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Innovative and Sustainable Tomato Snack Bars: Utilizing Food Waste and Plant Proteins for Functional Products

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This project has received funding from the European Union's PRIMA programme under grant agreement No 2032

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INTRODUCTION

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Sustainable Production

- Sustainable food production is crucial for reducing environmental impact and ensuring food security.

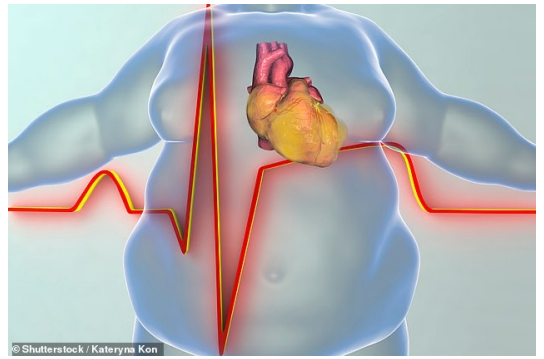
- Our study focuses on creating functional food products from food waste, specifically tomato waste, and plant-based proteins.

- This work aligns with several Sustainable Development Goals.

Mediterranean Diet

Ready-to-eat snacks

- Increasing demands for ready-to-eat and snack foods have changed the eating habits of consumers.
- Consumption of such foods constitutes a risk factor for developing cardiovascular diseases and obesity (Miranda et al., 2019).



Cardiovascular diseases and obesity

Mediterranen diet foods

- The Mediterranean diet is highly recommended for a balanced lifestyle (Casas et al., 2018).
- The diet comprises fruits and vegetables, vitamins, minerals, omega-3 fatty acids, lycopene, and polyphenols (Uylaşer & Yildiz, 2014).


Tomato


Olives


Pea


Sugar beet


Chickpea

- Tomatoes have lycopene, olives contain polyphenols, peas, chickpeas and sugar beet leaves are rich in protein.

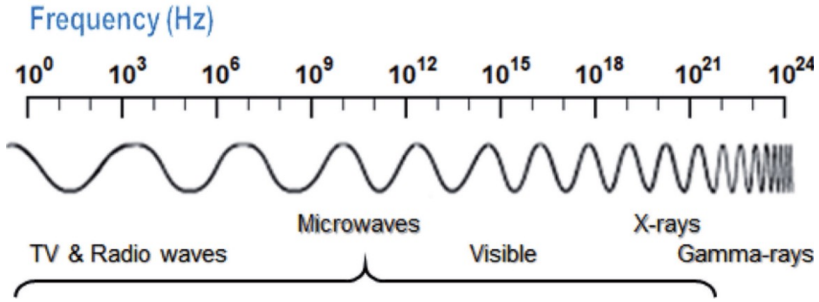
Snack bars

- More plant-based health-promoting alternatives of snacks with high nutritional value have been demanded nowadays. (Mostafavi et al., 2021)

Plant-based snack bars in industry

Microwave-Vacuum Drying

- Microwave drying is one of the novel food processing techniques (Baghel, 2023).
- Microwaves convert electromagnetic energy into thermal energy by causing internal friction and vibrations of polar molecules in food.



Electromagnetic wave spectrum (Ari Adi et al., 2019).

Dehydrated fruits

- High temperatures and long processing times are not desired for high food quality.
- Microwave-assisted heating systems have gained significant interest due to their advantages (Yılmaz et al., 2018).
- Microwave vacuum (MWV) drying technology uses a vacuum to prevent high temperatures (González-Cavieres et al., 2021).
- Vacuuming results in reduced pressure, lowering the evaporation temperature.
- Shorter processing time, less energy consumption, and more nutrient preservation are achieved.

Microwave-vacuum dryer

MATERIALS AND METHODS

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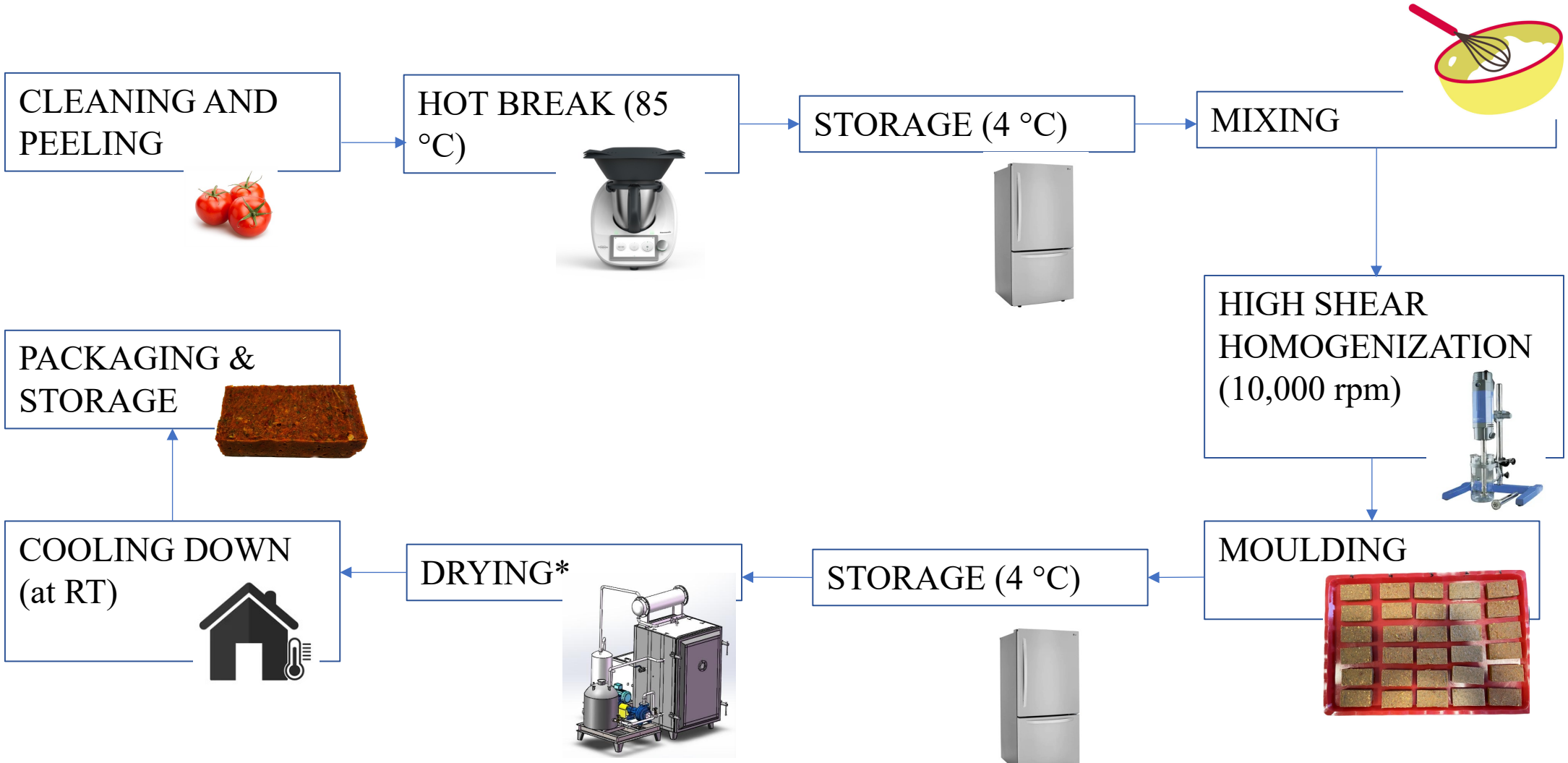
Materials for production

Table 1. Composition of the tomato snack bar

Ingredients	Amounts (g)
Tomato juice	100
PPI / CP / RUB	0 / 5 / 10
Salt	2
Olive powder	2
Rosemary	1
Thyme	1
Red pepper powder	1
LMP	1
Tomato powder	10

Flow chart of production



*Microwave-vacuum dryer was run at 100% power, 20-kPa vacuum pressure for 6-minutes. A conventional oven was used at 120°C for 90 minutes to obtain the control samples.

Experimental Design and Studied Parameters

Table 2. Experimental Design of tomato snack bars

Sample#	PEA (%)	CHICKPEA (%)	RUBISCO (%)
1	5	-	5
2	10	-	-
3	5	5	-
4	-	5	5
5	-	10	-
6*	10	-	-

*Represents the conventionally dried sample.

STUDIED PARAMETERS
Water activity
Moisture content
Color measurement
Texture
Lycopene content
NMR T_2
Sensory

Color

- CIE$L^*a^*b^*$ values were measured using a portable Spectro colorimeter.

Serlab SL400, İstanbul, Turkey

Moisture content & water activity, a_w

- The moisture content (MC) of samples was determined gravimetrically by drying the samples at 105°C.
- The a_w was determined by using a Water Activity Meter.

Aqua Lab 4TE (Decagon Devices Inc., Pullman, Wash., U.S.A)

NMR T_2

- T_2 relaxation times were measured using Carr-Purcell-Meiboom-Gill (CPMG) sequence.

Spin Track, Resonance Systems GmbH, Kirchheim/Teck, Germany

Lycopene

- Lycopene was extracted from the sample and read by UV-vis spectrophotometer.

Optizen Pop, Mecasys, Daejeon, Republic of Korea.

FTIR

- The powder forms of samples were examined using an IR Affinity-1 Spectrometer.

Shimadzu Corporation, Kyoto, Japan

Texture

- Texture Profile Analysis (TPA) was performed with a texture analyzer instrument.

CT3 Brookfield, Middleboro, USA

Sensory

- 6 Sensory panelist experts conducted tests on snack bars.

SELUZ Fragrance Company, Istanbul

RESULTS & DISCUSSION

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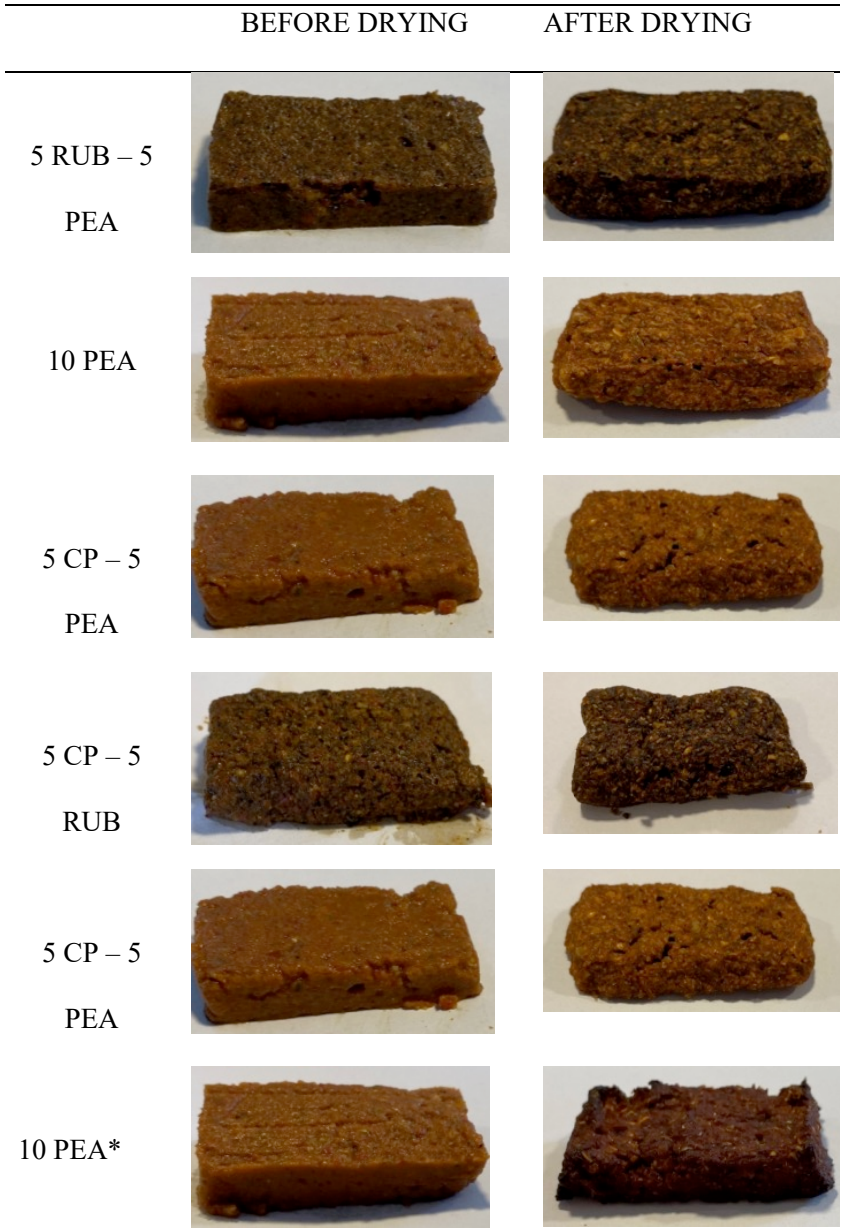
Formulation and visual appearance of the tomato snack bars



- All the proteins contributed to a good visual appearance and shape.
- Rubisco protein resulted in the darkest tomato snack bar.
- A darker color was observed for the conventional oven drying than MWV.
- Crust formation occurred in the conventionally dried snack bars.

Photos of tomato snack bars with different proteins before and after microwave-vacuum and conventional drying*

Color Results

Table 3. Effect of protein type and concentration on L^*, a^*, and b^* values of tomato snack bars

Protein 1 (%)	Protein 2 (%)	L^*	a^*	b^*
5 RUB	5 PEA	31.5 ± 0.0^{bc}	12.8 ± 0.2^{b}	19.9 ± 0.4^{bc}
10 PEA	-	38.1 ± 0.8^{aA}	21.2 ± 0.2^{aA}	27.1 ± 0.3^{aA}
5 CP	5 PEA	35.6 ± 1.0^{ab}	21.4 ± 0.2^{a}	26.0 ± 0.1^{a}
5 CP	5 RUB	27.6 ± 1.4^{c}	11.8 ± 0.0^{b}	17.5 ± 1.0^{c}
10 CP	-	32.8 ± 2.0^{b}	19.9 ± 0.7^{a}	23.6 ± 1.0^{ab}
10 PEA*	-	30.6 ± 0.3^{B}	17.6 ± 0.2^{B}	17.9 ± 0.5^{B}

*Represents the conventionally dried sample. Different small letters indicate significant differences ($p < 0.05$) within the microwave-vacuum dried samples, whereas different capital letters indicate significant differences ($p < 0.05$) between conventionally dried and microwave-vacuum dried samples at the same protein type and concentration. Errors are represented as standard deviations.

- Pea, chickpea, and rubisco proteins contributed to the lightness, redness, and yellowness in descending order.

Water activity and Moisture content Results

Table 4. Moisture content and water activity of tomato snack bars

Protein 1 (%)	Protein 2 (%)	Moisture Content (%)	a_w
5 RUB	5 PEA	22.3 ± 1.6^{a}	0.66 ± 0.0^{a}
10 PEA	-	22.2 ± 2.1^{aA}	0.65 ± 0.0^{aA}
5 CP	5 PEA	21.3 ± 0.7^{a}	0.66 ± 0.0^{a}
5 CP	5 RUB	21.1 ± 1.8^{a}	0.66 ± 0.0^{a}
10 CP	-	19.8 ± 0.9^{a}	0.64 ± 0.0^{a}
10 PEA*	-	32.9 ± 1.6^{B}	0.69 ± 0.0^{A}

*Represents the conventionally dried sample. Different small letters indicate significant differences ($p < 0.05$) within the microwave-vacuum dried samples, whereas different capital letters indicate significant differences ($p < 0.05$) between conventionally dried and microwave-vacuum dried samples at the same protein type and concentration. Errors are represented as standard deviations.

- There were no significant differences between the samples for both water activity (a_w) and moisture content for the microwave-vacuum dried samples ($p>0.05$).
- Moisture content was significantly higher in the conventional sample.

Lycopene Results

Table 5. Lycopene content of tomato snack bars

Protein 1 (%)	Protein 2 (%)	Lycopene (mg lycopene/g dry solid)
5 RUB	5 PEA	48.3 ± 2.6^{a}
10 PEA	-	32.6 ± 3.3^{bA}
5 CP	5 PEA	48.4 ± 6.0^{a}
5 CP	5 RUB	50.3 ± 5.4^{a}
10 CP	-	30.8 ± 2.3^{b}
10 PEA*	-	39.7 ± 5.2^{A}

*Represents the conventionally dried sample. Different small letters indicate significant differences ($p < 0.05$) within the microwave-vacuum dried samples, whereas different capital letters indicate significant differences ($p < 0.05$) between conventionally dried and microwave-vacuum dried samples at the same protein type and concentration. Errors are represented as standard deviations.

- Lycopene amount was higher in mixed protein samples, especially rubisco-added ones.
- Lycopene content did not change significantly ($p>0.05$) with drying type.

Texture Results

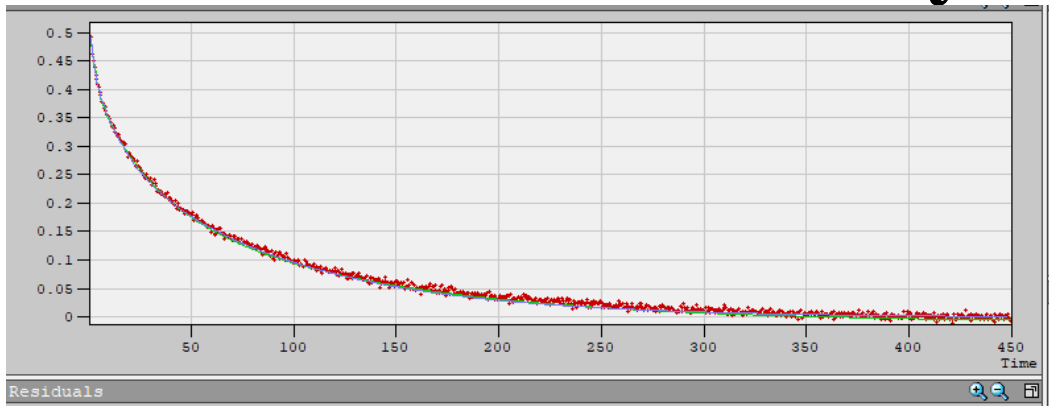
Table 6. Textural properties of tomato snack bars

Protein 1 (%)	Protein 2 (%)	Hardness (N)	Gumminess (N)	Chewiness (g.cm)	Cohesiveness
5 RUB	5 PEA	22.7 ± 6.4^{a}	11.7 ± 3.4^{ab}	144.7 ± 15.3^{a}	0.52 ± 0.0^{ab}
10 PEA	-	19.2 ± 3.2^{aA}	10.4 ± 1.8^{abA}	162 ± 0.8^{aB}	0.54 ± 0.0^{aA}
5 CP	5 PEA	21.2 ± 6.8^{a}	11.3 ± 3.2^{ab}	162.7 ± 4.9^{a}	0.54 ± 0.0^{a}
5 CP	5 RUB	17.5 ± 5.1^{a}	8.3 ± 2.3^{b}	88 ± 5.7^{b}	0.48 ± 0.0^{b}
10 CP	-	24.7 ± 4.8^{a}	13.6 ± 1.8^{a}	157.3 ± 9.7^{a}	0.56 ± 0.0^{a}
10 PEA*	-	27.8 ± 8.7^{A}	15.0 ± 4.6^{A}	225.7 ± 14.7^{A}	0.54 ± 0.0^{A}

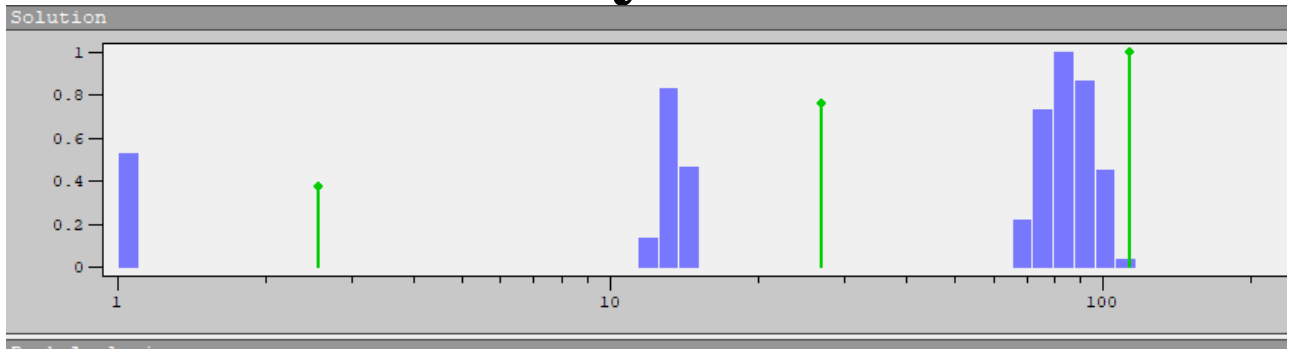
*Represents the conventionally dried sample. Different small letters indicate significant differences ($p < 0.05$) within the microwave-vacuum dried samples, whereas different capital letters indicate significant differences ($p < 0.05$) between conventionally dried and microwave-vacuum dried samples at the same protein type and concentration. Errors are represented as standard deviations.

- Hardness values were found insignificant ($p>0.05$) among the different protein samples.
- Rubisco protein decreased, and pea protein increased the values of other textural attributes.
- The chewiness of the conventionally dried sample was significantly higher than that of the microwave-vacuum-dried samples.

Distribution of water by NMR relaxometry



Data and fitted curve



Distribution & discrete component analysis mode of XPFit software for a representative T2 data

- Three-component model of the transverse relaxation behavior was examined.
- Each proton pool is represented with a peak and its corresponding area (contribution to the signal).
- Short, T_{21}: strongly bound.
- Moderate, T_{22}: weaker interaction of water with solids.
- Long, T_{23}: the least interaction with polymer structure (bulk water).

Distribution analysis

Fitting range : [1; 900]
Number of Intervals : 70
Boundaries : [1.000; 900.0]
Resolution : 0
χ^2 : 0.047

Peak Num	B	Bnorm	τ	T	Std τ
1	0.049	0.100	1.051	1.051	0.029
2	0.134	0.272	13.47	13.15	0.871
3	0.309	0.628	85.58	83.32	9.949

Background : 0

Discrete Components Analysis

Fitting range : [1; 900]
χ^2 : 0.050
$\Delta\chi^2$ [Error Analysis] : 3.5e-7

Exponential	B	Bnorm	τ
1	0.090	0.175	2.514
Confidence Interval	- 0.022 , + 0.024		- 1.886 , + 1.110
2	0.184	0.357	26.58
Confidence Interval	- 0.019 , + 0.023		- 5.943 , + 5.644
3	0.242	0.469	112.4
Confidence Interval	- 0.033 , + 0.023		- 9.661 , + 12.94

Background : -0.009
Confidence Interval :- 0.003 + 0.002

Peak analysis

NMR T_2 Results

Table 7. T_2 values and their corresponding areas of tomato snack bars

Protein 1 (%)	Protein 2 (%)	T_{21} (ms)	T_{22} (ms)	T_{23} (ms)
5 RUB	5 PEA	1.47 ± 0.04^{a}	14.27 ± 0.92^{c}	80.79 ± 0.17^{c}
10 PEA	-	1.38 ± 0.03^{abB}	15.18 ± 0.68^{bcA}	82.9 ± 2.74^{cA}
5 CP	5 PEA	1.18 ± 0.12^{bc}	21.07 ± 0.04^{a}	91.11 ± 1.27^{a}
5 CP	5 RUB	1.32 ± 0.07^{ab}	17.29 ± 0.94^{b}	84.51 ± 2.27^{bc}
10 CP	-	1.08 ± 0.03^{c}	21.12 ± 0.24^{a}	89.54 ± 0.47^{ab}
10 PEA*	-	2.36 ± 0.03^{A}	12.69 ± 0.02^{B}	82.78 ± 0.02^{A}

*Represents the conventionally dried sample. Different small letters indicate significant differences ($p < 0.05$) within the microwave-vacuum dried samples, whereas different capital letters indicate significant differences ($p < 0.05$) between conventionally dried and microwave-vacuum dried samples at the same protein type and concentration. Errors are represented as standard deviations.

- T_2 was affected by drying type; mw-vacuum drying was more successful in removing the bound water due to shorter T_{21}.

Sensory Results

Table 8. The taste and flavor evaluation results were as follows:

Sample	Tomato paste flavor	Dried tomato flavor	Saltiness	Sweetness	Sourness/ Astringency	Spicy notes	Crunchiness	Overall impression
5 RUB- 5 PEA	2.5	2	1.5	1.5	3	3.2	1	2.5
10 PEA	1.5	3	2	1.5	3.2	2.5	1	2.8
5 CP- 5 PEA	2	3.2	1.8	1.5	2.5	2.5	1	4
5 CP- 5 RUB	3	1.5	2	1.2	3.4	2.8	1	2.6
10 CP	1.8	2	1.5	1.5	2	1.5	1.5	2
CONV 10 PEA	1	3.5	2	1.2	2.5	2	1	3.5

- Sensory results showed that the best formulation was the chickpea-pea mixture dried in MWV in terms of appearance and taste.

Sustainability Approach of the Study

Contribution to SDGs:

SDG 2: Zero Hunger: By promoting the use of food waste and transforming it into nutritious snack bars. By utilizing agricultural waste, such as sugar beet leaves and tomato skins, we are not only reducing food waste but also creating a sustainable food source that can help alleviate hunger and provide essential nutrients.

SDG 3: Good Health and Well-being: The tomato snack bars are enriched with plant-based proteins and antioxidants like lycopene from tomatoes and health-promoting compounds from olives. This offers a healthy, nutrient-dense snack option that can help improve dietary habits and overall health.

Sustainability Approach of the Study

Contribution to SDGs:

SDG 12: Responsible Consumption and Production: By utilizing food waste and sustainable ingredients in the production of tomato snack bars. This approach encourages more sustainable food production practices and promotes the efficient use of resources, reducing the environmental impact of food production.

SDG 13: Climate Action: Reducing food waste helps lower greenhouse gas emissions associated with food production and waste management. Additionally, plant-based proteins have a lower carbon footprint compared to animal-based proteins, contributing to climate change mitigation.

SDG 15: Life on Land: By promoting the use of agricultural by-products such as tomato waste and sugar beet leaves. This practice helps reduce the environmental burden on land and supports biodiversity by encouraging the use of diverse plant-based ingredients.

Key Ingredients in the Sustainability Aspect

- **Sustainability Aspects of Key Ingredients**:

Olive Powder: The production of olive powder involves drying and grinding olives, a process that can utilize surplus or lower-grade olives that might otherwise go to waste. Using olive powder not only adds nutritional value to the snack bars but also supports sustainable agricultural practices.

Tomato Powder: Tomato powder is produced by drying and grinding tomatoes, preserving their nutritional properties such as vitamins, minerals, and antioxidants like lycopene. This process is an effective way to use residue or damaged tomatoes that are not suitable for fresh sale. Incorporating tomato powder into snack bars helps reduce food waste.

Rubisco Protein: Rubisco protein is extracted from sugar beet leaves, which are often considered a by-product of sugar production. Rubisco is a highly efficient protein providing a valuable source of plant-based protein. Utilizing rubisco protein from sugar beet leaves adds value to what would otherwise be agricultural waste, supporting circular economy principles.

CONCLUSION & FUTURE WORK

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CONCLUSIONS

- The snack bars contribute to multiple SDGs by utilizing food waste and plant-based proteins.
- Our work demonstrates how innovative food products can contribute to a more sustainable and healthy future.
- The study demonstrated the feasibility of producing healthy snack bars economically.
- Functional snack bars can be produced with a minimal number of ingredients by using mw-vacuum drying.
- Protein types and concentrations affected the properties of snack bars.
- Browning, and crust formation occurred more in the conventionally dried samples, which were undesirable characteristics.
- Microwave-vacuum drying is superior to conventional drying in terms of time and energy efficiency, and quality properties.

FUNTOMP DECLARATION

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- Some part of the study was presented at the 37th **EFFOST** conference in 2023.

THANK YOU ☺

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BACK-UP SLIDES

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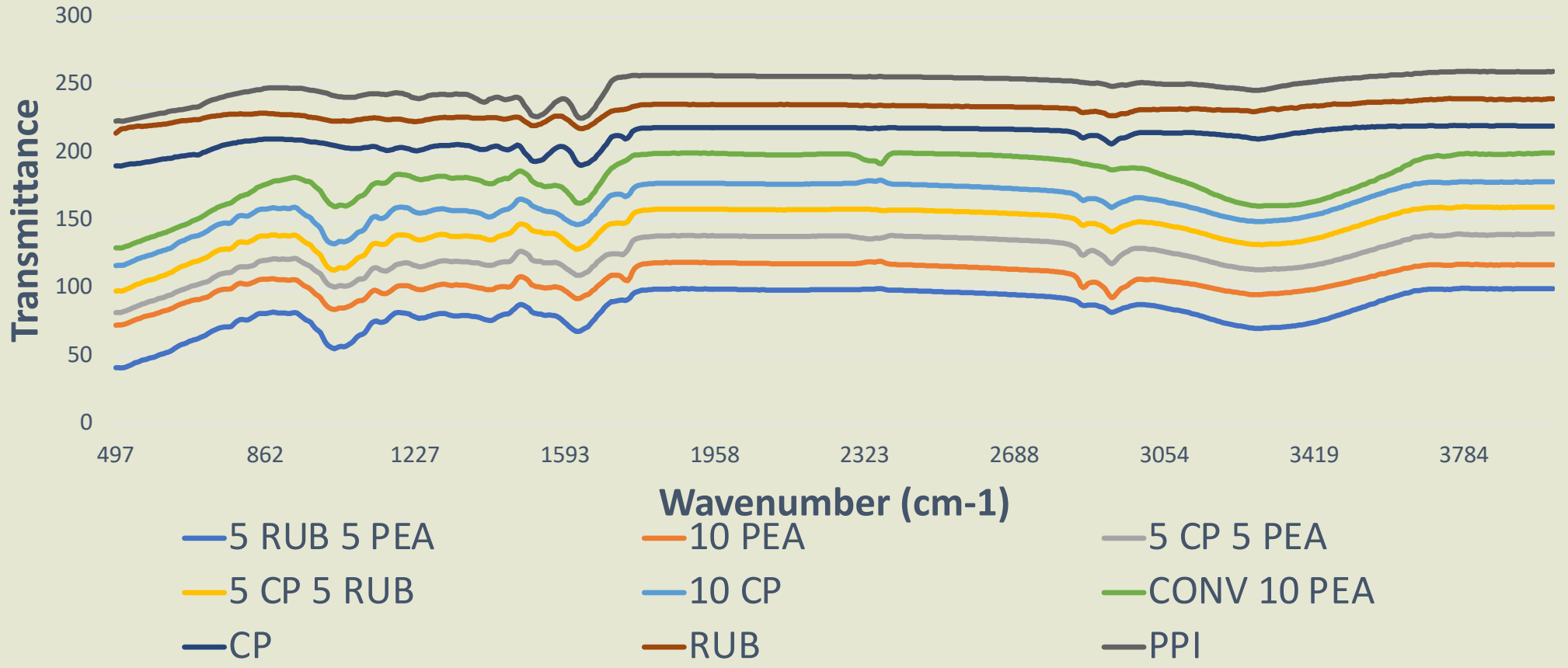
FTIR spectroscopy



FTIR spectra of the snack bars and selected proteins

NMR Area Results

Table 9. Area values and their corresponding areas of tomato snack bars

Protein 1 (%)	Protein 2 (%)	Area (%)	Area (%)	Area (%)
5 RUB	5 PEA	77.9 ± 0.59^{a}	9.7 ± 0.22^{c}	12.43 ± 0.57^{c}
10 PEA	-	79.5 ± 0.50^{aA}	8.23 ± 0.42^{dB}	12.23 ± 0.25^{Ca}
5 CP	5 PEA	73.8 ± 0.88^{b}	10.93 ± 0.60^{b}	15.27 ± 0.45^{b}
5 CP	5 RUB	72.7 ± 0.49^{b}	10.9 ± 0.29^{bc}	16.4 ± 0.72^{b}
10 CP	-	68.5 ± 0.50^{c}	13.0 ± 0.12^{a}	18.5 ± 0.57^{a}
10 PEA*	-	78.3 ± 0.08^{B}	12.6 ± 0.04^{A}	9.03 ± 0.05^{B}

*Represents the conventionally dried sample. Different small letters indicate significant differences ($p < 0.05$) within the microwave-vacuum dried samples, whereas different capital letters indicate significant differences ($p < 0.05$) between conventionally dried and microwave-vacuum dried samples at the same protein type and concentration. Errors are represented as standard deviations.