure of quinoa grain is; the pericarp, episperm (front), perisperm and embryo (radicle and cotyledons). The perisperm is the white tissue, composed mainly of starch and occupies a space of 60% of the total grain. Then it is composed of cotyledon in approximately 35%, endosperm in 5% and pericarp where it occupies almost 90% saponin (Arendt & Zannini, 2013). During cooking the starch absorbs water, increases its volume due to the increase in water content and then due to the osmotic pressure generated the structure tends to break and finally the cotyledons tend to be released. When the starch is heated in the presence of water, an irreversible process called gelatinization is carried out in which a series of internal starch hydrogen bonds are replaced by starch-water bonds (Pardhi *et al.,* 2016).

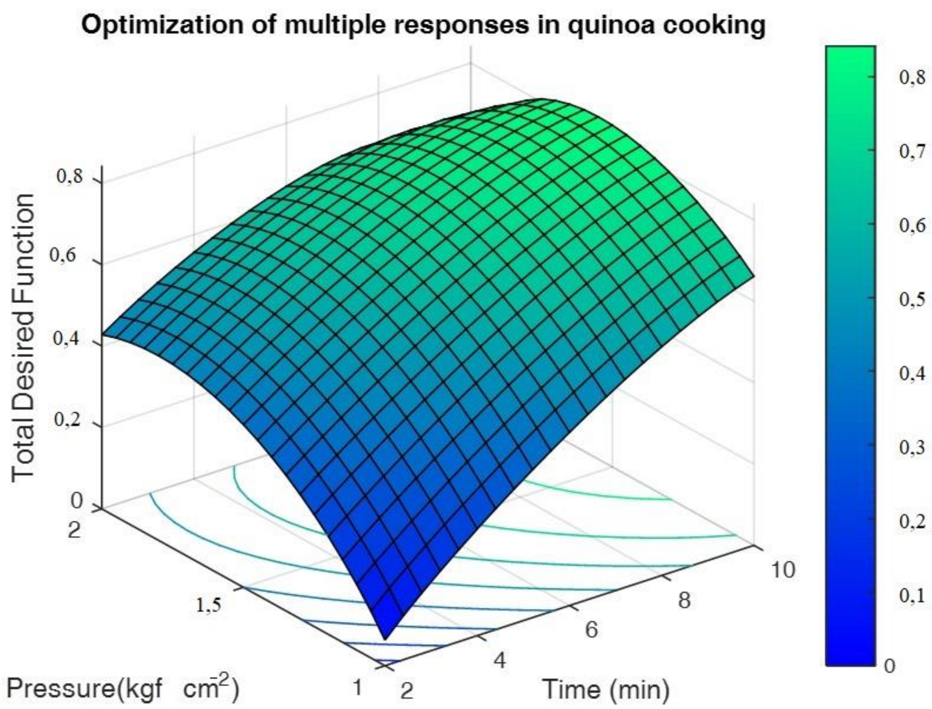

Figure 2. Total convenience function in cooking optimization of black quinoa ayrampo with saturated steam.

The region of the optimum value of the convenience function (Dx), can be seen as a narrow slope at the maximum pressure level (1,55 kgf cm^{-2}), and 10 minutes. The optimum processing condition for quinoa cooking was obtained according to the mathematical solutions of the total convenience function considering the optimization criteria (Table 4). The solution for the optimal condition that maximizes the value of the total convenience function was 0,8414. The correlation of the cooking parameters, through maximization of water absorption index, minimization of detached cotyledons and maximization of starch gelatinization, as indicators of cooking quinoa are: Pressure = 1,55 kgf cm^{-2}) and Time = 10 min to reach optimum cooking measured with the cooking indicators, through quantification of water absorption index = 8,2954 (g / g), detached cotyledons = 32,5412 (%) and gelatinization = 93,8261%.

These behaviors of the grains and their components during cooking are due to the variables involved in the process such as temperature, pressure and time. Pressure plays an important role during the process, as Ji *et al*. (2017), that the pressure, without shearing effort, could delay the gelatinization process due to a weak swelling of the starch granules, a very weak gel and a smaller amount of amylose released, in some cases it is not released and the starch granules tend to retain their shape

Quinoa starch has low gelatinization temperatures (59,2 ° C) (Li & Zhu, 2017a). The starch in quinoa is stored as discrete semicrystalline granules and consists of two main biopolymers: linear amylose (20-30 %) and highly branched amylopectin (70-80%) (Zhao *et al.*, 2015). The amylose content and starch amylopectin structure strongly influence its physicochemical properties and applications Chen *et al*. (2017). Starch gelatinization is an irreversible process, it consists of granular swelling, native crystalline fusion, loss of birefringence and solubilization of starch (Ji *et al.*, 2017). The solubility of starch is a consequence of water absorption, followed by the swelling of the granule and the increase in temperature. The solubility index indicates the degree of association (intragranular bonds) between starch polymers (amylose and amylopectin) (Araujo, Alicia, & Padilla, 2004).

3.2 COOKING - DEHYDRATION

Fig. 3A, B and C show the 3D response graphs obtained from the results of the maximization of whole grains, minimization of rehydration time and maximization of the water solubility index, during the cooking-dehydration of the black quinoa variety Ayrampo

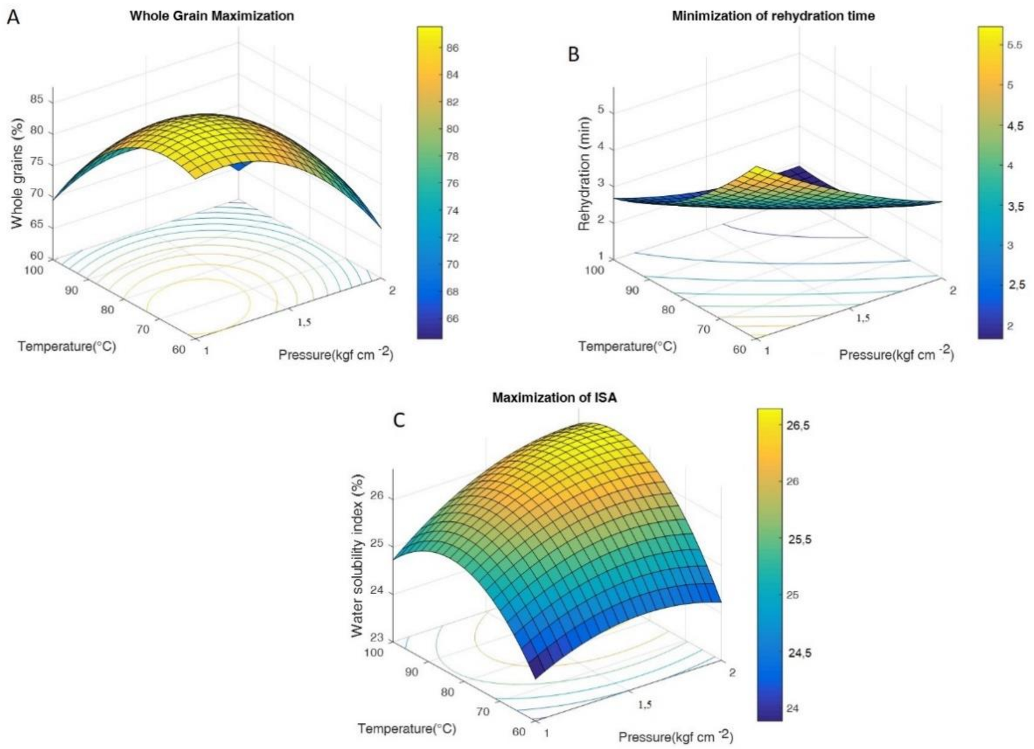

Figure 3. Response surface of: A- maximization of whole grains; B-Minimization of rehydration time; C-Maximization of water solubility index (ISA), during cooking-dehydration of quinoa black variety ayrampo.

The analysis of variance was developed to validate the accuracy of the model (Freedman, Pisani, & Purves, 2007), to verify the effectiveness of the model. In addition, p-values confirm the model from the statistical point of view. For our case study, the p-value of less than 0,05, the model is approved from the statistical point of view. In Table 4, the correlation of the dependent variables (whole grains, rehydration and starch water solubility indicator) with the independent variables (cooking vapor pressure (X1) and dehydration temperature (X2), according to the objective set.

Table 4

Analysis of the variance of the polynomial predictive models for the responses during cooking-drying of quinoa black variety Ayrampo.

Factors		Whole grains (%)		Rehydration (min)		Water solubility index (%)	
		coefficient	p-value	coefficient	p-value	coefficient	p-value
Factors	β_0	-2,975		24,7892		4,2525	
X_1(Pressure)	β_1	37,55	0,0016	0,06667	0,0000	3,84167	0,0000
X_2(Temperature)	β_2	1,9407	0,0034	- 0,31517	0,0000	0,424292	0,0000
X_1^2	β_{11}	- 24,65	0,0074	0,925	0,0335	- 1,775	0,0005
X_2^2	β_{22}	- 0,0166	0,0052	0,0012	0,0012	0,001203	0,0000
X_1X_2	β_{12}	0,31425	0,0480	0,0465	0,0005	0,03075	0,0012
R^2		0,9477	8,84e-04	0,9915	4,001e-06	0,9935	1,82e-06

p-value <0,05 is significant at α = 0,05.

The lack of adjustment is not significant at p-value> 0,05.

All the adjusted models presented coefficients of determination close to the unit ($R^2 \geq 0,9$) which indicates that the models satisfactorily explain the variability of the responses; The mathematical model was a quadratic model obtained from the regression analysis for the dependent variables in terms of the independent variables is expressed through the following equations 6 - 8:

$$GS = -2,975 + 37,55 * Pressure + 1,94071 * Temperature - 24,65 * Pressure^2 + 0,31425 * Pressure * Temperature - 0,0165937 * Temperature^2 \quad (6)$$

RH = 24,7892 - 8,19833* Pressure - 0,315167* Temperature + 0,925* Pressure ^2 + 0,0465* Pressure * Temperature + 0,00120312* Temperature ^2 (7)

ISA = 4,2525 + 3,84167* Pressure + 0,424292* Temperature - 1,775* Pressure ^2 + 0,03075* Pressure * Temperature - 0,00270937* Temperature ^2 (8)

3.3 ANALYSIS OF COOKING-DEHYDRATION OPTIMIZATION

The results of the optimization of multiple responses for cooking-dehydration can be seen in Table 5 and Fig. 4. The optimal condition that maximizes the value of the total convenience function was 0,92. The optimum conditions of the cooking - dehydration process were: cooking pressure 1,5 kgf cm-2, drying temperature of 82 ° C, and optimized responses maximizing whole grains during cooking of 84,10 (%), rehydration minimization of 2,54 (min) and starch solubility index of 26,38 (%).

Table 5

Optimum operating conditions for the cooking-dehydration of quinoa black variety ayrampo (Cooking pressure and drying temperature)

Product	Optimal conditions		Optimized Answers			DT
	Pressure (kgf cm^{-2})	Temperature (°C)	Whole grains (%)	Rehydration (min)	ISA (%)	max
objective	-	-	Max.	Min.	Max.	
Quinoa	1,5	82	84,10	2,54	26,38	0,92

Fig. 4 shows the optimization combined with a combined desirability (D = 0,92) of the dependent variables according to the following criteria: maximize undamaged grains (%), minimize rehydration time (min) and Maximize the water solubility index (%) based on the independent variables of cooking pressure (kgf cm^{-2}) and temperature (° C) of dehydration. in order to determine optimal cooking-dehydrated areas of quinoa black variety ayrampo

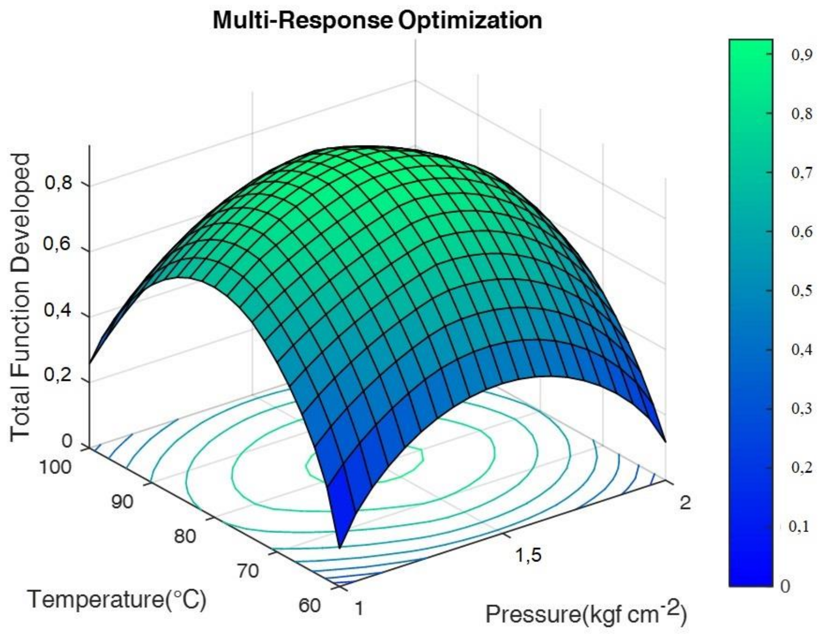

Figure 4. Total convenience function of cooking-dehydration optimization, of black quinoa ayrampo variety.

The form shown in Fig. 4, the behavior of pressure and temperature, during the evaluation of the response variables such as minimization of damage to the grain, minimization of rehydration and maximization of the solubility index of quinoa starch during cooking. Dehydration is due to the behavior of the components of quinoa. Structural, physicochemical and biochemical changes induced by water removal during drying are often not very reversible (Prothon *et al.*, 2003; Beck *et al.*, 2012); Fang and Catchmark, 2014; Žepič *et al.*, 2014). Rehydration is often insufficient to recover the initial properties, leading to a general loss of functionality after processing (Fernandes Diniz *et al.*, 2004; Fang and Catchmark, 2014). The dry material rehydration process is described as the combination of the humidification, subsidence, dispersion and swelling steps (Forny *et al.*, 2011).

Amylose content has been considered as the most important determinant of cereal food quality. In the mid-1990s, it was proposed that the texture of cooked cereal is also related to the fine structure of amylopectin (Li *et al*., 2016).

During dehydration the intracellular water migrates from the intracellular space to the intercellular spaces. Understanding the periods in which cell membranes are broken is crucial, since this knowledge can be used to design a more efficient drying system (Khan *et al.*, 2017).

The decrease in swelling capacity after drying is clearly due to a general contraction of the structure of the material. Its final functionality depends largely on its processing history and, in particular, on the structural modifications that occur during drying and rehydration (Déléris & Wallecan, 2017).

Cooked cereals require further studies for knowledge of satisfactory structural quality, acceptability and shelf life. However, as an alternative to this technological problem was the study of cooking at high steam pressure, high temperature and short time. Wang *et al*. (2017) show an inadequate management of parameters of this dehydration process, leading to a drastic deterioration of product quality such as surface hardening, prolonged rehydration, contraction and discoloration of the product.

Andean pseudocereals are consumed after cooking. However, culinary methods can lead to considerable losses of soluble nutrients, namely minerals (Barampama & Simard, 1995). The differences in structural changes between raw and cooked foods may be greater than 90%. Therefore, high pressure steam cooking and high temperature drying treatments can have an impact on the knowledge of cooking and dehydrated variables in the significant level of structural changes of carbohydrates, and ensure their digestibility of intake of nutrients.

Quinoa starch has physicochemical properties such as: low gelatinization temperatures (59.2 ° C), amylose content (for example, 3-20%), granule size (~ 1.5 μm) (Li & Zhu, 2017a). Quinoa has a starch with more than 50% of the dry weight of the seeds. The quality of quinoa products can be highly determined by the properties of starch (Li & Zhu, 2017b). Quinoa starch granules are polygonal with a diameter of 0.3 - 1.7 μm, presented as single, spherical entities and oblong aggregates (10 - 20 μm). Quinoa starch contains 8.4% amylose., Gelatinization temperature 53 to 66 ° C (Srichuwong *et al.*, 2017). Carbohydrates are the predominant component in quinoa with 80.45% (Encina-Zelada *et al.*, 2017), texture variations during cooking are mainly due to changes in carbohydrates.

The drying problems are diverse since several food materials with very different physical / chemical properties need to be dried at different production scales and with very different product quality specifications (Musielak *et al*., 2016). Drying is a well-studied unit operation in process engineering, whose main objective is to "dehydrate" a material at faster and faster speeds that optimize energy expenditure. Dehydration should be considered not only as a unit operation, but also as a powerful method to produce unique food structures even from the same raw material, be it a tissue, a liquid dispersion or a dry powder (Aguilera *et al*., 2003). In this context, food dehydration is reviewed from the perspective of recent advances in the science of food materials, knowledge of desiccation in nature, microstructural sounding, new processing technologies and deeper knowledge about drying mechanisms, among others. The role of the structure in dehydrated products seems evident to understand transport mechanisms and to design functional properties (Aguilera *et al*., 2003)

Loss, gain and moisture transfer often affect food materials. Whether derived from the interaction with the atmosphere or with another component of the food, such changes always cause a deterioration of the general quality of the food through softening, hardening, decomposition, swelling or contraction due to phase or dissolution transitions. In most cases, water migration leads to organoleptic or microbiological changes in food (Roudaut & Debeaufort, 2011).

3.4 SHELF LIFE

The values shown in Table 6, the values of form (β) and scale (α) were calculated for the values of 40, 50 and 60 ° C respectively from the regression curves of the Weibull accumulated risk plot of the attribute Sensory presence of aldehyde formation, the parameters of form (β) and scale (α) for 20 ° C were calculated using numerical solutions of interpolation of Lagrange.

Table 6

Values of the shape and scale parameter for the sensory evaluated in the instantaneous quinoa stored at different temperatures at accelerated tests.

T(°C)	α	β
20	36,68	3,68
40	14,58	3,225
50	6,98	3,142
60	1,68	3,067

According to the results shown in Table 7, the useful life is 779 days (approximately 2,2 years), considering the sensory attribute.

Table 7

Shelf life (days) at different storage temperatures for instant dehydrated quinoa.

Temperature (°C)	Time (days)
20	799
40	54
50	27
60	12

4 CONCLUSIONS

The correlation of the variables during cooking and cooking - dehydration has been demonstrated. The optimal variables for the evaluation of cooking were: cooking pressure of 1,55 $kgf.cm^{-2}$, cooking time of 10 minutes and maximum desirability function (D = 0,8414). The optimal variables in the evaluation of cooking-dehydration were: cooking pressure of 1,5 kgf.cm-2 and dehydration temperature of 82 ° C, for a maximum desirability function (D = 0,92). The shelf life in the environmental conditions of 20 ° C was 799 days.

BIBLIOGRAPHIC REFERENCES

AOAC (1990). Official methods of analysis (15th ed.). Washington, DC: Association of Official Analytical Chemists.

Official Analytical Chemists.

Aguilera, J. M., Chiralt, A., & Fito, P. (2003). Food dehydration and product structure. *Trends in Food Science & Technology*, *14*(10), 432-437. doi:https://doi.org/10.1016/S0924-2244(03)00122-5

Ahmed, I., Qazi, I. M., & Jamal, S. (2016). Developments in osmotic dehydration technique for the preservation of fruits and vegetables. *Innovative Food Science & Emerging Technologies, 34*(Supplement C), 29-43. doi:https://doi.org/10.1016/j.ifset.2016.01.003

Araujo, C., Alicia, M. R., & Padilla, F. (2004). Caracterización del almidón nativo de Dioscorea bulbifera L. .

Arendt, E. K., & Zannini, E. (2013). 12 - Quinoa *Cereal Grains for the Food and Beverage Industries* (pp. 409-438): Woodhead Publishing.

Barampama, Z., & Simard, R., E. (1995). Effects of soaking, cooking and fermentation on composition, in-vitro starch digestibility and nutritive value of common beans. *Plant foods for human nutrition, 48*, 349 - 365.

Beck, S., Bouchard, J., & Berry, R. (2012). Dispersibility in Water of Dried Nanocrystalline Cellulose. *Biomacromolecules, 13*(5), 1486-1494. doi:10.1021/bm300191k

Birch, G. G., & Priestley, R. J. (1973). Degree of Gelatinisation of Cooked Rice. *Starch - Stärke, 25*(3), 98-100. doi:10.1002/star.19730250308

Corzo, O., Bracho, N., Vásquez, A., & Pereira, A. (2008). *Optimization of thin layer drying process for coroba slices* (Vol. 85).

Corzo, O., & Gomez, E. R. (2004). Optimization of osmotic dehydration of cantaloupe using desired function methodology. *Journal of Food Engineering, 64*(2), 213-219. doi:https://doi.org/10.1016/j.jfoodeng.2003.09.035

Chen, X., Guo, L., Chen, P., Xu, Y., Hao, H., & Du, X. (2017). Investigation of the high-amylose maize starch gelatinization behaviours in glycerol-water systems. *Journal of Cereal Science, 77*(Supplement C), 135-140. doi:https://doi.org/10.1016/j.jcs.2017.08.012

Déléris, I., & Wallecan, J. (2017). *Relationship between processing history and functionality recovery after rehydration of dried cellulose-based suspensions: A critical review* (Vol. 246).

Derringer, G. S., Ronald. (1980). Simultaneous Optimization of Several Response Variables. *Journal of Quality Technology,, 12, 214–219.*

Encina-Zelada, C., Cadavez, V., Pereda, J., Gómez-Pando, L., Salvá-Ruíz, B., Teixeira, J. A., . . . Gonzales-Barron, U. (2017). Estimation of composition of quinoa (Chenopodium quinoa Willd.) grains by Near-Infrared Transmission spectroscopy. *LWT - Food Science and Technology, 79*, 126-134. doi:http://dx.doi.org/10.1016/j.lwt.2017.01.026

Fang, L., & Catchmark, J. M. (2014). Structure characterization of native cellulose during dehydration and rehydration. *Cellulose, 21*(6), 3951-3963. doi:10.1007/s10570-014-0435-8

Fernandes Diniz, J. M. B., Gil, M. H., & Castro, J. A. A. M. (2004). Hornification—its origin and interpretation in wood pulps. *Wood Science and Technology, 37*(6), 489-494. doi:10.1007/s00226-003-0216-2

Forny, L., Marabi, A., & Palzer, S. (2011). Wetting, disintegration and dissolution of agglomerated water soluble powders. *Powder Technology, 206*(1), 72-78. doi:https://doi.org/10.1016/j.powtec.2010.07.022

Freedman, D., Pisani, R., & Purves, R. (2007). Statistics (4th edn): Norton, New York.

Giri, S. K., & Prasad, S. (2007). Optimization of Microwave-Vacuum Drying of Button Mushrooms Using Response-Surface Methodology. *Drying Technology, 25*(5), 901-911. doi:10.1080/07373930701370407

Golestani, R., Raisi, A., & Aroujalian, A. (2013). *Mathematical Modeling on Air Drying of Apples Considering Shrinkage and Variable Diffusion Coefficient* (Vol. 31).

Graf, B. L., Rojas-Silva, P., Rojo, L. E., Delatorre-Herrera, J., Baldeón, M. E., & Raskin, I. (2015). Innovations in Health Value and Functional Food Development of Quinoa (Chenopodium quinoa Willd.). *Comprehensive Reviews in Food Science and Food Safety, 14*(4), 431-445. doi:10.1111/1541-4337.12135

Helrick, K. (1990). Official methods of analysis *Official methods of analysis*: AOAC.

Jafari, M., Koocheki, A., & Milani, E. (2017). Effect of extrusion cooking of sorghum flour on rheology, morphology and heating rate of sorghum–wheat composite dough. *Journal of Cereal Science, 77*, 49-57. doi:http://dx.doi.org/10.1016/j.jcs.2017.07.011

Ji, Z., Yu, L., Liu, H., Bao, X., Wang, Y., & Chen, L. (2017). Effect of pressure with shear stress on gelatinization of starches with different amylose/amylopectin ratios. *Food Hydrocolloids, 72*, 331-337. doi:http://dx.doi.org/10.1016/j.foodhyd.2017.06.015

Jiao, A., Xu, X., & Jin, Z. (2014). Modelling of dehydration–rehydration of instant rice in combined microwave-hot air drying. *Food and Bioproducts Processing, 92*(3), 259-265. doi:http://dx.doi.org/10.1016/j.fbp.2013.08.002

Kaur, S., Sarkar, B. C., Sharma, H. K., & Singh, C. (2009). Optimization of Enzymatic Hydrolysis Pretreatment Conditions for Enhanced Juice Recovery from Guava Fruit Using Response Surface Methodology. *Food and Bioprocess Technology, 2*(1), 96-100. doi:10.1007/s11947-008-0119-1

Khan, M. I. H., Wellard, R. M., Nagy, S. A., Joardder, M. U. H., & Karim, M. A. (2017). Experimental investigation of bound and free water transport process during drying of hygroscopic food material. *International Journal of Thermal Sciences, 117*, 266-273. doi:https://doi.org/10.1016/j.ijthermalsci.2017.04.006

Kumar, D., Prasad, S., & Murthy, G. S. (2014). Optimization of microwave-assisted hot air drying conditions of okra using response surface methodology. *J Food Sci Technol, 51*(2), 221-232. doi:10.1007/s13197-011-0487-9

Leite, T. S., de Jesus, A. L. T., Schmiele, M., Tribst, A. A. L., & Cristianini, M. (2017). High pressure processing (HPP) of pea starch: Effect on the gelatinization properties. *LWT - Food Science and Technology, 76*, 361-369. doi:https://doi.org/10.1016/j.lwt.2016.07.036

Li, G., & Zhu, F. (2017a). Amylopectin molecular structure in relation to physicochemical properties of quinoa starch. *Carbohydrate Polymers, 164*, 396-402. doi:http://dx.doi.org/10.1016/j.carbpol.2017.02.014

Li, G., & Zhu, F. (2017b). Physicochemical properties of quinoa flour as affected by starch interactions. *Food Chemistry, 221*, 1560-1568. doi:http://dx.doi.org/10.1016/j.foodchem.2016.10.137

Li, H., Prakash, S., Nicholson, T. M., Fitzgerald, M. A., & Gilbert, R. G. (2016). The importance of amylose and amylopectin fine structure for textural properties of cooked rice grains. *Food Chemistry, 196*, 702-711. doi:https://doi.org/10.1016/j.foodchem.2015.09.112

Majdi, H., Esfahani, J. A., & Mohebbi, M. (2019). Optimization of convective drying by response surface methodology. *Computers and Electronics in Agriculture, 156*, 574-584. doi:https://doi.org/10.1016/j.compag.2018.12.021

Martinez Delfa, G., Olivieri, A., & Boschetti, C. E. (2009). Multiple response optimization of styrene–butadiene rubber emulsion polymerization. *Computers & Chemical Engineering, 33*(4), 850-856. doi:https://doi.org/10.1016/j.compchemeng.2009.01.002

Mestry, A. P., Mujumdar, A. S., & Thorat, B. N. (2011). Optimization of Spray Drying of an Innovative Functional Food: Fermented Mixed Juice of Carrot and Watermelon. *Drying Technology, 29*(10), 1121-1131. doi:10.1080/07373937.2011.566968

Montgomery, D. C. (2017). *Design and analysis of experiments*: John wiley & sons.

Mota, C., Nascimento, A. C., Santos, M., Delgado, I., Coelho, I., Rego, A., . . . Castanheira, I. (2016). The effect of cooking methods on the mineral content of quinoa (Chenopodium quinoa), amaranth (Amaranthus sp.) and buckwheat (Fagopyrum esculentum). *Journal of Food Composition and Analysis, 49*, 57-64. doi:https://doi.org/10.1016/j.jfca.2016.02.006

Musielak, G., Mierzwa, D., & Kroehnke, J. (2016). Food drying enhancement by ultrasound – A review. *Trends in Food Science & Technology, 56*, 126-141. doi:http://dx.doi.org/10.1016/j.tifs.2016.08.003

Myers, R. H., Montgomery, D. C., & Anderson-Cook, C. M. (2016). *Response surface methodology: process and product optimization using designed experiments*: John Wiley & Sons.

Pardhi, S. D., Singh, B., Nayik, G. A., & Dar, B. N. (2016). Evaluation of functional properties of extruded snacks developed from brown rice grits by using response surface methodology. *Journal of the Saudi Society of Agricultural Sciences*. doi:https://doi.org/10.1016/j.jssas.2016.11.006

Pérez-Francisco, J. M., Cerecero-Enríquez, R., Andrade-González, I., Ragazzo-Sánchez, J. A., & Luna-Solano, G. (2008). Optimization of Vegetal Pear Drying Using Response Surface Methodology. *Drying Technology, 26*(11), 1401-1405. doi:10.1080/07373930802333601

Prothon, F., Ahrné, L., & Sjöholm, I. (2003). *Mechanisms and Prevention of Plant Tissue Collapse during Dehydration: A Critical Review* (Vol. 43).

Roudaut, G., & Debeaufort, F. (2011). 3 - Moisture loss, gain and migration in foods *Food and Beverage Stability and Shelf Life* (pp. 63-105): Woodhead Publishing.

Srichuwong, S., Curti, D., Austin, S., King, R., Lamothe, L., & Gloria-Hernandez, H. (2017). Physicochemical properties and starch digestibility of whole grain sorghums, millet, quinoa and amaranth flours, as affected by starch and non-starch constituents. *Food Chemistry, 233*, 1-10. doi:http://dx.doi.org/10.1016/j.foodchem.2017.04.019

Wang, R., Chen, C., & Guo, S. (2017). Effects of drying methods on starch crystallinity of gelatinized foxtail millet (α-millet) and its eating quality. *Journal of Food Engineering, 207*, 81-89. doi:https://doi.org/10.1016/j.jfoodeng.2017.03.018

Žepič, V., Fabjan Erika, Š., Kasunič, M., Korošec Romana, C., Hančič, A., Oven, P., . . . Poljanšek, I. (2014). Morphological, thermal, and structural aspects of dried and redispersed nanofibrillated cellulose (NFC) *Holzforschung* (Vol. 68, pp. 657).

Zhao, D., Palaparthi, A. D., Huang, Q., Fu, X., Liu, H., & Yu, L. (2015). Effects of ionic liquid 1-allyl-3-methylimidazolium chloride treatment on the microstructure and phase transition of cornstarch. *Industrial Crops and Products, 77*, 139-145. doi:http://dx.doi.org/10.1016/j.indcrop.2015.08.063