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MIDDLE EAST TECHNICAL UNIVERSITY

FORMULATION AND CHARACTERIZATION OF A FUNCTIONALIZED TOMATO SNACK BAR

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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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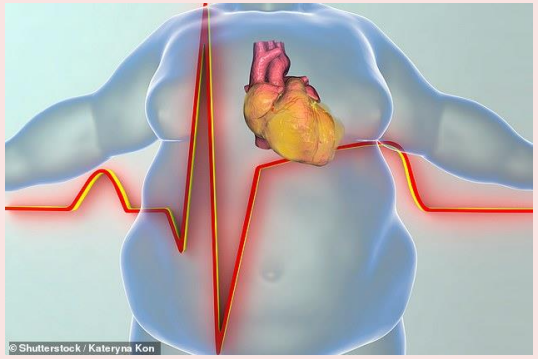
Ready-to-eat snacks

- 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 one of the best options for a healthy lifestyle (Casas et al., 2018).
- The diet comprises fruits and vegetables, vitamins, minerals, omega-3 fatty acids, lycopene, and polyphenols (Uylaşer & Yildiz, 2014).

Tomato

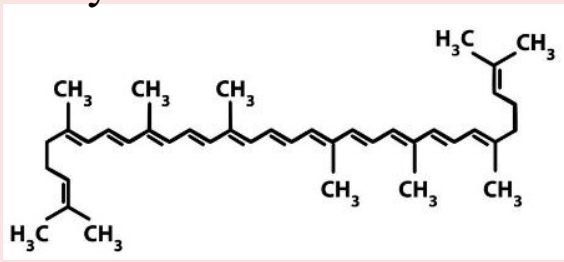
Olives

Pea

- Tomatoes are high in lycopene, olives contain polyphenols, and peas are rich in protein and fiber.

- Tomatoes, a red-colored fruit rich in lycopene and calcium, can enhance the nutritional value of many foods (Ali et al., 2021).
- Lycopene, a lipophilic carotenoid, is predominantly found in red fruits and vegetables (Leslie et al., 2015).

Tomato

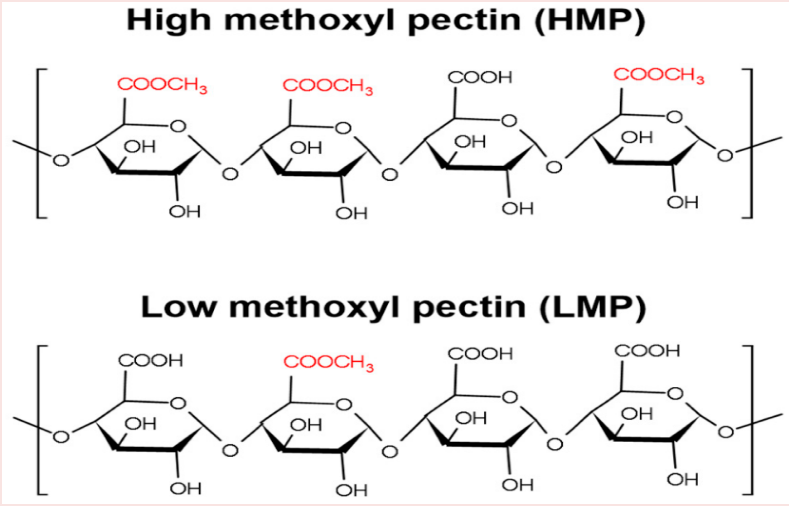


Molecular Structure of Lycopene

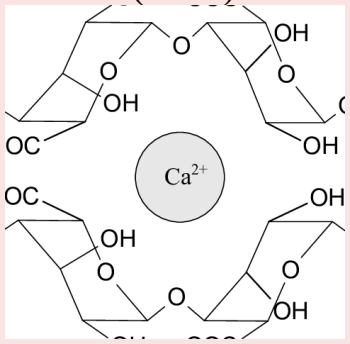
- Pectins are acid polysaccharides found in many fruits and used as gelling or thickening agents in the food industry (Witkamp, 2010).

Pectin

- Classification of pectins can be done by low-ester pectin and high-ester pectin.
- Degree of esterification (DE) is also known as degree of methylation (DM).
- LMP-Ca^{++} interaction enhances the gelling ability of foods.

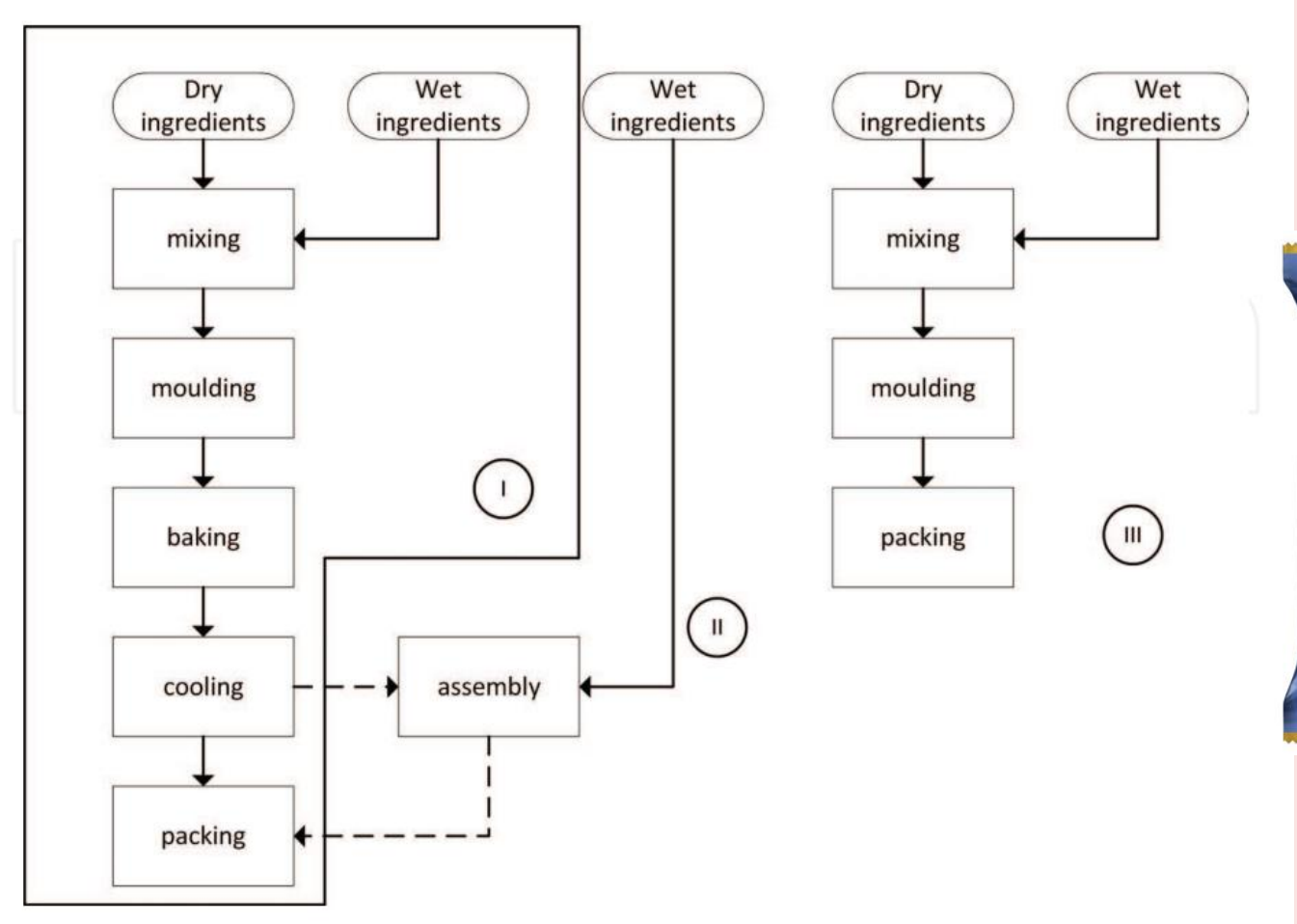


Chemical structure of LMP and HMP (Steigerwald et al., 2022).



Calcium-pectin interaction

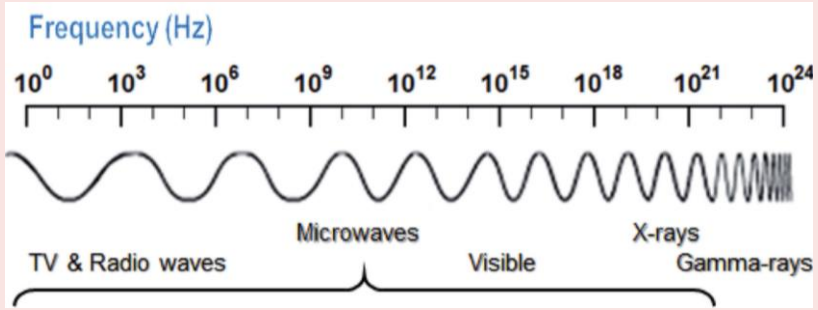
- More plant-based health-promoting alternatives of snacks with high nutritional value have been demanded nowadays (Mostafavi et al., 2021).
- Conventional snack bar production often includes molding and baking steps (Ramírez-Jiménez et al., 2018).



Flow chart of baked (1), baked with filling (2), and cold-formed snack bars (3) (Constantin & Istrati, 2018).

Plant-based snack bars

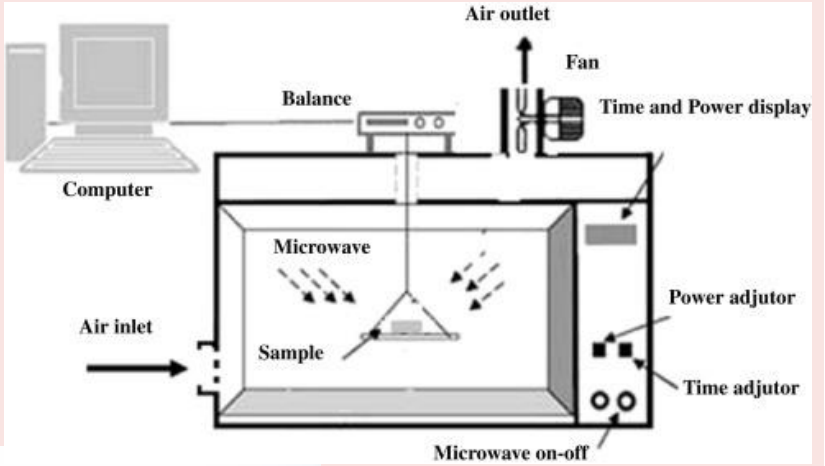
- There are novel processing techniques for drying of foods (Baghel, 2023).
- Microwave drying is one of them.
- Electromagnetic energy is converted to thermal energy by microwaves, due to internal friction and vibrations of the polar molecules in foods.



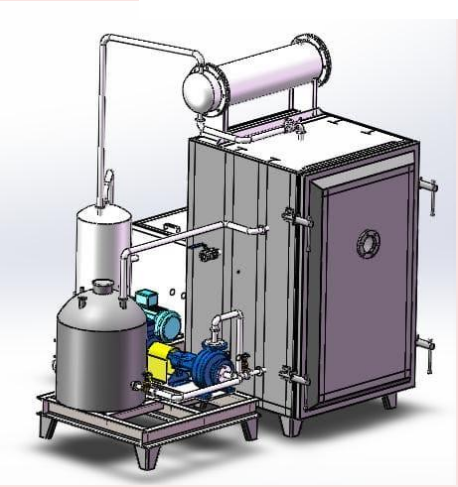
Electromagnetic wave spectrum (Ari Adi et al., 2019).

- 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).
- It helps to decrease processing time, energy consumption and preserve more nutrients.

Different types of novel dryers

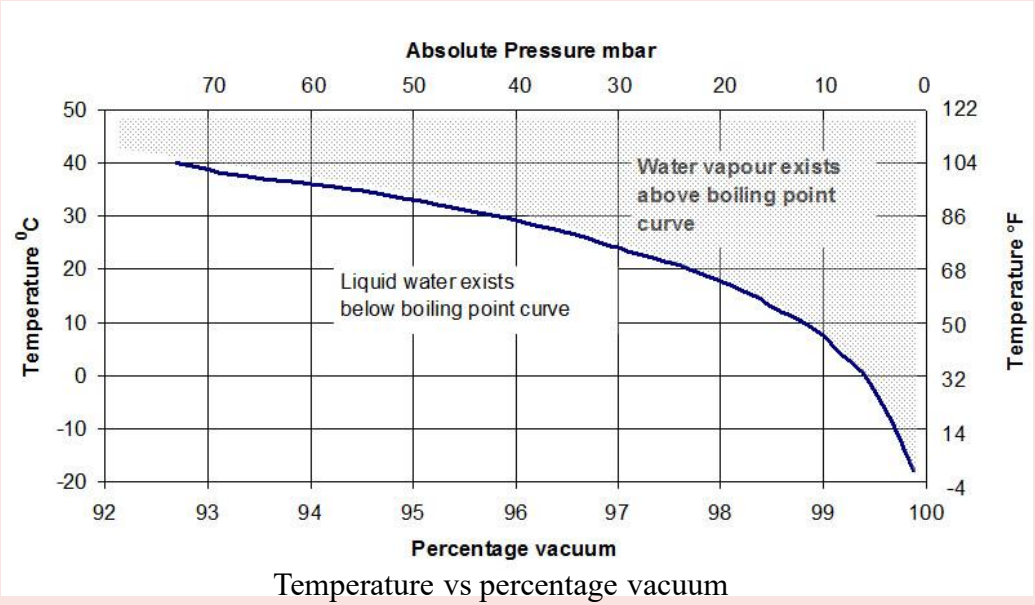


Microwave drying



Microwave-vacuum dryer

- Microwave vacuum drying technology prevents high temperatures by the involvement of a vacuum during microwave processing (González-Cavieres et al., 2021).
- Vacuuming leads to a decrease in the pressure inside the microwave vacuum chamber, leading to a decrease in evaporation temperature.



Temperature vs percentage vacuum

- Shorter processing time, less energy consumption, and more nutrient preservation are achieved.

Comprehensive overview of our microwave-vacuum dryer

MATERIALS AND METHODS

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Experimental Design

FACTORS	LEVEL
Tomato Powder, TP (%) (w/w)	0-8-12-16
Low Methoxyl Pectin, LMP (%)	0-1-2-3
Drying type	Microwave-vacuum dryer (150 torr, 100% power, 5 min) & Conventional oven (120°C, 90 min)

Materials for production

Ingredients	Amounts (g)
Tomato juice	100
PPI	10
Salt	2
Olive powder	2
Mint	1
Thyme	1
Red pepper powder	1
LMP*	1/2/3
TP*	8/12/16

*All LMP and TP concentrations are given as 100-g tomato juice basis

Flow chart of production

CLEANING AND PEELING

HOT BREAK (85 °C)

STORAGE (4 °C)

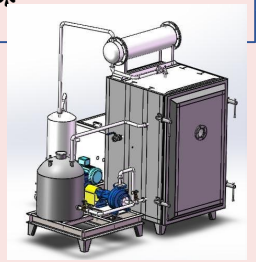
MIXING

HIGH SHEAR HOMOGENIZATION (10,000 rpm)

MOULDING

STORAGE (4 °C)

DRYING*



COOLING DOWN (at RT)

PACKAGING & STORAGE

*Drying was conducted by microwave-vacuum and conventional oven

Studied parameters

	Mw-vacuum drying (150 torr, 100% power, 5 min)	Conventional drying (120°C, 90 min)
Color measurement	+	+
Moisture content	+	+
Water activity	+	+
Moisture Sorption Isotherm	+	
NMR T_2	+	+
Lycopene content	+	+
FTIR spectroscopy	+	+
Texture	+	+

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

RESULTS & DISCUSSION

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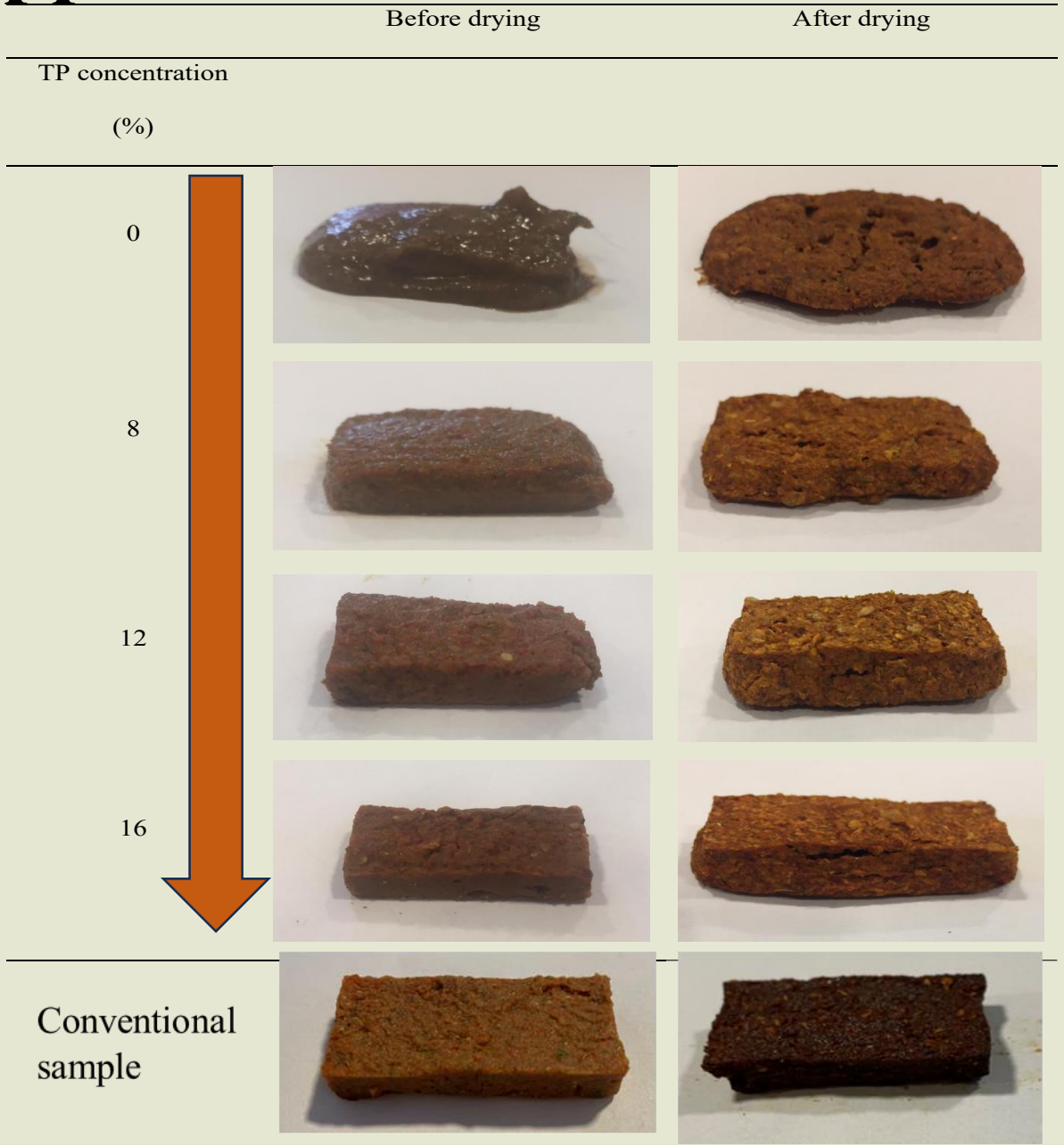
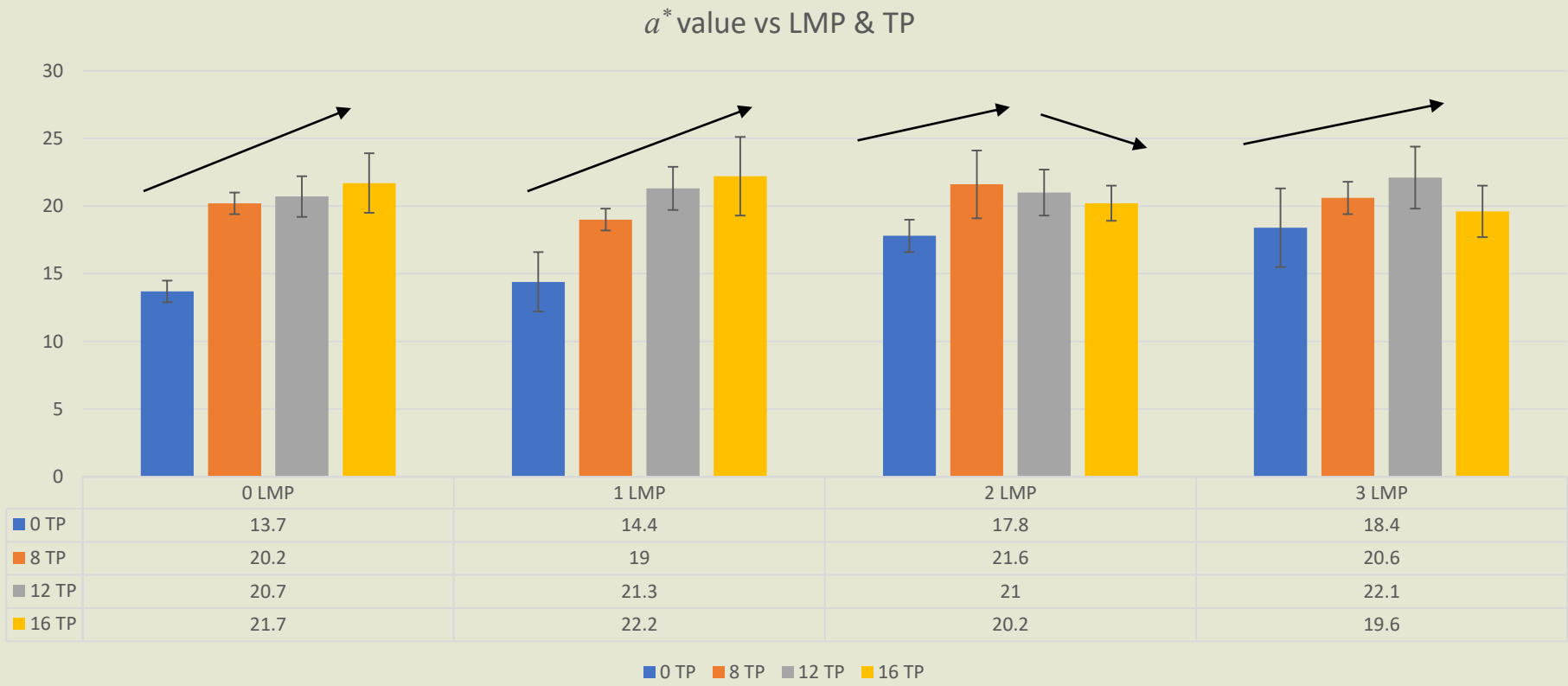
Formulation and visual appearance of the tomato snack bars

- TP had important effect on structure.
- Deformation increased as TP decreased.
- Conventional drying caused browning.



Color a^* value (redness) TP vs LMP

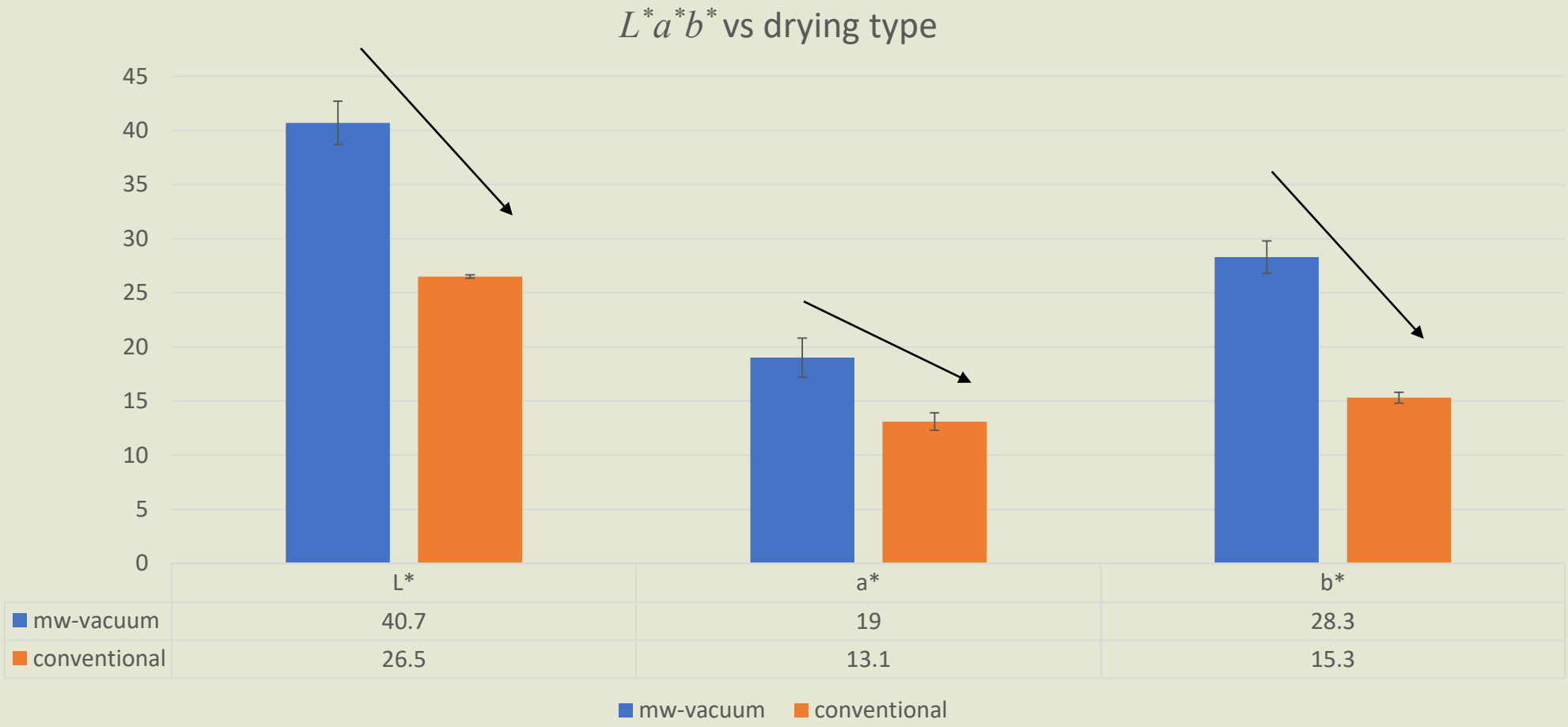
- As TP increased, a^* usually increased until LMP caused a decrease in its value.



	0 LMP	1 LMP	2 LMP	3 LMP
0 TP	13.7	14.4	17.8	18.4
8 TP	20.2	19	21.6	20.6
12 TP	20.7	21.3	21	22.1
16 TP	21.7	22.2	20.2	19.6

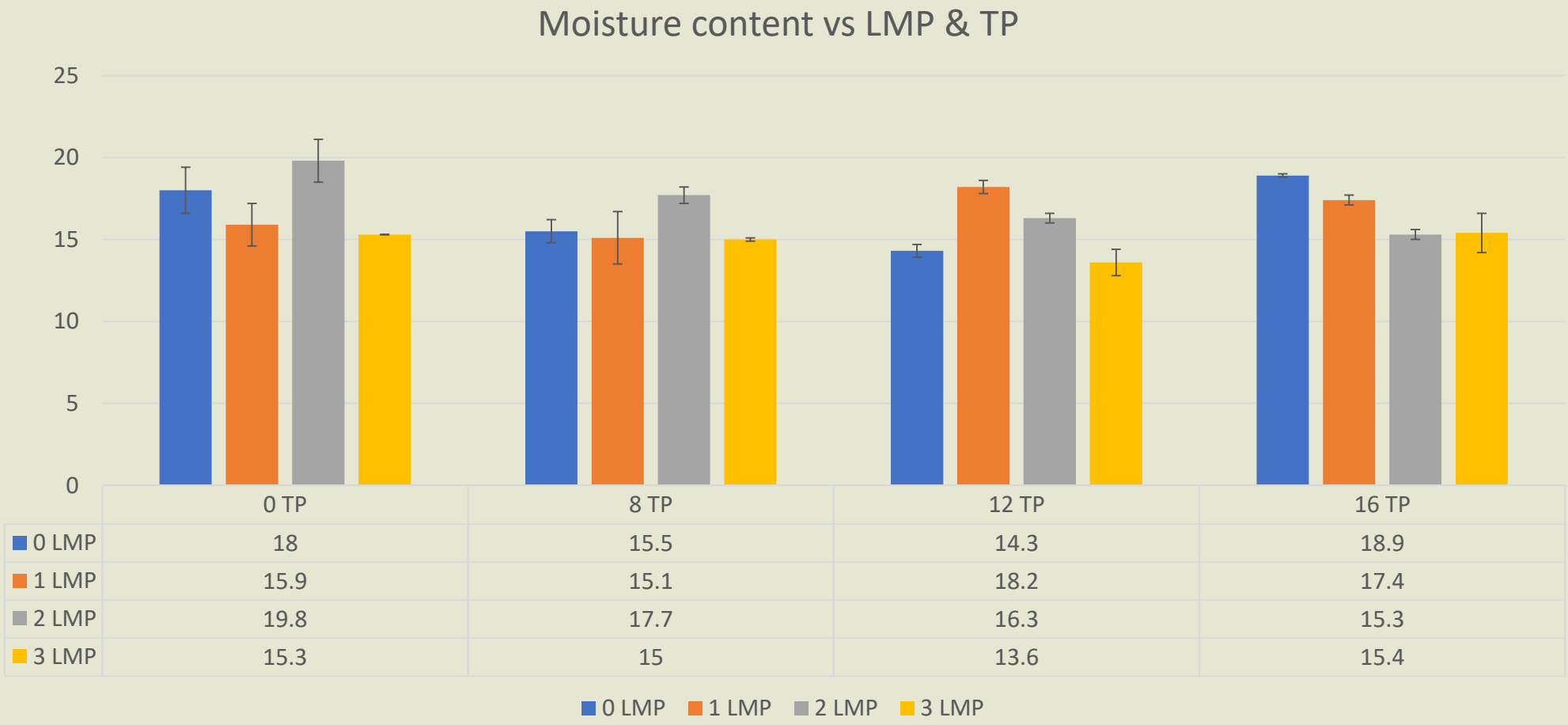
Color comparison of drying types

- There was a sharp decrease in L^*,a^*, b^* values due to the browning reaction in conventional drying.



Moisture content (w/w %)

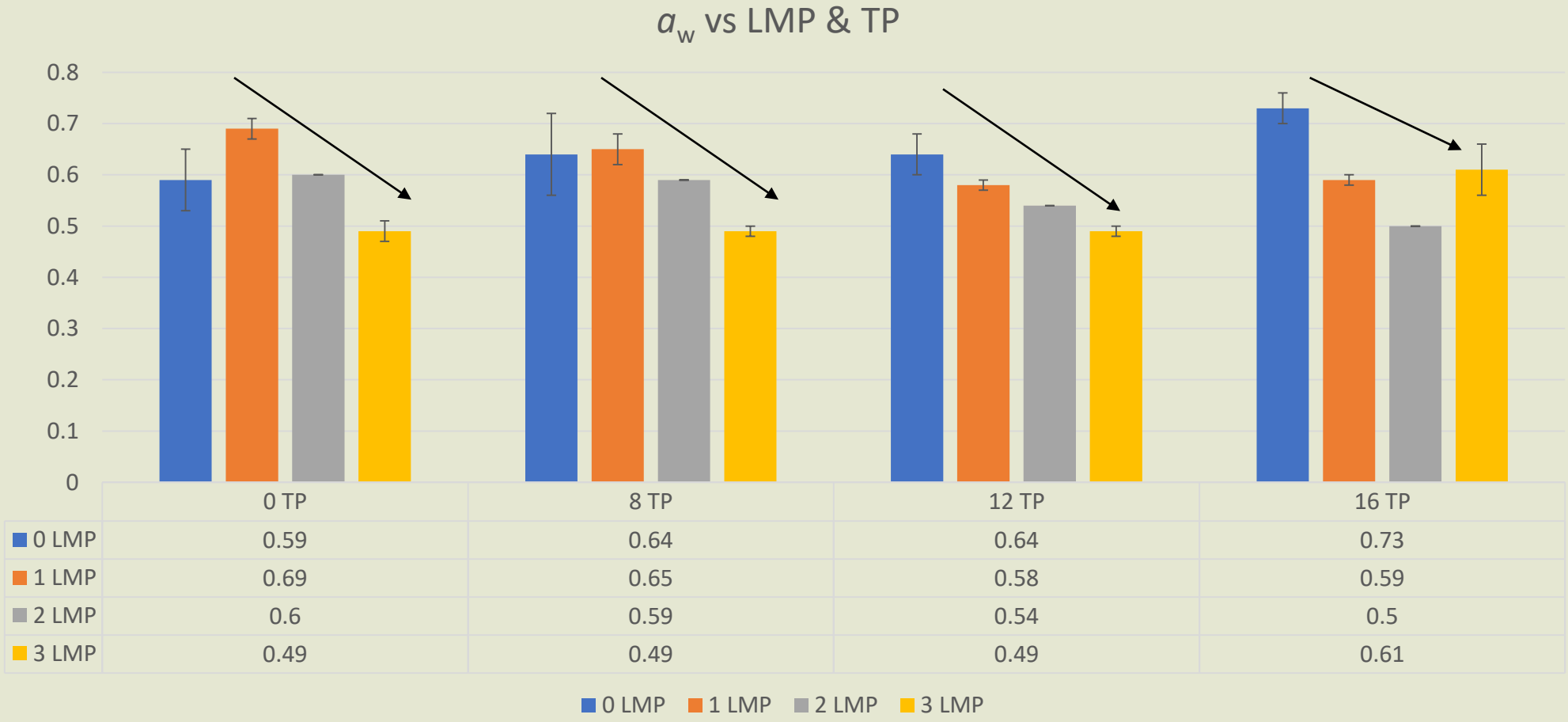
- MC: 13.6-19.8%.
- MC was independent of both LMP and TP.



	0 TP	8 TP	12 TP	16 TP
0 LMP	18	15.5	14.3	18.9
1 LMP	15.9	15.1	18.2	17.4
2 LMP	19.8	17.7	16.3	15.3
3 LMP	15.3	15	13.6	15.4

Water activity (a_w)

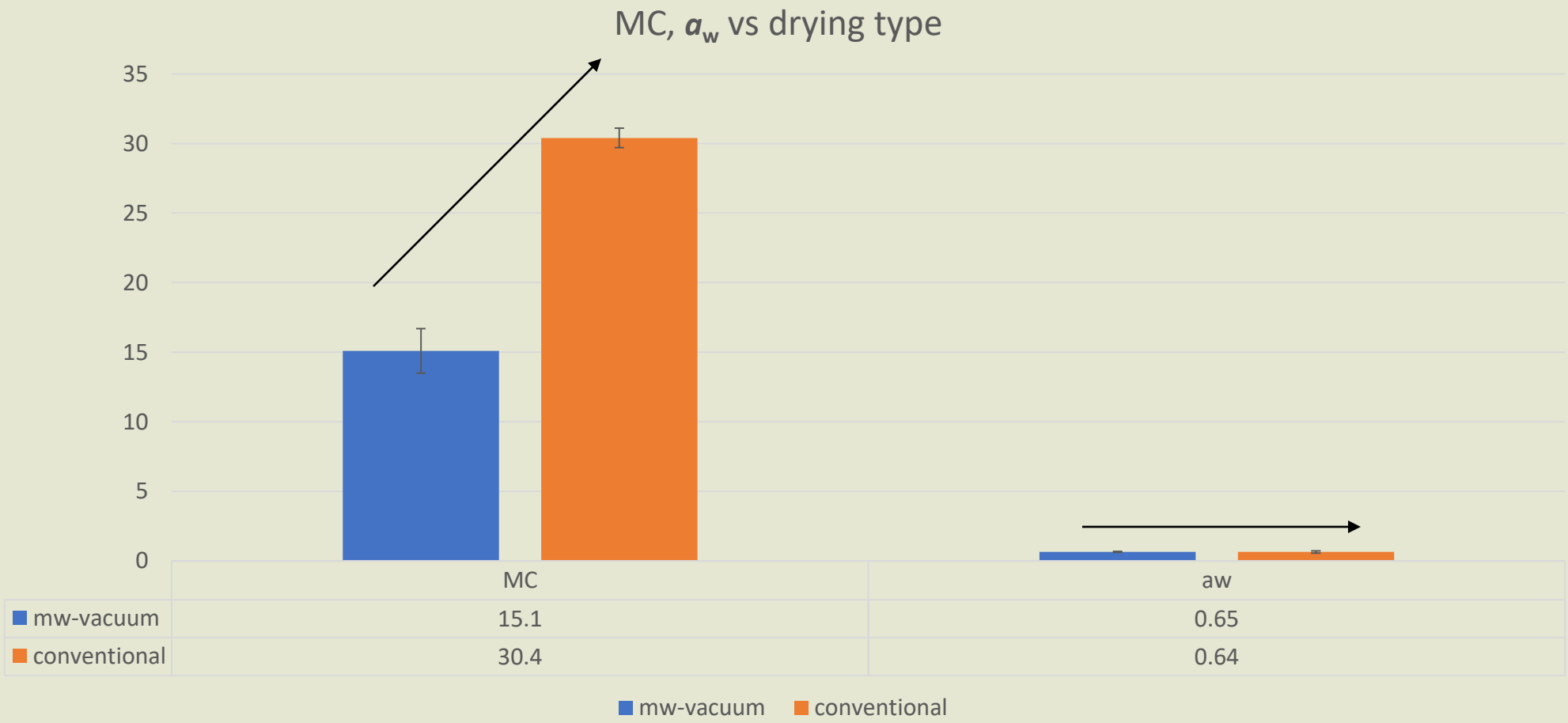
- $a_w \sim 0.6$.
- As LMP increases, a_w usually decreases.



	0 TP	8 TP	12 TP	16 TP
0 LMP	0.59	0.64	0.64	0.73
1 LMP	0.69	0.65	0.58	0.59
2 LMP	0.6	0.59	0.54	0.5
3 LMP	0.49	0.49	0.49	0.61

Moisture content & a_w comparison of drying types (w/w%)

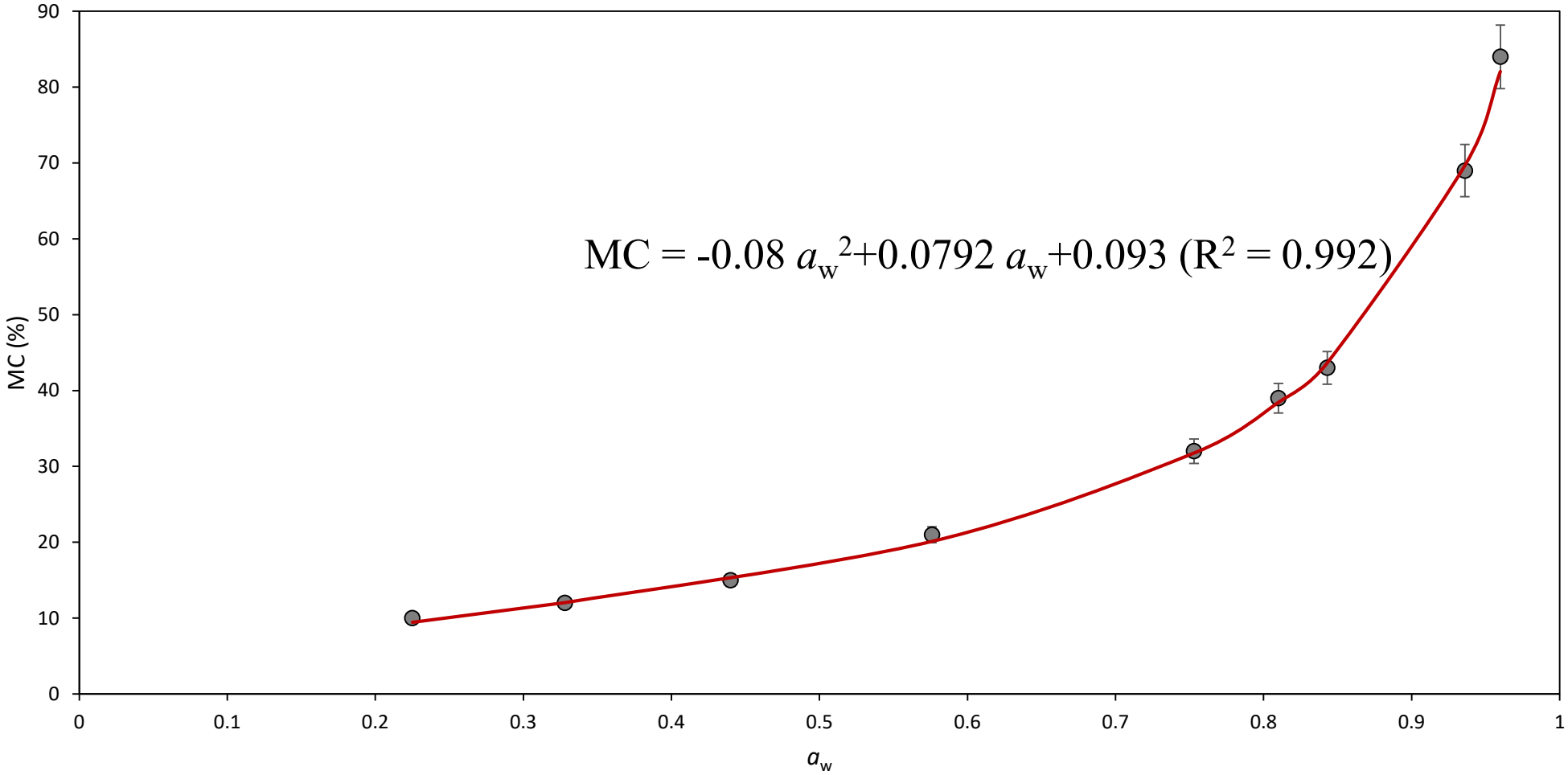
- Conventional drying retained more MC than microwave-vacuum drying.



Moisture sorption isotherm

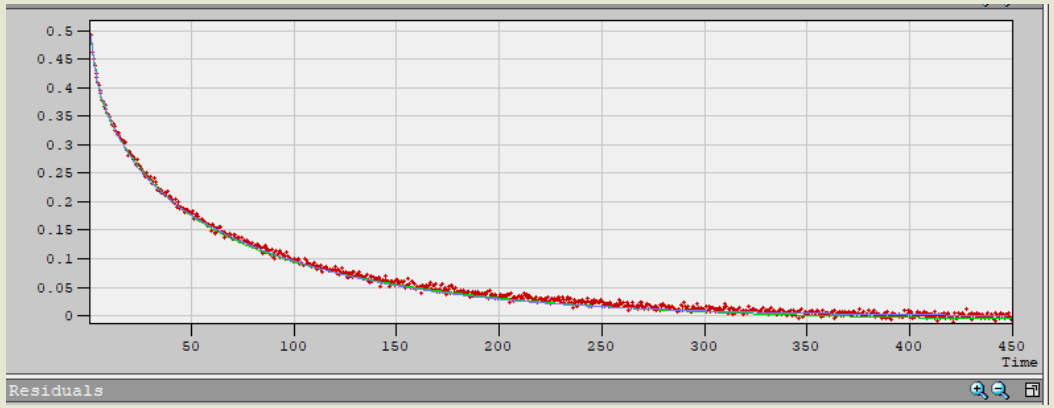
- Data fitted well with GAB model.
- Sigmoidal shape, Type 2 curve.

$$MC = \frac{M_0 C K a_w}{(1 - K a_w) \times (1 - K a_w + C K a_w)}$$

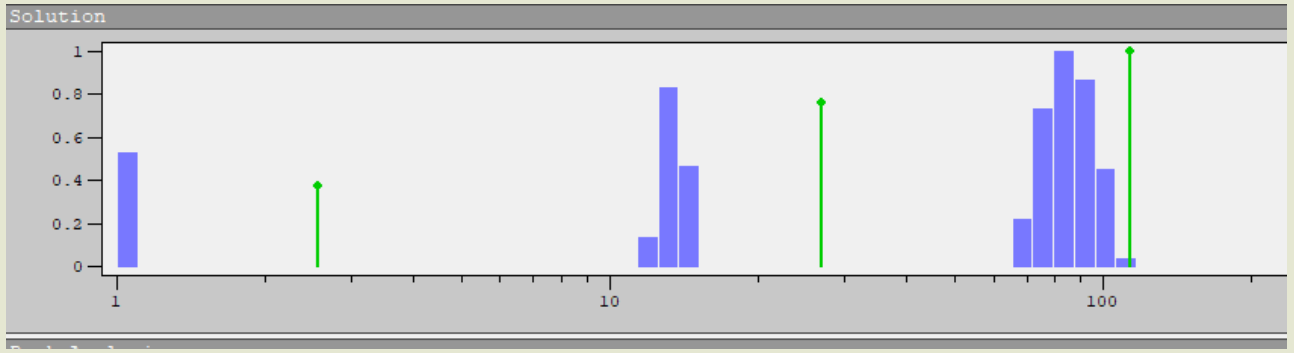


Moisture sorption isotherm of tomato snack bar at 25°C. Solid line represents the GAB model.

Distribution of water



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).
- T_2 was affected by dry matter.
- The effect of TP was higher than LMP.

Distribution analysis

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

Peak Num	B	B_{norm}	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

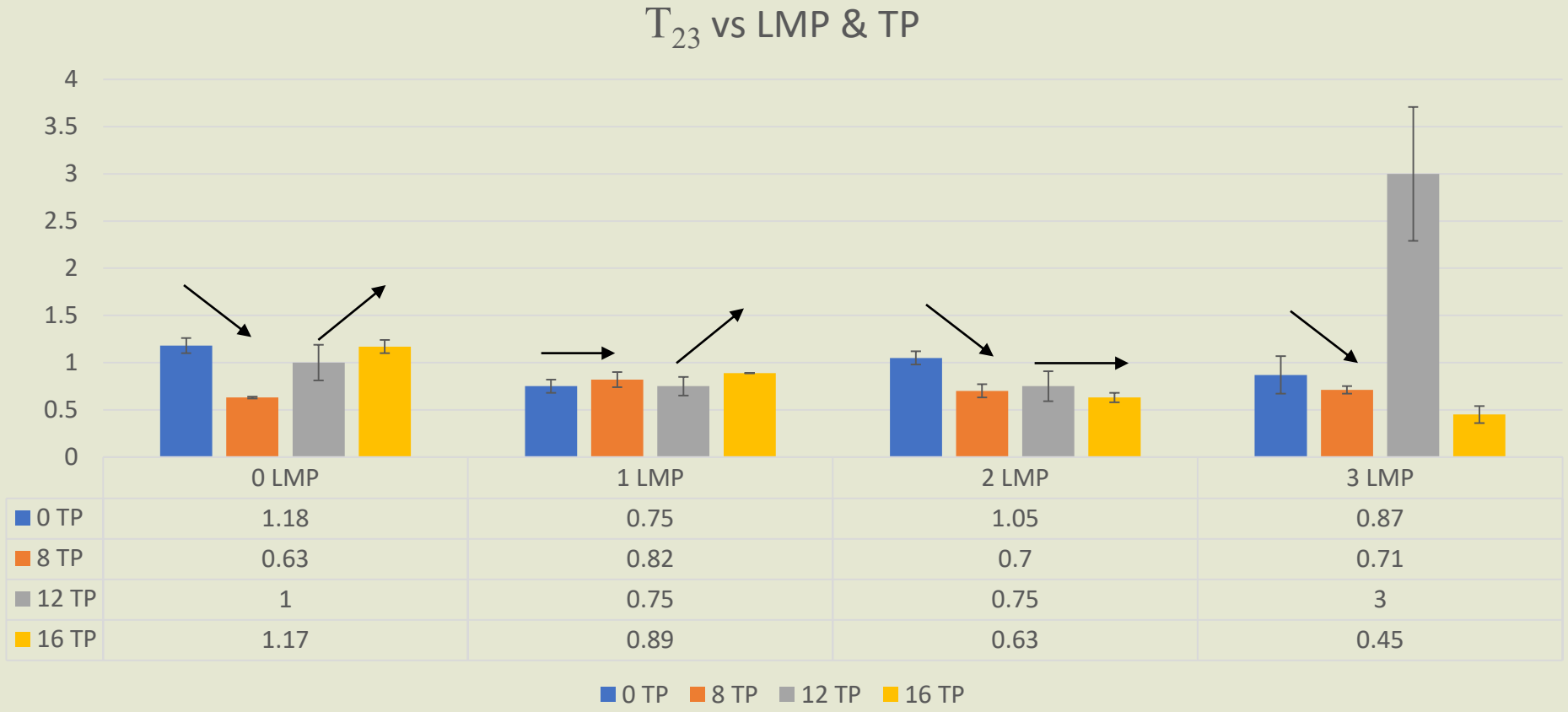
Exponential	B	B_{norm}	τ
1	0.090	0.175	2.514
Confidence Interval	- 0.022 , + 0.024		- 1.886 , + 1.110
2	0.184	0.357	26.58
Confidence Interval	- 0.019 , + 0.023		- 5.943 , + 5.644
3	0.242	0.469	112.4
Confidence Interval	- 0.033 , + 0.023		- 9.661 , + 12.94

Background : -0.009
Confidence Interval :- 0.003 + 0.002

Peak analysis

T21 relaxation times

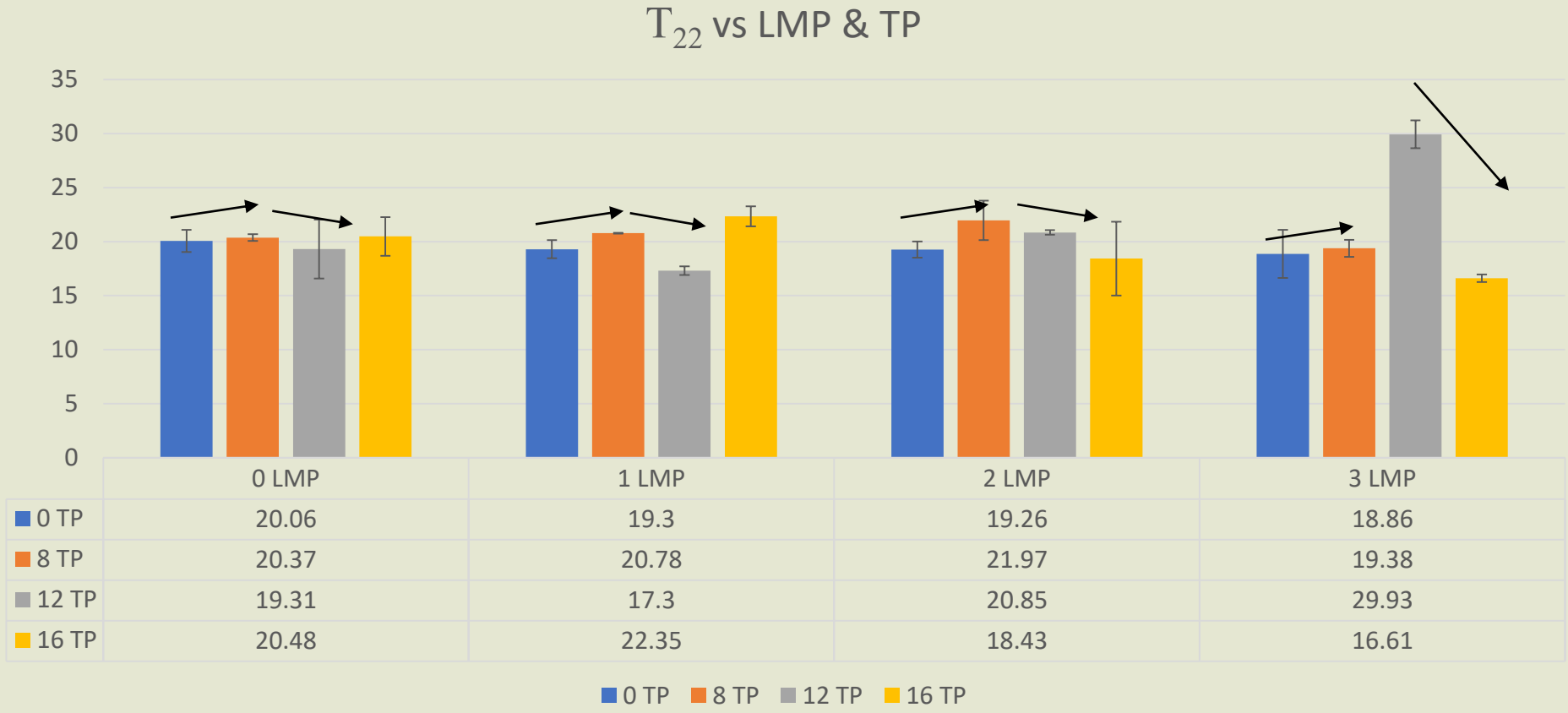
- As TP increased (up to 8%), T_{21} usually decreased.
- Beyond the 8% TP, the opposite trend was seen.



	0 LMP	1 LMP	2 LMP	3 LMP
0 TP	1.18	0.75	1.05	0.87
8 TP	0.63	0.82	0.7	0.71
12 TP	1	0.75	0.75	3
16 TP	1.17	0.89	0.63	0.45

T22 relaxation times

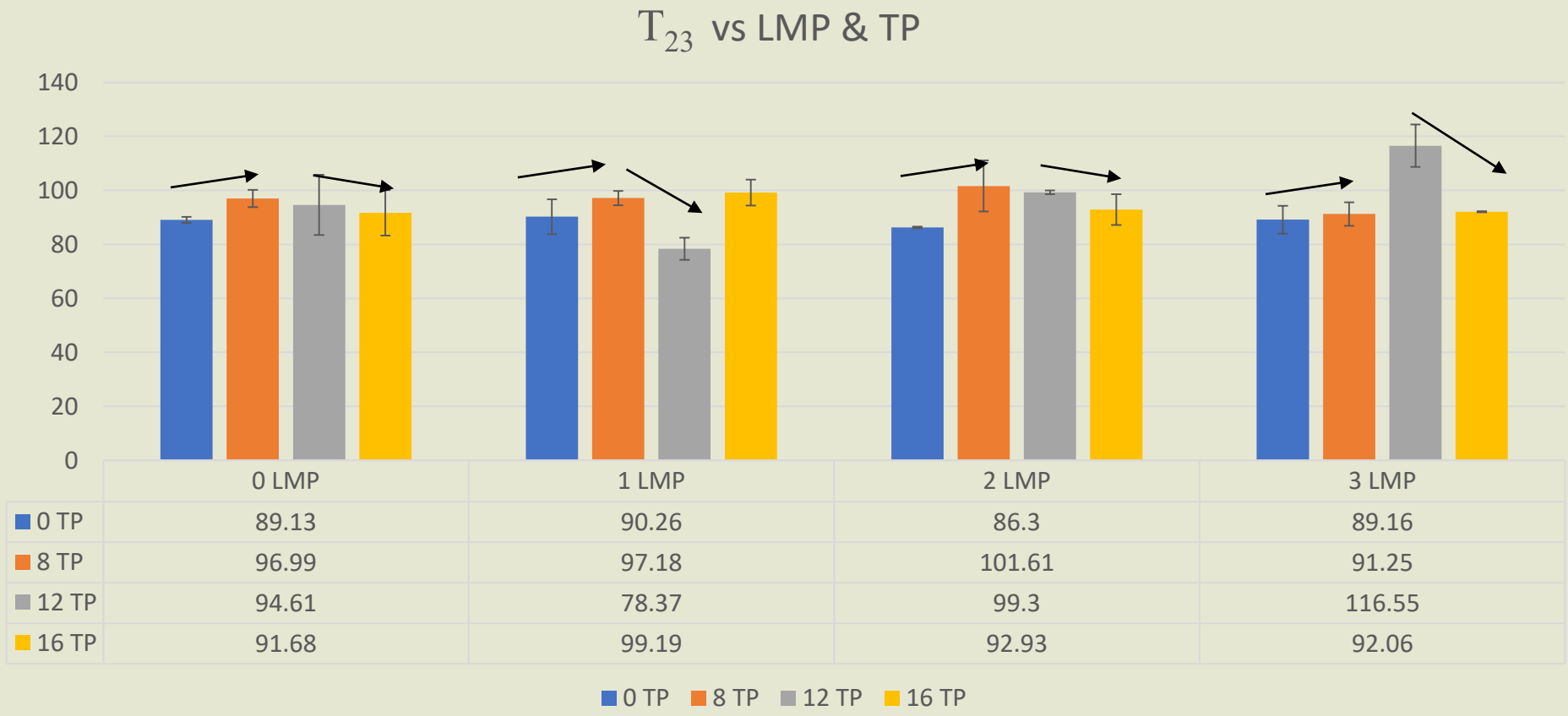
- As TP increased up to 8%; T_{22} usually increased.
- Beyond the 8% TP, the opposite trend was seen.



	0 LMP	1 LMP	2 LMP	3 LMP
0 TP	20.06	19.3	19.26	18.86
8 TP	20.37	20.78	21.97	19.38
12 TP	19.31	17.3	20.85	29.93
16 TP	20.48	22.35	18.43	16.61

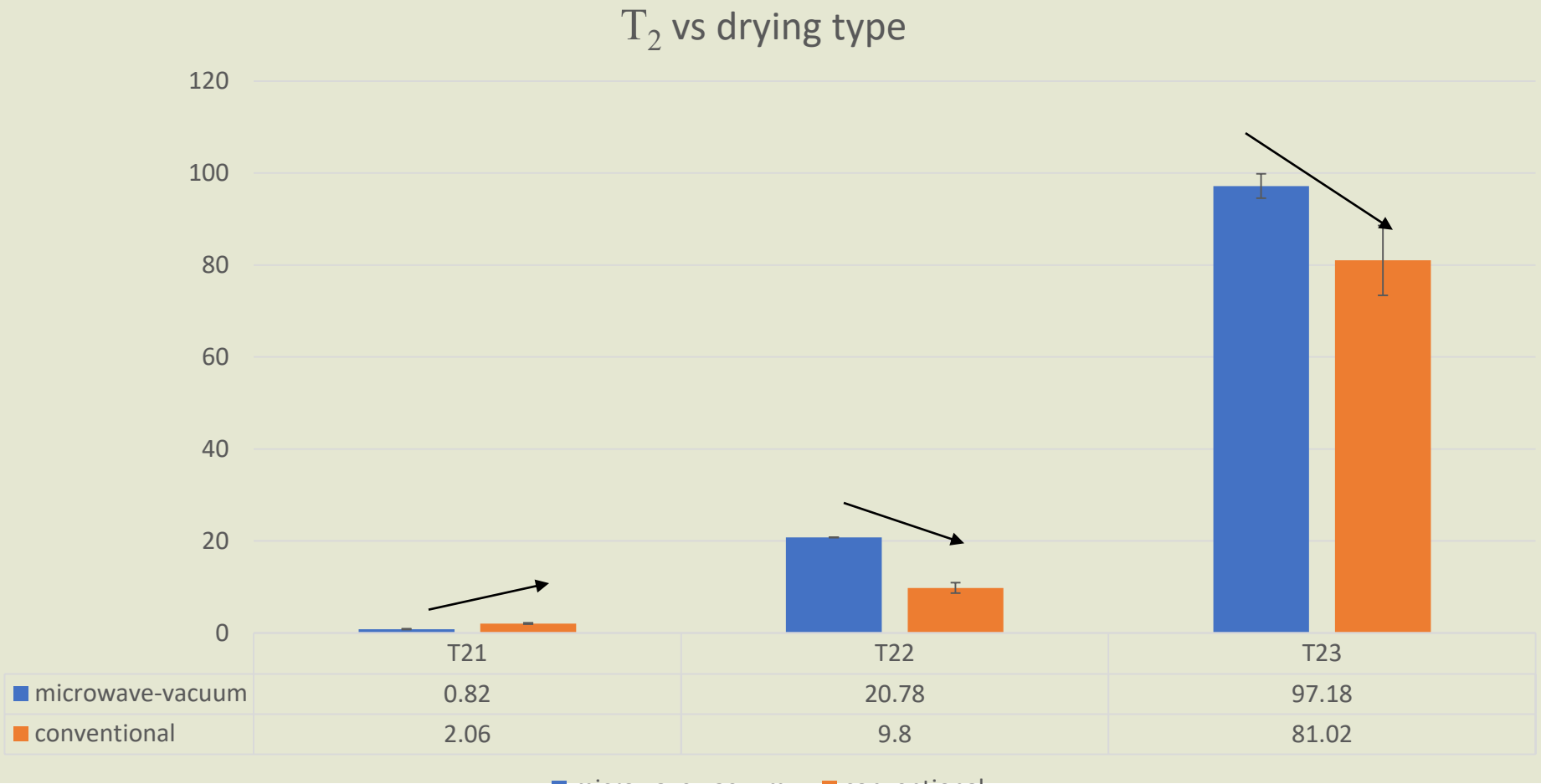
T23 relaxation times

- As TP increased up to 8%; T_{23} usually increased.
- Beyond the 8% TP, the opposite trend was seen.



Drying type comparison of T_2

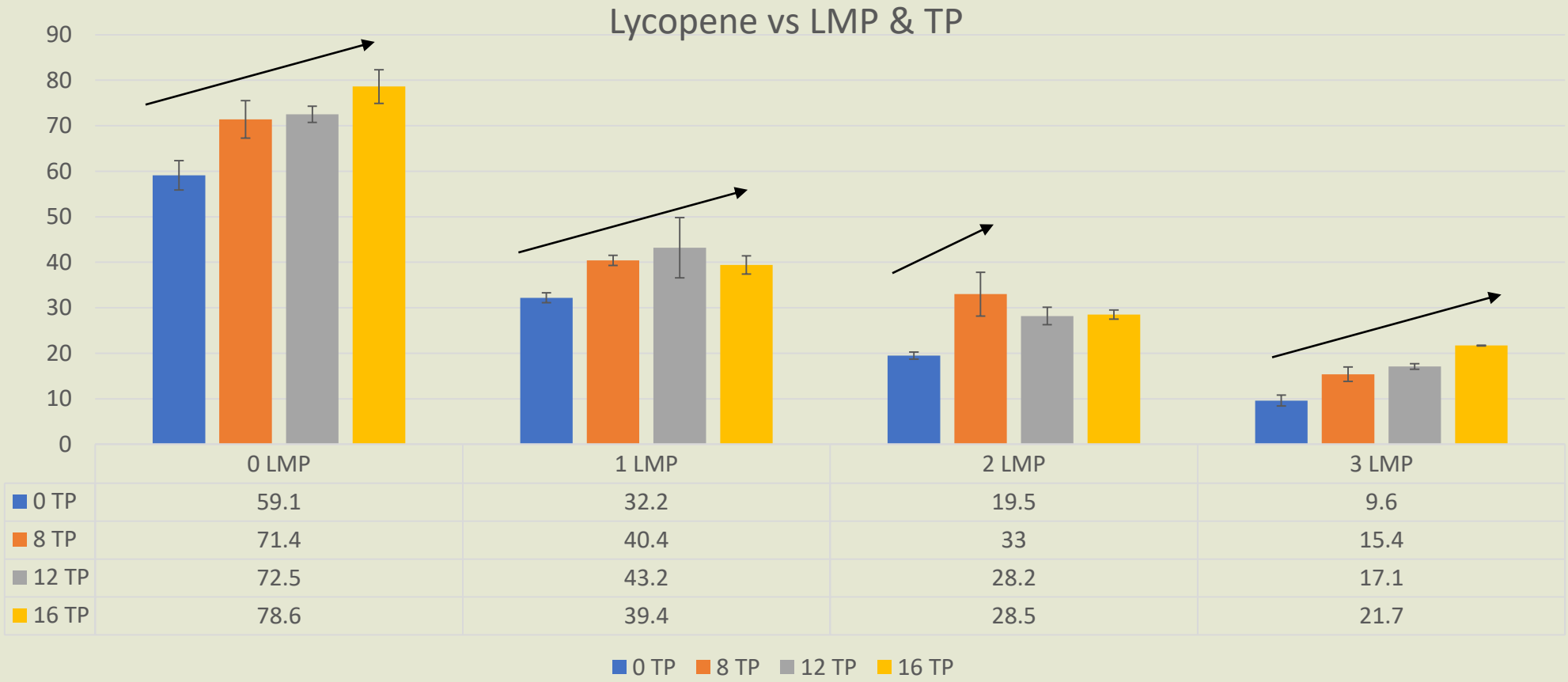
- Dynamics of polymer-water interactions changed due to drying types.
- Higher T_{21} but shorter T_{22}, T_{23} for conventionally dried one.
- More bound water retained in conventional drying.
- Mw-vacuum drying was more successful in removing bound water.



Lycopene

- LMP, and TP had significant effects.
- Direct relationship with TP.
- Indirect relationship with LMP.

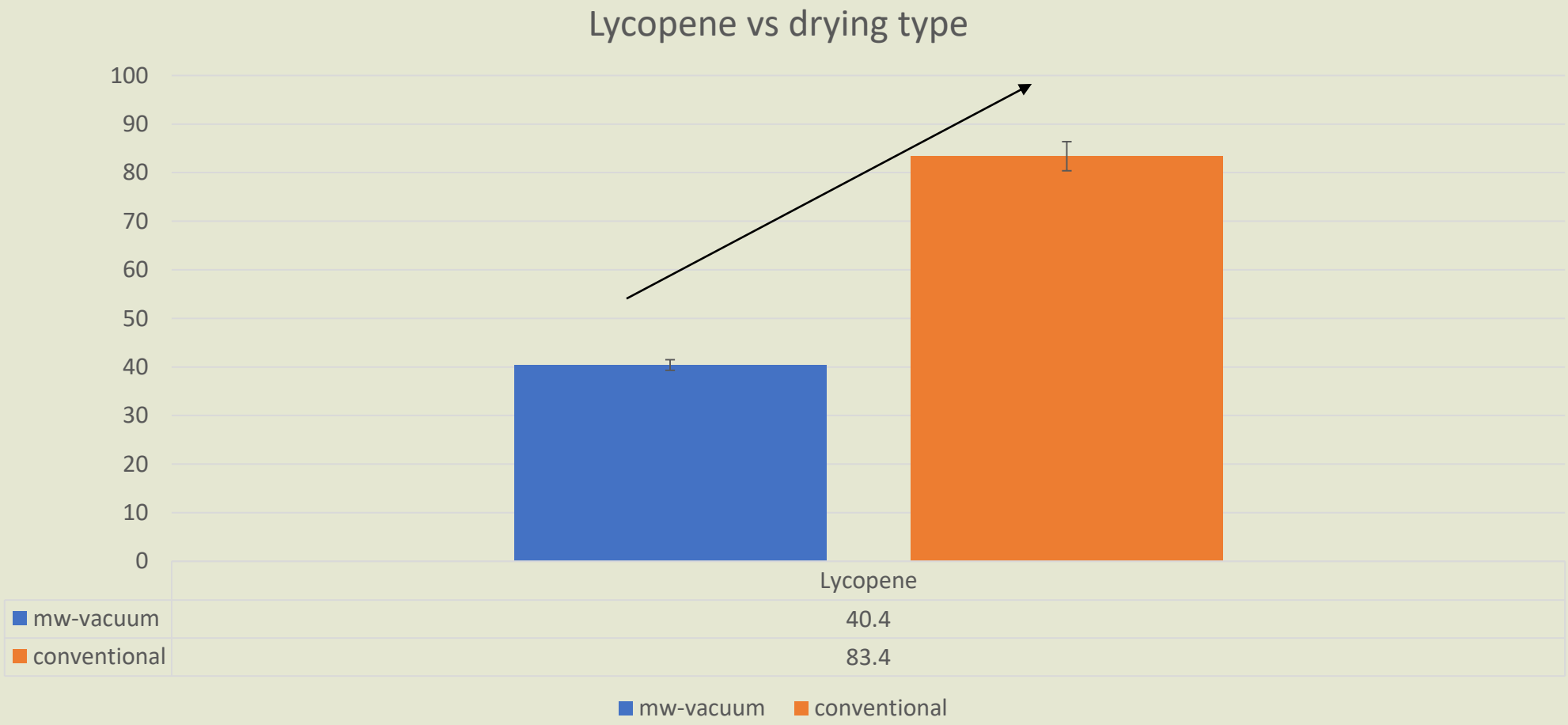
- The highest lycopene is in the sample w/o LMP.
- The lowest lycopene is in the sample of 3% LMP.
- LMP is detrimental to lycopene.
- Denser pectin network was causing lycopene entrapment.
- Pectin-lycopene complex was in the presence of amphiphilic protein.



	0 LMP	1 LMP	2 LMP	3 LMP
0 TP	59.1	32.2	19.5	9.6
8 TP	71.4	40.4	33	15.4
12 TP	72.5	43.2	28.2	17.1
16 TP	78.6	39.4	28.5	21.7

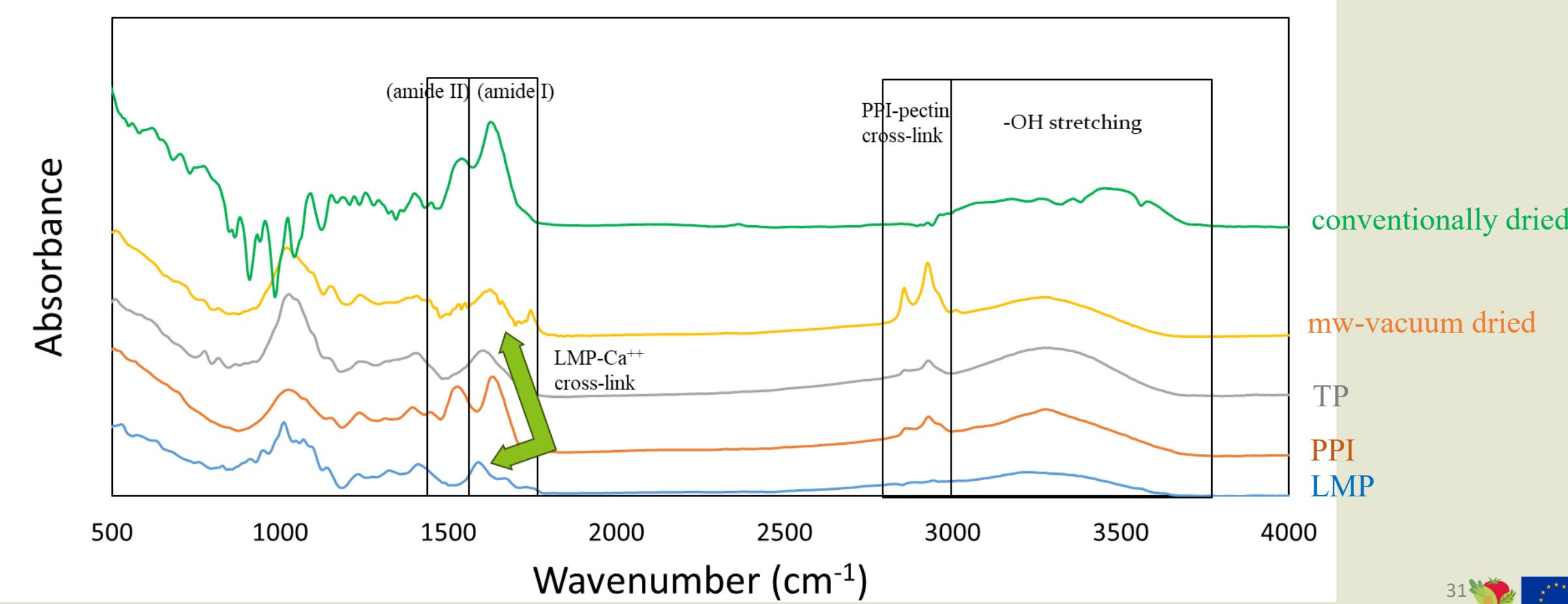
Drying type comparison of lycopene

- Longer drying times and higher temperature enhanced lycopene release in conventional drying.



FTIR spectroscopy

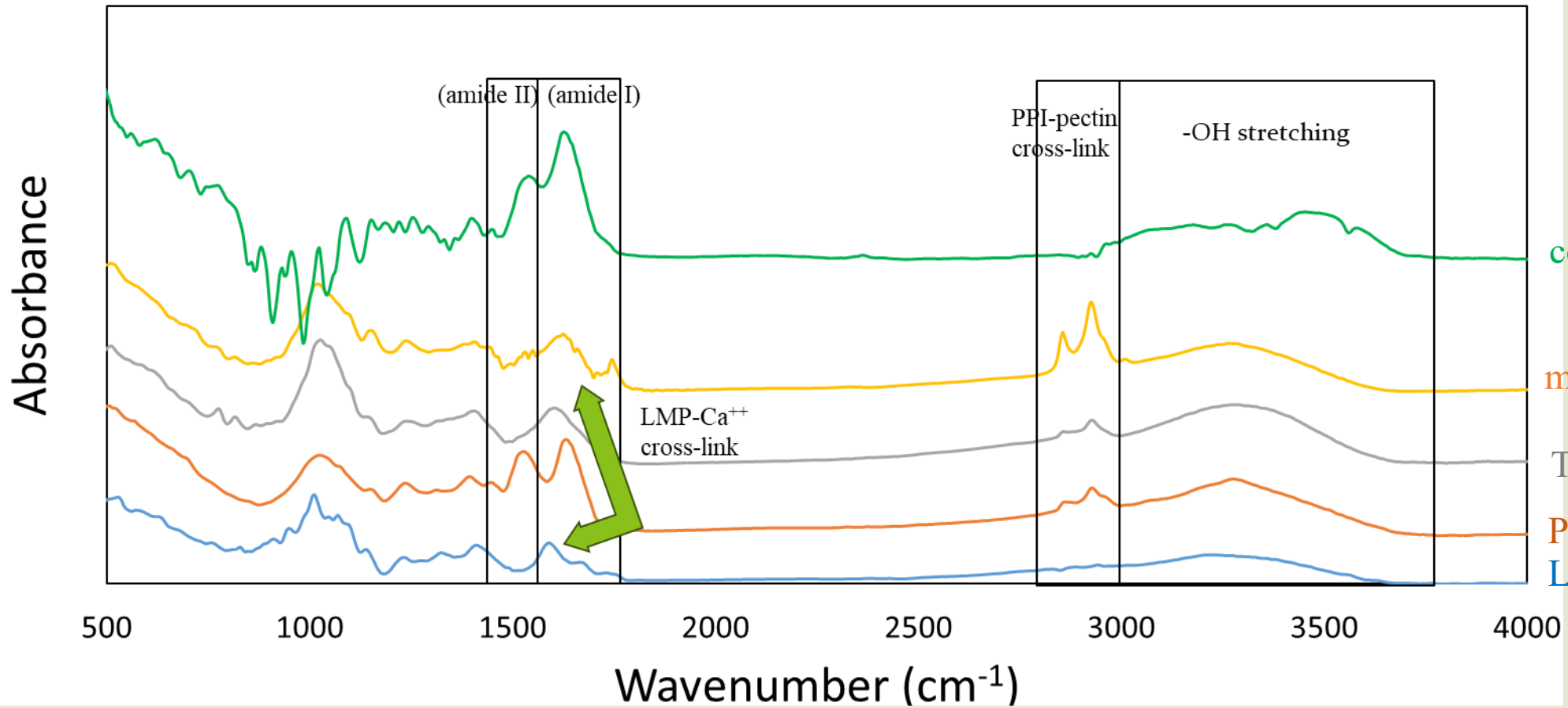
- LMP formed cross-link both with calcium and protein.
- Drying type affected amide and –OH spectra through pectin and protein interactions.
- High temperatures for too long process could denature proteins during traditional drying.



FTIR spectra of LMP (blue), PPI (orange), TP (grey), microwave-vacuum-dried (yellow) and conventionally dried (green) tomato snack bar

FTIR spectroscopy

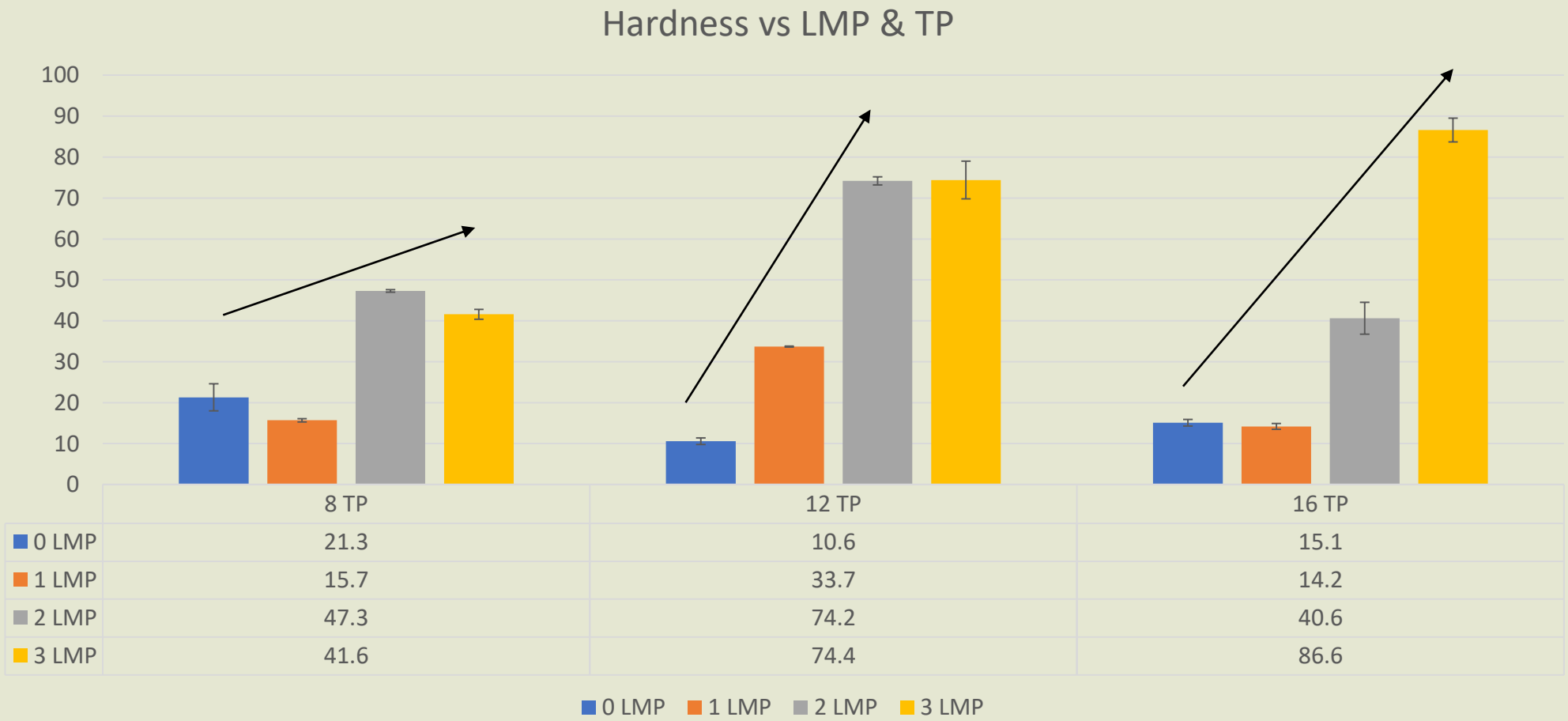
- Microwave-vacuum process involves electrostatic pectin-protein interaction.
- Conventional drying had two distinct peaks in Amide I and II regions, while microwave drying had several peaks.
- MW processes caused protein structures to be more disordered as denaturation was still ongoing.
- The drying method affected the -OH bands.
- In mw-drying, more -OH groups engaged in hydrogen bonding, resulting in a wider and smoother -OH region.



FTIR spectra of LMP (blue), PPI (orange), TP (grey), microwave-vacuum-dried (yellow) and conventionally dried (green) tomato snack bar

Hardness

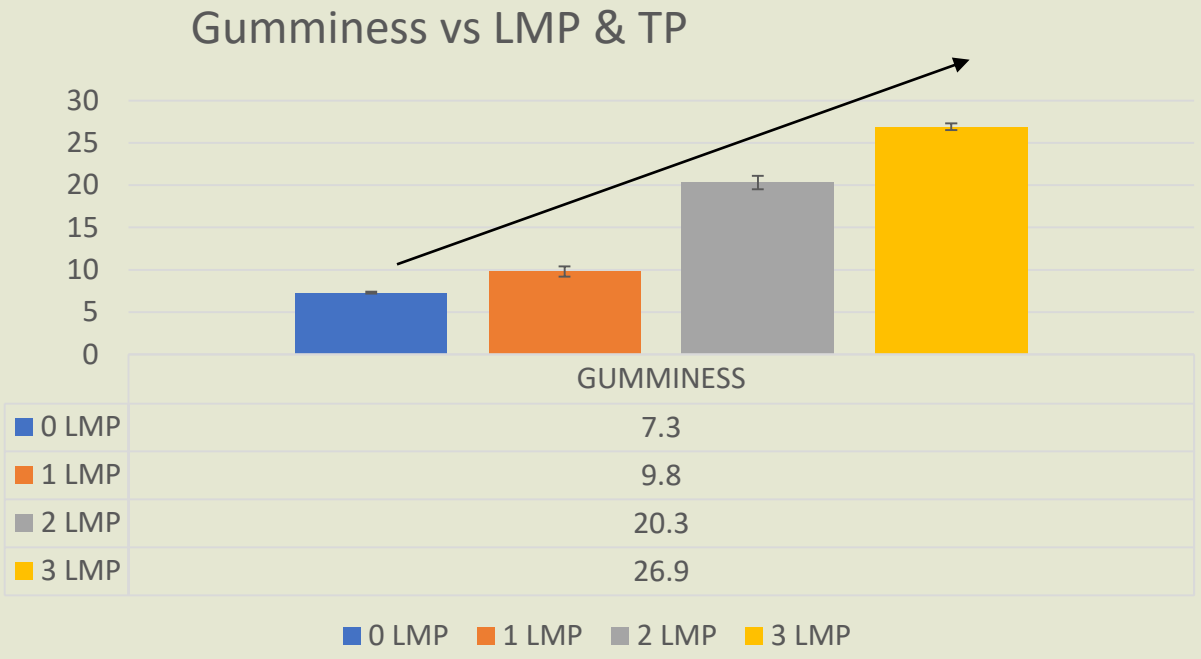
- Water acts as a plasticizer, and LMP binds to it.
- LMP increase causing hardness to rise.
- The LMP caused a decrease in a_w and an increase in hardness, resulting in a more rigid network.
- There was no correlation between TP and hardness statistically.

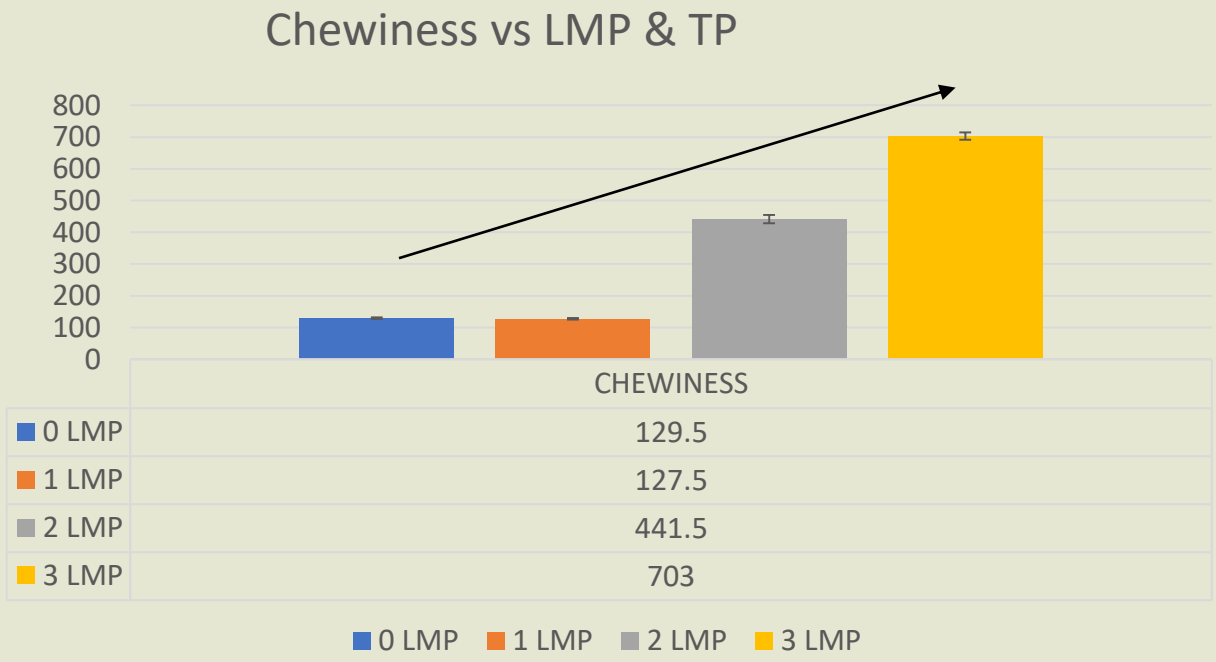


	8 TP	12 TP	16 TP
0 LMP	21.3	10.6	15.1
1 LMP	15.7	33.7	14.2
2 LMP	47.3	74.2	40.6
3 LMP	41.6	74.4	86.6

Gumminess & Chewiness

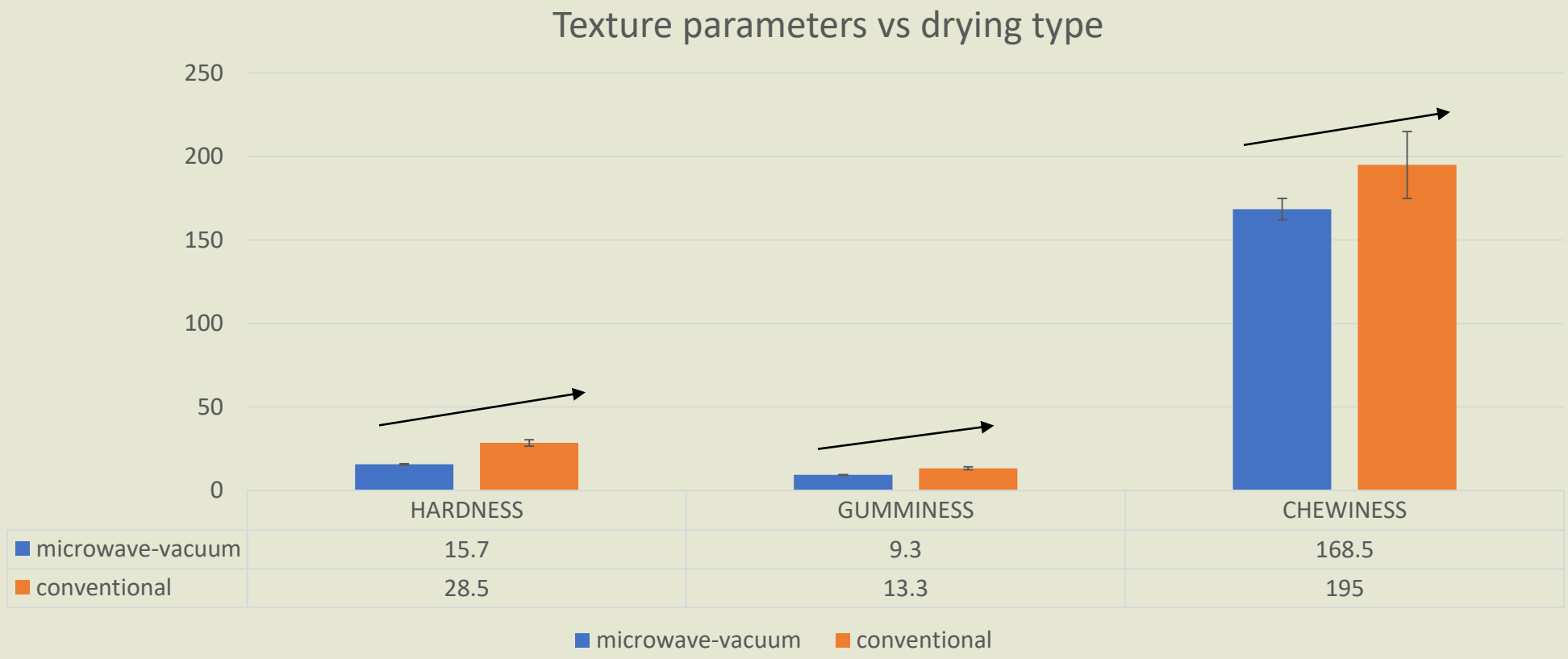
- LMP had a greater impact on other texture parameters compared to TP.
- Increase in LMP, increased gumminess, and chewiness.
- The LMP-protein interaction affected gumminess positively.





Drying type comparison of texture

- The texture values of the conventional sample were higher compared to the mw-vacuum sample.
- Higher moisture content is related to the higher gumminess.
- Uneven heating and crust formation on the surface of conventional dried sample increased hardness.
- The puffing effect of the microwave increased porous structure of the samples.
- Evaporation was from inside to the surface for mw-vacuum; from surface to inside for conventional oven.



CONCLUSION & RECOMMENDATIONS

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CONCLUSIONS

- Functional snack bars can be produced with a minimal number of ingredients by using mw-vacuum drying.
- Mw-vacuum drying is an energy and time-efficient process (Drying time is shortened by 93% and saved energy by 88%.).
- For color preservation, microwave-vacuum drying was superior to the conventional oven.
- Textural properties were also affected by the type of drying; mw-vacuum drying created higher-quality snack bars.
- The microwave-vacuum process achieved a more homogeneous drying compared to conventional drying.
- The increasing LMP amounts reduced the lycopene availability.
- Transverse relaxation parameters could track the differences between the drying types.
- Microwave-vacuum drying was more successful than conventional drying in removing the strongly bound water fraction.
- LMP and TP can be used to alter the textural properties of snack bars.
- The study demonstrated the feasibility of producing healthy snack bars economically.

RECOMMENDATIONS

- Larger molds can be used for regular snack bar shape.
- Snack bars can be softer for toddlers and elderly individuals who struggle with chewing, or harder for general consumption.
- Production with different protein types can be tried.
- Ingredient types (e.g., spices) and concentrations can be changed by conducting sensory analyses to find the best formulation.
- Experiments on packaging's impact on shelf life microbial, peroxide, antioxidant, and phenolic levels can be conducted.
- The effects of vacuum packaging and different composite packaging materials can be examined.

NEW APPROACH

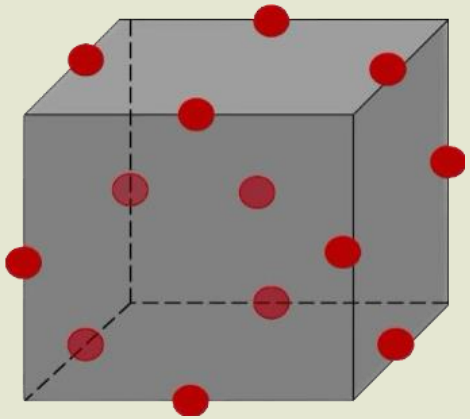
This project has received funding from the European Union's PRIMA programme under grant agreement No 2032

PRIMA
PARTNERSHIP FOR RESEARCH AND INNOVATION IN THE MEDITERRANEAN AREA

FunTomP

Response Surface Methodology (RSM)

- Box-Behnken design
- 2 replicates (30 runs)



	FACTORS	LOW	CENTER	HIGH
A	Microwave Power (%)	50	60	70
B	Vacuum Pressure (bars)	0.2	0.35	0.5
C	Drying Time (minutes)	8	10	12

Studied Parameters
Color measurement
Moisture content
Water activity
Lycopene content
Texture
Energy

Results

RESPONSE	GOAL	SOLUTION
Energy	Minimum	1426 kJ
Hardness	Maximum	41 (N)
Lycopene	Maximum	211 (mg)
Color (a*)	Maximum	22.7
Moisture Content	Target (15%)	15.4
Water Activity	Target (0.55)	0.55

FACTORS	OPTIMUM LEVEL
Microwave Power (%)	58.5
Vacuum Pressure (bars)	0.5
Drying Time (minutes)	9.8

Tomato bars dried with RSM

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