Journal of Pharmaceutical Research International

24(5): 1-13, 2018; Article no.JPRI.45346
ISSN: 2456-9119
(Past name: British Journal of Pharmaceutical Research, Past ISSN: 2231-2919, NLM ID: 101631759)

Effect of Flour Composition and Temperature on Physico-chemical and Sensory Properties of Quinoa Based Extrudates

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Authors' contributions

This work was carried out in collaboration between all authors. All authors read and approved the final manuscript.

Article Information

DOI: 10.9734/JPRI/2018/45346
Editor(s):
(1) Dr. Jongwha Chang, University of Texas, College of Pharmacy, USA.
Reviewers:
(1) Patrícia Matos Scheuer, Federal Institute of Santa Catarina, Brazil.
(2) K. C. Yadav, Tribhuvan University, Nepal.
Complete Peer review History: http://www.sciencedomain.org/review-history/27569

Original Research Article

Received 19 September 2018
Accepted 26 November 2018
Published 04 December 2018

ABSTRACT

Aim: Quinoa has extraordinary and promising nutritional and cultivation features, therefore supplementing or replacing of common cereal grains with quinoa carries high potential benefits to consumers worldwide. Quinoa incorporation in diets can be made more acceptable through extrusion cooking which is cost effective process. However for quinoa extrusion it is used to be incorporated with other flours to enhance its extrusion properties. Therefore the current study aims to develop suitable ingredient blends and extrusion temperature for preparing acceptable quinoa based extrudates.
Study Design: Randomized block design (RCBD) design was used.
Place and Duration of Study: Department of Foods and Nutrition, Professor Jayashankar Telangana State Agricultural University, Hyderabad, Between November 2015 and June 2016.
Methodology: Seven formulation of quinoa flour blended with different proportions of corn, oats, rice and sweet potato flours were extruded at three different temperatures (100˚C, 130˚C and 150˚C) and total of 21 treatments were obtained. Their sensory acceptability and physico-chemical properties such expansion ratio, bulk density, hardness, colour, WAI and WSI were evaluated.

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Results: Lower Bulk density, lower hardness, lighter colour and higher sensory score were observed in extrudates processed at highest temperature (150˚C). However, the highest expansion was observed at 130˚C for most formulations. Two formulations were observed to have desirable properties such as highest expansion ratio, lowest bulk density, most desirable colour and sensory acceptability namely Quinoa:Corn:Rice (60:25:15) and Quinoa:Oats:Rice (60:25:15).
Conclusion: Two formulation were found most desirable namely Quinoa:Corn:Rice (60:25:15) and Quinoa:Oats:Rice (60:25:15). However Quinoa:Oats:Rice can be better blend in view of nutritional prospect.

Keywords: Quinoa; oats; extrusion; expansion; physico-chemicals properties; sensory evaluation.

1. INTRODUCTION

Quinoa has gained worldwide attraction in last two decades due to its impressive nutritional quality and great cultivation features. Quinoa can survive extreme weather conditions such as very hot and very cold temperatures, salinity, alkaline soils, high altitudes and low rainfall [1]. These features make quinoa able to grow almost in any place in the world. Moreover in term of nutritional quality Quinoa observed to have high protein quality and also higher contents of mineral (iron, phosphorous and calcium), B-vitamins and fiber than wheat, Rice, oat, barley or corn as reported by the Food and Agriculture Organization (FAO) [2]. The quality of quinoa protein is reported to be equivalent to that of casein (milk protein) in term of protein efficiency ratio, protein digestibility and nitrogen balance [3]. Quinoa protein has great amino acid balance especially high lysine and methionine contents which are the limiting amino acids in cereals and legumes, respectively. Moreover, quinoa can be considered as gluten-free grain so it is suitable for people who have wheat allergy or celiac patients [4]. It was suggested that supplementing or completely replacing of common cereal grains (rice, corn and wheat) with a grain with better nutritional value (such as quinoa) carries great benefits to the consumers worldwide [5]. So it was not a surprise to declare year 2013 as the “International Year of Quinoa” by the United Nations to spotlight global attention on quinoa as potential crop for food security, nutrition and poverty [6].

However quinoa can have a negative side due to presence of saponins especially in the hull which is the major anti nutritional compound that impart a bitter taste to quinoa and can have toxic anti-nutrient properties when consumed in high amounts [7]. Thus quinoa is mostly dehulled/ polished and washed beforeits use [8]. Extrusion and roasting can play a significant role in saponins destructionhence reduction bitter taste imparted by quinoa [5]. Extrusion cooking could be an attractive method for quinoa incorporation into the diets [9]. Extrusion is HTST process that utilises high pressure and thermal treatments simultaneously along with mechanical shearing, which result in components modifications such as protein denaturation and starch gelatinisation [10]. It is worldwide used Technology for producing snack foods, baby foods, ready-to-eat cereals, pasta and pet foods [11]. There are very few studies in the literature on quinoa extrudates, blending either with corn or cassava [12-14], however the percentage of quinoa was up to 50%.There were no studies in the literature using a higher percentage of quinoa. Hence the present study was proposed to use quinoa at higher percentage blending with other grains with high starch content. Since flours from corn, rice, oat and sweet potato were reported to have good extrusion capabilities due to high starch percentage and quality, it should help in achieving desirable physical properties of quinoa extrudates such as expansion, bulk density, brittleness etc. and enhancing the nutritional value as well.

2. MATERIALS AND METHODS

2.1 Raw Material Preparation

Quinoa was gratis from Inner Being & Wellness Pvt Ltd- Hyderabad, India. Other ingredients (Sweet potato, corn, oats, and rice) were procured from local market in Hyderabad. Quinoa was dehulled (Gurunanak Engineering Co, Hyderabad) and milled to produce quinoa flour, corn, oats, rice were pulverised to reduce size to 420 microns (BSS 36 sieve) using commercial pulveriser (Able manufacturers, Hyderabad, India). Sweet potato flour was prepared as per the method described by Yadav et al. [15]. The prepared raw materials were stored in tightly sealed poly-ethylene bags and were kept in refrigerator at 4ºC for further use in extrusion processing.

2.2 Product Development

Seven quinoa based formulations were designed as shown in Table 1. The moisture content of the flour combination/formulations was estimated by Automatic Moisture Analyzer (MAC 50/NH (LCD/Halogen), Radwag, Poland). The flours were mixed according to formulations on a dry-to-dry weight basis. The mixtures were then conditioned to 16 % moisture by spraying with a calculated amount of water and mixing continuously in a blender. The samples were then kept in tightly sealed poly-ethylene bags overnight at room temperature. Preliminary extrusion testswere done to determine the levels and ranges of the factors to be used.

2.3 Extrusion

A co-rotating twin-screw extruder (Basic Technology Pvt. Ltd., Kolkata, India) with three zones (feeding zone, cooking zone, and die zone) was used. The extrusion conditions are briefly; die diameter -3 mm, feed rate-7 kg/h and screw speed-300 RPM. Extrusion cooking was conducted under three different temperatures (100˚C, 130˚C and 150˚C). The extruder was kept for 60 minutes to stabilise the pre-set temperature prior to extrusion. Feeding of the pre-conditioned composite flour was accomplished by using a twin screw volumetric gravity feeder. The extrudates were collected at the end of the die and dried at 50˚C in a tray drier for 3 h duration. The samples were then packed in poly-ethylene bags for further analysis.

2.4 Expansion Ratio

Expansion ratio (ER) was measured according Ding et al. [13], which defined expansion ratio as the ratio of the diameter of the extrudate to the diameter of the die. The diameter was measured using digital vernier calipers. Cylindrical extrudate rods of about 60 mm in length were chosen and a minimum of 4 values of extrudate diameter were recorded for each rod. At least 15 such rods were randomly chosen and a total of 60 diameter values were recorded per sample.

$$Expansionratio\ (ER) = \frac{DiameterofExtrudate}{DiameteroftheDie}$$

2.5 Bulk Density

For Bulk density calculation the length and diameter (cm) of 15 randomly chosen rods was measured using digital vernier caliper and their individual weight was recorded. The bulk Density was then calculated using the following formula reported by Stojceska et al. [16].

$$Bulk\ Density\ (g/cm3) = \frac{4\ m}{\pi d^2 L}$$

Where m is the average extrudate mass (g), L is the average extrudate length (cm) and d is the average diameter (cm) of the extrudates.

2.6 Water Solubility Index (WSI) and Water Absorption Index (WAI)

WAI and WSI were determined by the method of Anderson [17]. A sample of 2.5 g of extrudate powder was weighed and suspended in 30 mL of distilled water at room temperature in a 50 mL tube, then was shaken gently for 30 minutes, then centrifuged at 3,000 RPM for 15 min. The supernatant was carefully poured into a tarred Petri-dish. The precipitated gel was then weighed in order to calculate the WAI. The weight of the dried solids after evaporating the supernatant was used to calculate WSI. The weight of dry matter in the 2.5 g of flour was used for calculation of WAI and WSI.

Table 1. Composition of different formulations used for quinoa based Extrudates

Ingredients	Formulations						
	QCR	QCP	QCT	QCTR	QCTP	QTR	QTP
Quinoa (Q)	60	60	60	60	60	60	60
Corn (C)	25	25	20	15	15	0	0
Oat (T)	0	0	20	15	15	25	25
Rice (R)	15	0	0	10	0	15	0
Sweet Potato (P)	0	15	0	0	10	0	15
Total	100%	100%	100%	100%	100%	100%	100%

All formulations were extruded at three different temperatures (100˚C, 130˚C and 150˚C)

$$WAI = \frac{Weight of Gel}{Weight of dry matter}$$

$$WSI = \frac{Weight of solids in supernatant x\ 100}{Weight of dry matter}$$

2.7 Colour Measurements

Colour properties of extruded snacks were measured using Hunter lab.(CIE L*, a*, b* colour space). Colour measurements were performed on extrudate powder, transparent Petri dish was used to hold the sample during colour measurements. The colour of extrudates was recorded as the average of three L*, a*, and b* readings, where L* (brightness or lightness) range from 0 (black) to 100 (white), b* from blue (-) to yellow (+) and a* of green (-) to red (+). Black then white calibration plates were used to standardise the instrument before colour measurements.

2.8 Hardness

A CT3 Brookfield Texture Analyzer (Middleboro, MA) equipped with a Rotary Base and TA7 blade was used to measure the Hardness of the extrudates. Hardness is defined as the maximum force per unit area of the extrudate that is required to break the sample into two pieces [18]. Five replicates of randomly chosen extrudate rods were placed in between the knife probe and rotary base. A trigger force of 50 g was set. This is the amount of force the probe should sense before starting to measure the breaking strength. During measurement a 50 % compression test was used and the probe was lowered at 1 mm speed until the extrudate rod broke into two pieces.

2.9 Sensory Evaluation

A panel of 15 members consisting of students and staff of the Post graduate and research centre PG&RC, Professor Jayashankar Telangana State Agricultural University, Hyderabad, India evaluated the extrudates. Written instructions were given and the panels were asked to evaluate the products for acceptability of its colour, taste, flavor, texture and overall acceptability by using nine points hedonic scale [19].

2.10 Scanning Electron Microscopy of Best Selected Quinoa Based Extrudates

Best selected sample was scanned under scanning electron microscope (SEM-Model: JOEL-JSM 5600). The dried samples were mounted over the stubs with double-sided carbon conductivity tape, and thin layer of gold coat over the samples were done by using an automated splatter coater (Model – JEOL JFC-1600) for 3 minutes and scanned under Scanning Electron Microscope (SEM – Model: JOEL-JSM 5600) at required magnifications as per the standard procedures at RUSKA Lab's college of Sri P.V. Narasimha Rao Telangana State University for Veterinary, Rajendranagar, Hyderabad, India [20].

2.11 Statistical Analysis of Data

The results were analysed for variance using ANOVA test followed by post hoc LSD test (P= .05), using Statgraphics Centurion software, Version 17.1.11.

3. RESULTS AND DISCUSSION

3.1 Expansion Ratio (ER)

Pair wise comparisons between treatments showed significant difference in the expansion ratio among the seven formulations studied (P= .05) which ranged from 2.99 to 3.44. QCR showed highest expansion ratio among the formulations (3.44) followed by QTR (3.25). These two formulations had 15% rice in common indicating the role of rice to enhance the expansion ratio of quinoa based extrudates while QCTR which contained less rice had lower expansion ratio (3.10). Positive effect of rice on expansion ratio could be due to increase of starch proportion than fat, protein and dietary fiber. Negative effect of high protein on expansion ratio was reported by Omwamba and Mahungu [21] and Guy [22]. Irrespective of formulations, among the three temperatures studied highestexpansion ratio was observed in extrudates prepared at 130˚C (3.19) followed by those prepared at 100˚C (3.11). This is in accordance with Omwamba and Mahungu [23] study, where protein rich ingredients were used and it was reported that expansion ratio of extrudates showed an increase with temperature increase up to about 130˚C and further increase in temperature negatively impacted expansion ratio. The interaction effect between temperature and flour blends (Table 2) was significant and significantly highest expansion ratio was observed for QCR at 130˚C (3.50) as well as QTP at 100˚C (3.50). However the interaction effect showed complicated results that can further simplified by considering at the basic ingredients of each blend. In simple word it can be said that favorable extrusion temperature was 130˚C for corn and rice and was 100˚C or low temperature for oats and sweet potato, however blending effect of corn-sweet potato was exception in which higher temperature was accompanied by higher expansion ratio. Moreover the rice blended formulations showed higher expansion ratio than blends without rice, which confirm the role of rice in enhancing the expansion ratio of quinoa based extrudates.

Table 2. Physico-chemical parameters and colour values of extrudates of quinoa based formulations

Level	Expansion	Bulk Density (g/cm3)	Hardness (g)	WAI	WSI	Color L*	Color a*	Color b*
GRAND MEAN	3.13	0.21	1440.24	6.28	12.28	75.91	2.75	23.84
Treatment								
QCR	3.44	0.16	$1430.00^{b,c,d}$	$6.14^{a,b}$	17.34	78.33	2.54	24.68
QCP	2.87	0.27	$1341.25^{a,b,c}$	6.38^{d}	11.01^{a}	74.74	2.85	26.06
QCT	3.03	0.23^{c}	$1281.67^{a,b}$	6.38^{d}	8.86	75.03	2.83^{a}	24.39
QCTR	3.10	0.20^{a}	$1580.83^{c,d,e}$	6.48^{d}	9.63	76.10	2.65	23.35
QCTP	2.99	$0.23^{b,c}$	1128.75^{a}	$6.33^{c,d}$	11.58^{a}	75.52	2.82^{a}	24.35
QTR	3.25	0.20^{a}	1720.33^{e}	$6.21^{b,c}$	12.77	76.48	2.81^{a}	21.71
QTP	3.21	0.22^{b}	$1598.83^{d,e}$	6.01^{a}	14.78	75.18	2.78	22.34
Temperature(˚C)								
100	3.11	0.24	1547.50^{a}	6.16^{a}	12.03^{a}	73.73	3.00	24.13
130	3.19	0.21	1683.93^{a}	6.18^{a}	12.47^{b}	76.94	2.53	23.27
150	3.08	0.20	1089.29	6.49	$12.34^{a,b}$	77.06	2.74	24.13
Treatment x Temperature(˚C)								
QCR,100	3.36	0.18	1395.00	6.35	12.59	77.33	3.00	24.55
QCR,130	3.50	0.15	2126.25	5.77	20.93	78.35	2.42	24.71
QCR,150	3.46	0.14	768.75	6.29	18.51	79.30	2.20	24.77
QCP,100	2.44	0.39	2162.50	5.20	14.69	71.31	3.00	26.31
QCP,130	2.97	0.25	942.50	6.85	8.39	75.24	2.84	25.97
QCP,150	3.20	0.18	918.75	7.10	9.95	77.68	2.72	25.90
QCT,100	2.95	0.27	716.25	6.75	8.36	72.81	3.08	25.24
QCT,130	3.24	0.20	1401.25	5.61	9.50	76.12	2.48	23.73
QCT,150	2.88	0.22	1727.50	6.80	8.72	76.15	2.93	24.21
QCTR,100	3.07	0.21	1906.25	6.75	6.78	74.52	2.80	24.07
QCTR,130	3.30	0.16	1577.50	6.49	9.92	77.17	2.24	21.22
QCTR,150	2.92	0.21	1258.75	6.20	12.19	76.60	2.90	24.76
QCTP,100	3.16	0.19	1413.75	6.00	12.37	72.59	3.06	24.67
QCTP,130	2.95	0.25	1138.75	6.42	11.17	76.96	2.73	24.21
QCTP,150	2.87	0.23	833.75	6.59	11.21	77.01	2.68	24.18
QTR,100	3.28	0.20	1373.50	6.35	13.36	74.81	3.33	21.25
QTR,130	3.24	0.21	2483.75	6.40	10.88	78.67	2.24	21.22
QTR,150	3.24	0.18	1303.75	5.89	14.08	75.96	2.86	22.67
QTP,100	3.50	0.21	1865.25	5.74	16.10	72.71	2.70	22.79
QTP,130	3.14	0.23	2117.50	5.70	16.54	76.10	2.76	21.85
QTP,150	3.00	0.23	813.75	6.58	11.72	76.73	2.87	22.39

**Significant at 5% level; Note: Values in same column with similar superscript are not significantly different from each other at 5% level as shown by post hoc LSD. QCR= Quinoa + Corn + Rice, QCP= Quinoa + Corn + Sweet Potato, QCT= Quinoa + Corn + Oats, QCTR= Quinoa + Corn + Oats + Rice, QCTP= Quinoa + Corn + Oats + Sweet Potato, QTR= Quinoa + Oats + Rice, QTP= Quinoa + Oats + Sweet Potato.*

3.2 Bulk Density (BD)

There was significant effect of treatment, temperature and their interaction on bulk density (P= .05) (Table 2). However there was a good relation between low bulk density and high expansion ratio where expansion ratio can indicate the size the bulk density can indicate the size to weight rate. The bulk density ranged from 0.16 g/cm^3 to 0.27 g/cm^3. Irrespective of temperature, QCR showed desirable lowest BD among all the blends (0.16 g/cm^3) followed by QTR and QCTR (0.20 g/cm^3) indicating the role of rice in lowering the bulk density of quinoa based extrudates which could be due to the increase in the starch content and decrease of the other components. Irrespective of the treatments, lowest BD was observed in the extrudates prepared at 150˚C (0.20 g/cm^3) followed by at 130˚C (0.21 g/cm^3) and at 100˚C (0.24 g/cm^3) which is in accordance with the study reported by Altan et al. [24]. Higher temperature leads to a more potential energy for flashing off the super-heated water out of the extrudate when it reach die end. Thus higher barrel temperatures cause the extrudates at the die end to lose more moisture and hence become lighter in weight [25]. Moreover increasing barrel temperature lead to a decrease in the melt viscosity and increase in the vapor pressure of water leading to higher bubble growth, which lead to higher expansion and smaller bubble wall thickness, thus reducing hardness and bulk density of the extrudates [25,26,27].

The interaction effect of treatment and temperature was also significant (P= .05) Table 2. The lowest BD was observed in QCR at 150˚C (0.14g/cm^3) followed by QCR at 130˚C (0.15 g/cm^3). QTP and QCTP showed higher BD with 0.22g/cm^3 and 0.23 g/cm^3 respectively, and it was observed that these two formulations had relatively lower BD at low extrusion temperature (100˚C). Here also many complicated interaction effect were observed and their simplification can be through considering the basic blends ingredients. In simple word it can be said that favorable extrusion temperature was 150˚C or high temperature for corn and rice and was 100˚C or low temperature for oats and sweet potato, however blending effect of corn-oats was exception in which 130 ˚C was more preferred and accompanied by lower bulk density while blends of oats-sweet potato had lower BD with lower temperature. Moreover the rice blended formulations showed higher expansion ratio than blends without rice. Which confirm the role of rice in enhancing the expansion ratio of quinoa based extrudates. This indicates good effect of sweet potato and oats blends on quinoa extrudates bulk density at lower temperature.

3.3 Hardness

There was a significant effect of treatment and temperature and their interaction on the hardness of the extrudates (P= .05) (Table 2). Hardness was measured as the maximum force (g) required under 50 % compression test to break the extruded rod into two pieces. The hardness ranged from 1128 g to 1720g as shown in Table 2. The lowest hardness was observed in QCTP, QCT, and QCP (1128.75g, 1281.67g and 1341.25g respectively) indicating good effect of sweet potato/corn mix and also oat/corn mix in lowering the hardness of extruded product. This effect could be due to low expansion ratio values for such formulations which made the breaking easier even though more compressed structure by lowering cutting distance required by knife probe of CT3 instrument so lower breaking force was required. QCR (1430g) was little behind QCTP but almost equal to QCT and QCP and by considering their expansion ratio values QCR could be considered better than QCT and QCTP. On the other hand QTP and QTR were hardest extrudates which had 25% of oats which indicated higher hardness when blending oat with Quinoa.

The temperature effect on the hardness showed that the lowest hardness was obtained in the extrudates prepared at 150˚C (1089.29g) followed by100˚C (1547.50g) as shown in Table 2. Ding et al. [13] reported that increasing barrel temperature led to a decrease in melt viscosity and an increase of the water vapor pressure. This favors the bubbles growth and thus led to higher expansion and lower density extrudates and also lower hardness of product. The interaction between temperature and treatments was also significant (P= .05) (Table 2). The lowest hardness was observed in QCT at 100˚C (716.25g) followed by QCR (768.72g), QTP (813.75g) and QCTP at 150˚C (833.75g).

3.4 Water Absorption Index (WAI) and Water Solubility Index (WSI)

The Water Absorption index (WAI) is a measurement of water absorbed by the flour and is related to its starch gelatinisation, so it can be used as index for starch gelatinisation [17]. Significant effect of treatments and temperature and their interaction was observed on the WAI (P= .05) (Table 2). WAI values for extruded quinoa based formulations ranged from 6.01 to 6.48 as shown in Table 2. The highest WAI was observed in QCTR, QCT, QCP and QCTP(6.48, 6.38 and 6.33 respectively) which had common ingredient that is corn/oat except QCP, on the other hand QCP showed higher WAI than QCTP and QTP which indicated better gelatinisation properties of corn/sweet potato mix than that of oat /sweet potato mix. QCR and QTR showed the lowest WAI that could be due to higher gelatinisation temperature of rice starch which led to lower gelatinisation. Irrespective of treatments, highest WAI was observed in extrudates prepared at 150˚C (6.49) followed by at 130˚C (6.18) and at 100˚C (6.16). However, there was no significant difference between 100˚C and 130˚C. Similar results were reported when measuring the WAI of

Table 3. Mean sensory evaluation scores of quinoa based extrudates

Level	Color	Texture	Taste	Flavor	Overall acceptability
GRAND MEAN	6.8	6.9	6.6	6.5	6.7
Treatment					
QCR	7.5^{b}	7.7^{c}	7.0^{c}	6.8c	$7.3^{c,d}$
QCP	5.8	5.9^{a}	5.7^{a}	5.6a	5.7^{a}
QCT	$6.5^{a,b}$	6.2^{a}	$6.1^{a,b}$	6.1a,b	$6.3^{a,b}$
QCTR	$7.1^{a,b}$	7.0^{b}	$6.7^{b,c}$	6.5b,c	$6.8^{b,c,d}$
QCTP	7.0^{a}	$7.0^{b,c}$	$6.8^{b,c}$	6.7c	$6.9^{b,c,d}$
QTR	7.3^{b}	$7.6^{b,c}$	7.3^{c}	7.0c	7.4^{d}
QTP	6.5^{a}	$7.0^{b,c}$	$6.8^{b,c}$	6.5b,c	$6.7^{b,c}$
Temperature (˚C)					
100	6.4	6.5	6.3^{a}	6.1^{a}	6.4^{a}
130	6.8	6.9^{a}	6.5^{a}	6.3^{a}	6.6^{a}
150	7.2	7.3^{a}	7.2	6.9	7.2
Treatment by Temperature (˚C)					
QCR,100	6.7	7.0	6.6	6.3	6.7
QCR,130	7.5	7.6	6.7	6.7	7.2
QCR,150	8.4	8.4	7.7	7.5	8.1
QCP,100	3.7	3.7	3.9	4.1	4.0
QCP,130	6.4	6.5	6.2	5.8	6.1
QCP,150	7.2	7.4	7.2	6.9	7.0
QCT,100	5.7	5.2	5.4	5.5	5.6
QCT,130	6.7	6.6	5.9	6.1	6.3
QCT,150	7.2	6.9	7.1	6.7	6.9
QCTR,100	7.0	6.7	6.6	6.7	6.6
QCTR,130	7.1	7.1	6.4	6.1	6.8
QCTR,150	7.1	7.3	7.1	6.7	7.1
QCTP,100	7.3	7.3	6.8	6.6	7.2
QCTP,130	6.6	6.6	6.8	6.7	6.6
QCTP,150	7.1	7.2	6.8	6.9	7.0
QTR,100	8.2	8.3	7.8	7.1	8.0
QTR,130	6.8	7.1	6.7	6.6	7.0
QTR,150	6.9	7.3	7.3	7.2	7.2
QTP,100	6.6	7.0	6.8	6.4	6.9
QTP,130	6.5	7.1	6.5	6.3	6.5
QTP,150	6.3	6.9	7.1	6.7	6.8

**Significant at 1% level; Note: Values in same column with similar superscript are not significantly different with each other at 5% level as shown by post hoc LSD. QCR= Quinoa + Corn + Rice, QCP= Quinoa + Corn + Sweet Potato, QCT= Quinoa + Corn + Oats, QCTR= Quinoa + Corn + Oats + Rice, QCTP= Quinoa + Corn + Oats + Sweet Potato, QTR= Quinoa + Oats + Rice, QTP= Quinoa + Oats + Sweet Potato.*

extruded quinoa based extrudates, whole pinto bean meal, and rice based extrudates including pea grits [27,28,29,30]. An opposite trend was reported by Gujral et al. [31], Yuliani et al. [32] and Hagenimana et al. [33].

The Water Solubility Index (WSI) is a measurement of soluble solids in the flour that is resulted from starch degradation during extrusion cooking [34,35]. WSI can be used as an indicator for measuring the degree of cooking in extruded products [17]. Unlike WAI there was no significant effect of temperature on WSI (p>0.05) (Table 2). WSI values for extruded quinoa based formulations ranged from 8.86% to 17.34% (Table 2). Lowest WSI value was obtained for QCT (8.86%) followed by QCTR (9.63 %), QCTP (11.58) and QCP (11.01%). This indicates the role of oat/corn mix in enhancing the WSI properties of extruded snacks. Highest WSI was observed in QCR (17.34%) followed by QTP (14.78%), which indicated higher degradation of starch molecules in those two formulations. Irrespective of treatments highest WSI was observed in extrudates prepared at 130˚C (12.47) followed by 150˚C (12.34). This phenomena was explained as increasing in temperature lead to increase in the starch gelatinisation degree and hence increase in the soluble starch amount which lead to increase of WSI [35]. However, there was no significant difference between 100˚C and 130˚C, as well as 130˚C and 150˚C (p>0.05).

3.5 Colour

Significant effect of treatment and temperature and their interaction was observed on L* a* b* values of the extrudates (P= .05) (Table 2). The most used system is the L* a* b* colour space due to its uniform colours distribution, and it is very close to human perception of colour [36]. Where L* stands for brightness, +a* redness, –a* greenness, +b* yellowness, and –b* blueness. The L* value for extruded quinoa based formulation ranged from 75.18 to 78.33 as shown in Table 2.QCR (78.33) showed most light colour and highest L* value among the formulations followed by QTR (76.48) and QCTR (76.10) which could be attributed to the presence of rice that is known to improve extruded product appearance by its light desirable colour. While QCP, QTP and QCT were the darker extrudates exhibiting low L* value when extruded at 100˚C, this could be due to lower expansion ratio value at that temperature which lead to more compressed structure and darker colour.

The a* values ranged from 2.54 to 2.83 while b* value ranged from 21.71 to 26.06. Highest a* value was observed in QCP (2.85) and lowest in QCR (2.54). There was no significant difference among QCTP, QCT and QTR. There was a significant interaction of temperature and treatment on a* value. Highest a* value was observed in QTR (3.33) followed by QCT (3.08) and QCTP (3.06) at 100˚C. On the other hand highest b* vale was observed in QCP (26.06) and it was higher than that of QCR, QCT, and QCTP (24.68, 24.39 and 24.35 respectively). The lowest b* value was observed in QTP (21.71) and QTR (22.34) which was expected due to the absence of corn that is known for its yellow colour in these two formulations.

3.6 Sensory Evaluation

The treatment and temperature and their interaction was significant on the sensory quality (P= .05, Table 3). It is interesting to observe that all formulations of quinoa extrudates processed at 150˚C temperature significantly scored higher than those that of other two temperatures in all sensory attributes evaluated. However, extrudates processed at 130˚C are relatively scored higher than those at 100˚C. Irrespective of the temperature, QCR and QTR scored highest in all sensory attributes followed by QCTR and QCTP. It could be observed that QCR and QTR had higher proportion of rice in their formulation compared to others, which resulted in acceptable texture, colour, taste and flavor of the extrudates. From the physico- chemical tests it could be observed that higher proportion of rice resulted in the higher expansion ratio, low BD and higher L* value. This suggests that inclusion of at least 15 percent rice in the quinoa based extrudates is favorable for better sensorial acceptability, which is crucial for any new product development.

3.7 Scanning Electron Microscopy

Sectional electron microscopy was used to scan the internal and external surface of QCR extrudates prepared at 130˚C and 150˚C.It can be seen from Fig. 3, that all cells were collapsed which could be due to the extensive processing used (high temperature and low moisture). No starch and protein structures were seen only fat particles (bright circles) was recognised and also some fibre could be observed. Disappearance of the intact structure of a starch globule in SEM image indicated gelatinisation of starch in an extruded sample [36-38]. Extrusion cooking, depending on food mix composition and process conditions, causes swelling and rupture of starch granules and then lead to disappearance of native starch crystallinity and gelatinisation of starch granules [39].

Fig. 1. Extrudates of Quinoa based formulations at three different temperatures
QCR= Quinoa + Corn + Rice, QCP= Quinoa + Corn + Sweet Potato, QCT= Quinoa + Corn + Oats, QCTR= Quinoa + Corn + Oats + Rice, QCTP= Quinoa + Corn + Oats + Sweet Potato, QTR= Quinoa + Oats + Rice, QTP= Quinoa + Oats + Sweet Potato.

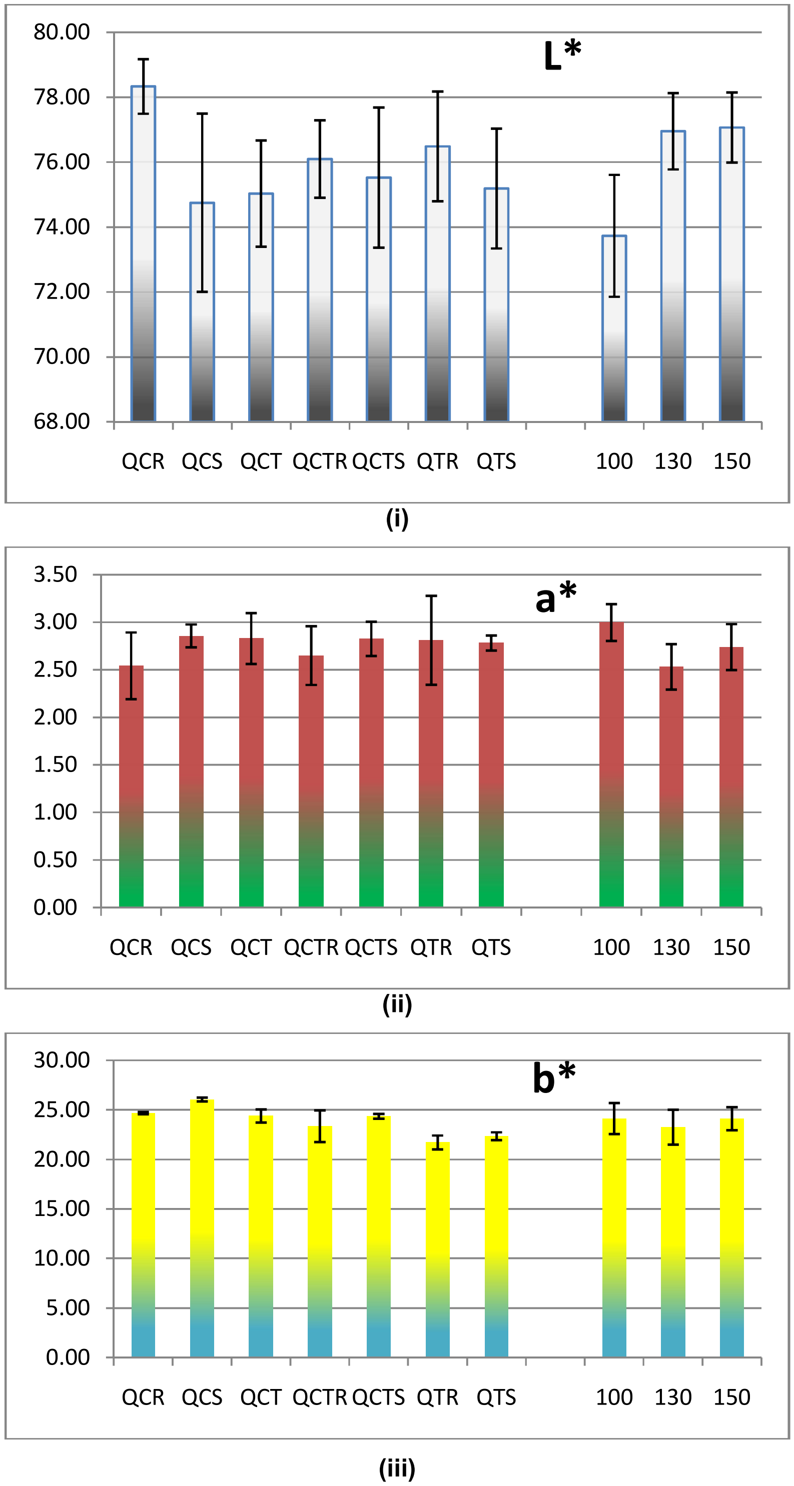

Fig. 2. L*, a* and b* value for extruded quinoa based formulations with SD

(i) L value, (ii) a* value, (iii) b* value, QCR= Quinoa + Corn + Rice, QCP= Quinoa + Corn + Sweet Potato, QCT= Quinoa + Corn + Oats, QCTR= Quinoa + Corn + Oats + Rice, QCTP= Quinoa + Corn + Oats + Sweet Potato, QTR= Quinoa + Oats + Rice, QTP= Quinoa + Oats + Sweet Potato*

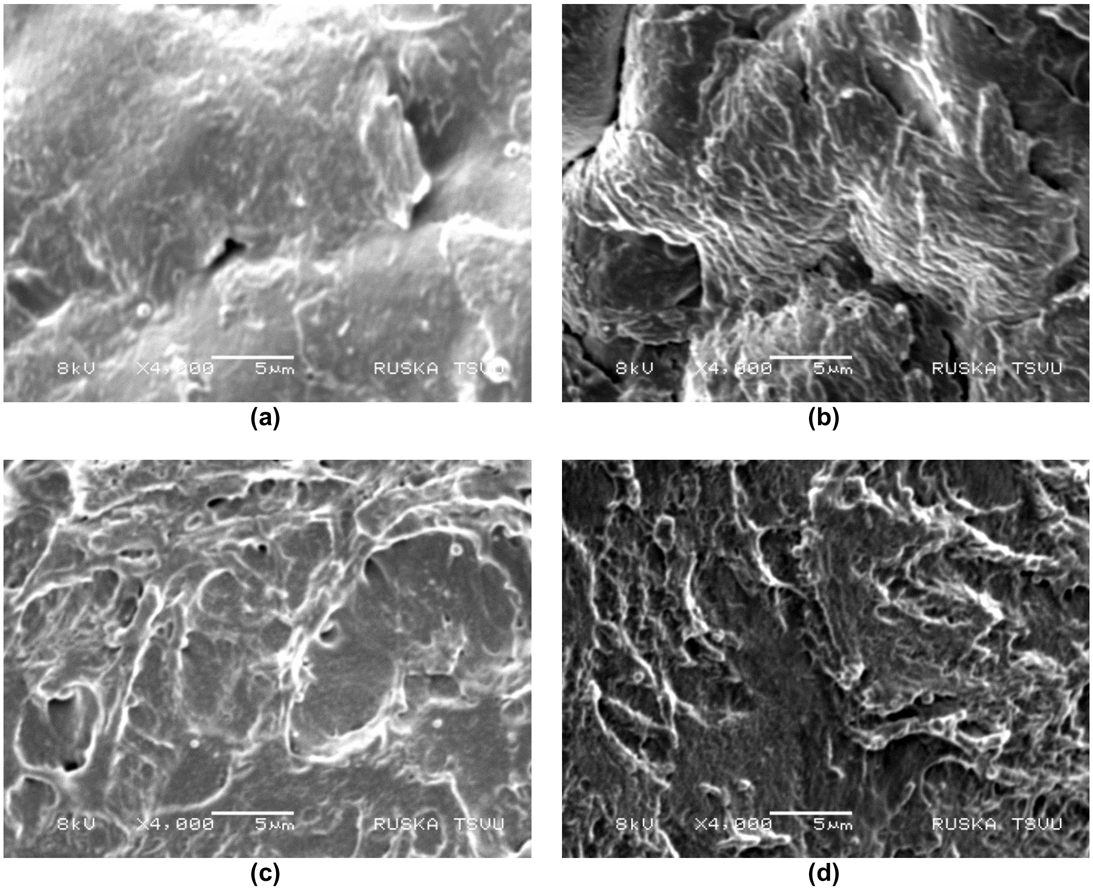

Fig. 3. Internal and external scanning electron microscopy pictures of the quinoa based extrudates at two different temperatures

a) External picture at 130˚C, b) External picture at 150˚C
c) Internal picture at 130˚C, d) Internal picture at 150˚C

The external surface was more smooth and homogenous with little roughness for QCR processed at 130˚C and less porous compared to QCR processed at 150˚C (Fig. 3). Serrated appearance was observed on the surface of the extrudates of QCR processed at 150˚C. Smooth surface in the earlier case might be due to the plasticity of the product as a result of its extrusion parameters. With regards to internal structure the QCR processed at 150˚C was more porous and crimped than QCR processed at 130˚C with some smoothness. Cell structure with thinner walls was observed in extrudates made at 150˚C extrudates. A clear and more fibrous network with more air spaces was also observed in extrudates processed at 150˚Ccompared to those at 130˚C. Rough and porous structure with air spaces are more preferred for this type of products. The results of the SME are well supported by high WAI, less hardness, low WSI and more lightness of the QCR processed at 150˚C.

4. CONCLUSION

Quinoa has great nutritional and cultivation features and can contribute greatly to the food security, incorporation of quinoa in the diet can be successfully done using extrusion cooking which is environmental friendly and cost effective technique. It was observed that QCR & QTR extrudates had favorable attributes in term of expansion, bulk density, L* value and sensory attributes evaluated. Moreover higher temperature had enhancement on product attributes such as bulk density, hardness, L*value, WAI and also all sensory attributes evaluated. Present study proved that it was possible to get acceptable extrudates by using 60% quinoa and the best formulation was QCR &

QTR (Quinoa: Corn: Rice& Quiona:Oats:Rice) at 60:25:15 proportion extruded at 150 C. QTR is promising combination which combine nutritional benefits of both quinoa and oats hence more protein and soluble dietary fiber, therefore QTR would be a better choice in nutritional aspect.

CONSENT AND ETHICAL APPROVAL

It is not applicable.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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Peer-review history:
The peer review history for this paper can be accessed here:
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